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Can depleting technological Opportunities explain the Stagnation of Productivity? Panel Data Evidence for 11 OECD countries

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0 Summary

We analyze the stagnating productivity levels observable across many Western economies during the last two decades. Relying on techniques to measure total factor productivities (TFP), we provide evidence for a set of 11 OECD countries observed over the period from 1993-2011 that TFP-levels exhibited growth rates of about 0.9% per year until 2000. In the period after 2000, the TFP levels almost stagnated with average annual growth rates declining to about 0.3%. The stagnating trends hold almost uniformly across the analyzed countries and across broad economic sectors. Following recently made claims in the literature, we analyze the hypothesis that the stagnating trend was due to generally declining technological opportunities. Our evidence suggests that the importance of intrasectoral innovation as measured by R&D remained relatively constant and was at best slightly decreasing. However, the importance of investments in the physical capital stock considerably declined after 2000. We take this as evidence that rather than a general depletion of technological opportunities, the possibilities to achieve TFP-growth via capital-embodied technical change became less abundant.

1 Introduction

There is a consensus in science, policy-making, and the public that innovation activities are key drivers of economic growth and prosperity. This consensus is, a large number of analyses provided evidence of consistently positive effects of R&D and patenting on growth and productivity measures, both at the firm and the country level (Pakes and Grilliches 1984, Bond et al. 2003, Hall et al. 2010). However, observations of the recent years cast doubt on the assumption of a stable positive relationship: in many countries, R&D-spending increased or at least stayed constant (Ha and Howitt 2007), while productivity growth slowed down (Eichengreen 2015). Syverson (2016), for example, presents figures indicating that labor productivity in growth in the US was 1.3% p.a. for the period 2005 to 2015, after having been more than twice as high in the preceding decennium 1995 to 2004. During the same period, R&D expenditures as a share of GDP rose from 2.4% to about 2.7%.

A now prominently voiced explanation of the weakening association between innovation and productivity claims that one of the major reasons for the stagnating productivities can be traced to the depletion of technological opportunities leading towards a period of "secular stagnation" (Gordon 2012, 2015, Eichengreen 2015). This technology-centered perspective however also has received criticism, with the counterargument being that the depletion of technological opportunities is largely phantasmal (Glaeser 2014). Correspondingly, Mokyr (2014) argues that technological opportunities in a large number of industries including computing, materials, and genetic engineering will continue to be high also in the future. Many authors therefore reject the technology-centered view and argue that the secular stagnation phenomenon is due to other macroeconomic factors such as a failure of current monetary policies (Summers 2014, 2015, Krugman 2014) or changes in the social welfare systems (Glaeser 2014).

Up to now, the debate on the role of technology for stagnating productivity levels is still unsettled also because it is based primarily on theoretical arguments. We intend to contribute to the discussion by providing systematic evidence of Gordon's depletion hypothesis. We propose, however, that the depletion hypotheses is in need of more conceptual clarity. In particular, we will argue that it was the declining potentials to benefit from capital-embodied technical change causing the declining gains in productivity. The assumption that technological opportunities deplete on a broad scale on the contrary is much less convincing given the obvious potentials in some key technologies, such medicine, biosciences, or the digitization in production (Mokyr 2014).

Relying on sector-level data for 11 countries covering the period from 1993-2011, we first corroborate stagnating trends of total factor productivities (TFP) showing that growth rates were comparatively large across countries and sectors with at most 1% in the period from 1993-2000 but shrunk to about 0.3% afterwards. Next, we provide evidence of a collapse in the importance of capital investment as a driver of TFP-growth after 2000. Descriptive evidence strongly supports the hypothesis that this breakdown was triggered by a slow-down in the trends of declining prices in the capital-goods sector - in particular as concerns ICT-equipment. At the same time, our results show the effects of firms' R&D activities on TFP growth remained quite constant over time. The importance of patenting even increased. In that respect, our results are favorable of a somewhat more nuanced version of the depletion hypotheses, where our results document a depletion of technological opportunities in the capital equipment sectors having been a key driver of TFP-growth in the 1990ies. However, the role of disembodied technological change as measured by R&D or patenting remained unaffected or even became more important. Thus, our evidence suggests that Gordon may be right in emphasizing the depletion opportunities related to capital-embodied technological change, in particular as resulting from the increasing use of ICT. However, the sector-internal potentials of innovation show little sign of decreasing importance. As a consequence, whether the world economy is likely to enter a phase of continuously stagnating productivity levels is largely speculative and depends on whether any sector is able to provide a technology bearing the potentials to induce capital-embodied technological change in large variety of sectors.

2 Theory

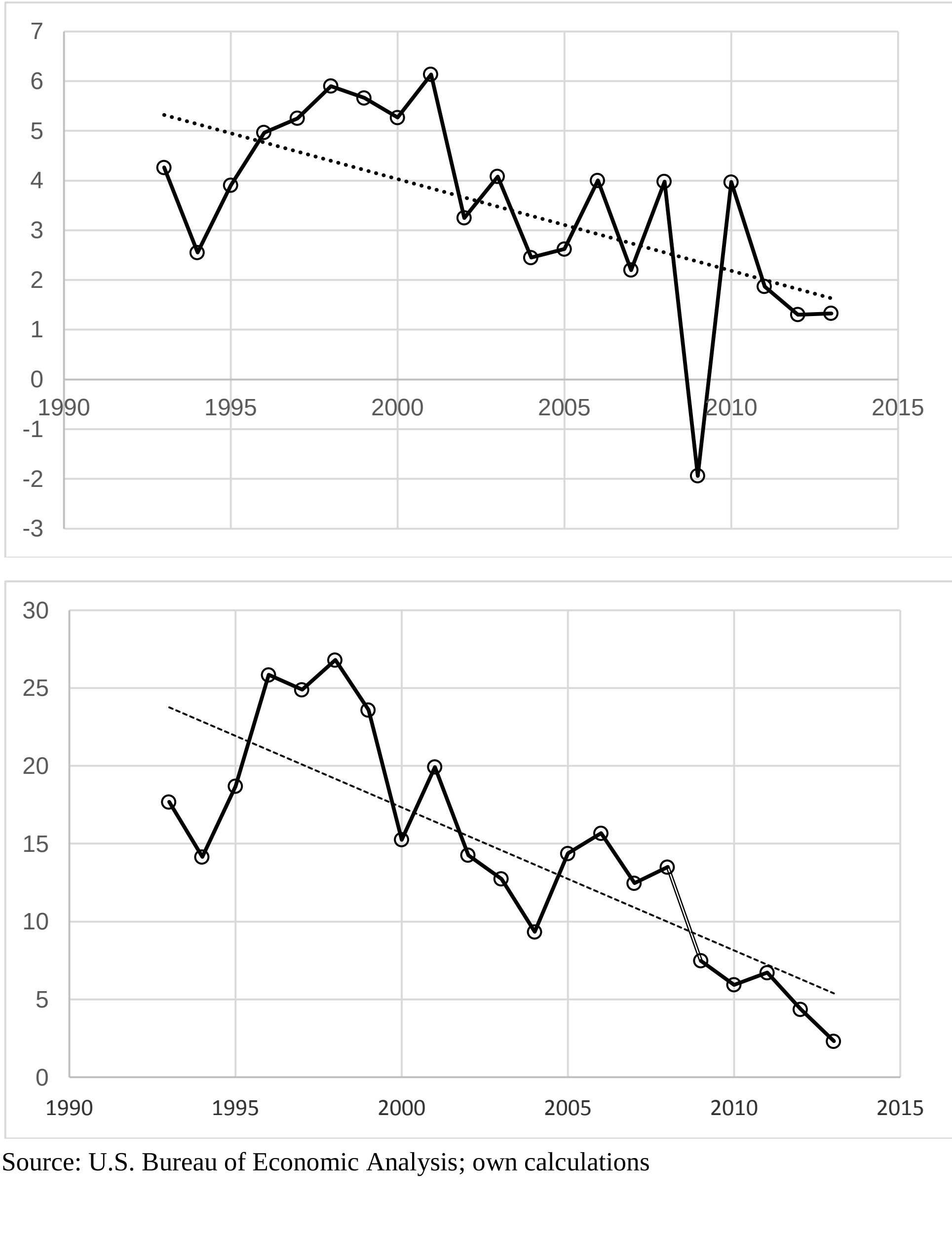
2.1 The supply-side view on secular stagnation

The depletion-view of the secular stagnation phenomenon has been voiced prominently by Gordon (2012, 2015) and claims that the great productivity gains of the past 200 years were attributable to three sequential industrial revolutions, which brought forth important technological innovations having the potential to increase productivities across a wide range of sectors (Eichengreen 2015). The first industrial revolution (IR#1) was driven by the steam engine and had its effect mainly in the 19th and century. IR#2 was driven by the almost simultaneous invention of general-purpose technologies related to electricity, combustion engines, chemical engineering, telephone and advances in medicine sustaining productivity growth until the late 1960ies. Finally, IR#3 was based on electronics and digitization and started off in the 1970ies. According to Gordon’s depletion view, each industrial revolution offers technological opportunities which are exploited over time and thereby are translated into productivity growth. Eventually, however, the technological opportunities deplete and innovation activities done within the technologies featured by the specific industrial revolution become subject to diminishing returns to scale.

While not making an explicit reference, Gordon's argument can indeed be seen as 'Dosian' in the sense that it is highly related to the notion of technological paradigms defined as socio-technical outlooks prescribing the field of inquiry, important problems, and the set of admissible solutions and methods (Dosi 1982, p. 152). Paradigms again consist of technological trajectories, which can be considered to represent technological development paths tied together by sufficiently similar rules or procedures as defined by their overarching paradigm (Dosi 1988, see also Eichengreen 2015). The important aspect of technological trajectories is that they have a finite lifecycle, where eventually technological opportunities deplete over time (Dosi et al. 2006, Fagerberg and Verspagen 2002, Schubert et al. 2018). The depletion of technological opportunities implies that technological trajectories eventually become infertile. Gordon's argument obviously relates to a view of infertility of technological trajectories, in particular ICT. However, he goes beyond the pure claim that technological opportunities in ICT depleted but he argues that also the most important advances in other sectors were reliant on ICT as a general purpose technology. The depletion of ICT-related technological opportunities thus had a direct negative effect on the innovation potentials in other sectors. Other authors were quite critical of that view arguing for genuine, i.e. ICT-independent, innovation potentials in several sectors (Mokyr 2014). In particular, while it may be true that the capital embodied technical change relating to investment in ICT and other capital goods may have declined, we will argue that it is less credible to assume that technological opportunities depleted across a broad range of sector.

Nonetheless, if one interprets Gordon's depletion hypotheses with respect to the potentials of other sectors to benefit from capital-embodied technical change through investing in better capital goods and improved ICT-equipment, his technology-focused view is not without support. Focusing on the US, Figure 1 shows that the decline in the relative annual price of capital goods was particularly high between 1995 and 2001. In this period, annual prices fell by up to 6%. After 2001, annual price reductions halved and after 2010 even fell to less than 2%. Even more pronounced are the figures for ICT-related capital investments where price reduction peaked in 1998 with about 27%, while in 2013 the cut in prices dropped to slightly above 2%.

Figure 1: Price decline for capital investment relative to consumer goods in the USA (upper panel: total capital investment. bottom panel: IT-related capital)



Source: U.S. Bureau of Economic Analysis; own calculations

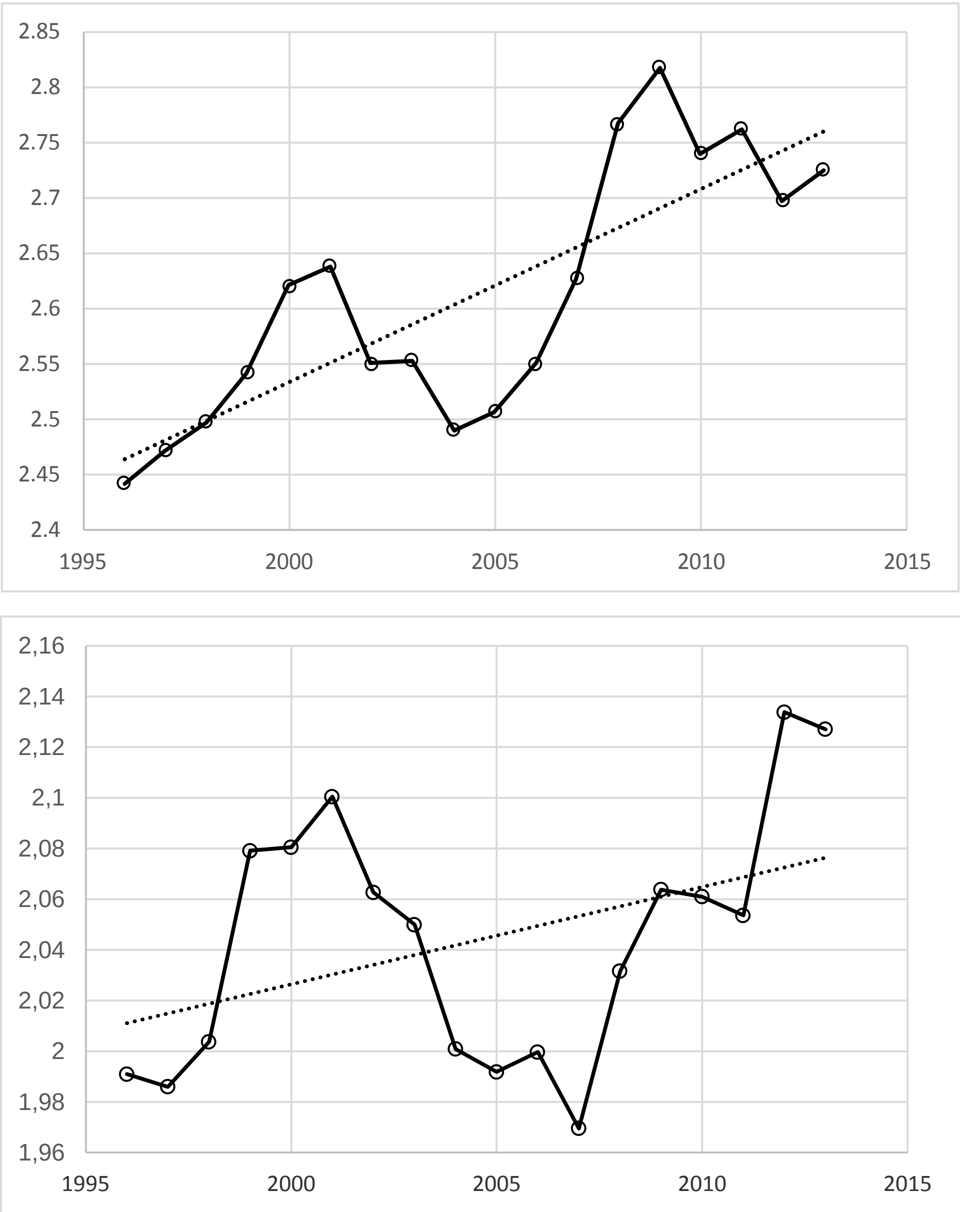
Figure 1 illustrates an important source of productivity gains, which is external to the firm. In particular, efficiency gains in the capital goods sector will entail a fall in prices, which can help firms in other sectors to increase their productivity even without innovating internally. The increases in efficiency are typically referred to as capital-embodied technical change because it results from investing in capital goods rather than from intramural innovation activities (Fisher 1965, Hulten 1992, Robinson 2013). In fact, a number of authors have argued that the observation of decreasing capital goods prices is not consistent with important predictions of the neoclassical growth model therefore necessitating a reformulation of modern growth theory (Whelan 2001, Licandro et al. 2002). In particular, Greenwood et al. (1997) have proposed a two-sector model, where the first sector produces a consumption good and the second sector produces a durable capital good for the production of the consumption good. The first sector benefits from embodied technical change resulting from efficiency gains in the second sector. Such a model is indeed consistent with macroeconomic patterns which the neoclassical model fails to address, in particular an increase real-capital investment relative to GDP (compare Licandro et al. 2002). Indeed, there is some evidence that in particular advances in ICT caused the induced substantial productivity gains for an extended period of time. A large literature has indeed argued that the strong effect of ICT on other sectors is due to its nature as a general purpose technology (GPT). The two main features of GPTs are that they cause substantial changes in the production processes of the using industry and they can be applied to a broad range of uses and thereby affect potentially many industries (Helpman and Trajtenberg 1998). While the positive effects of ICT may come with a substantial time-lags (Basu et al. 2003, Basu and Fernald 2007), there is some agreement that the benefits of ICT are positive - at least after sufficiently strong time lags. Furthermore, evidence suggests that the benefits mainly accrued in the using sectors rather than the originating ICT-sectors themselves (Oliner and Sichel 2000, Corrado et al. 2006, Bosworth and Triplett 2007).

It is obviously easy to reconcile the notion of embodied technological change with Gordon's depletion hypotheses. In particular, Figure 1 suggests that the rate of efficiency gains in the capital goods sectors have been high in the 1990ies but declined afterwards. Thus, the observation of decreasing productivity gains (Syverson 2016) may have its origin the depletion of technological opportunities in the capital goods sector. We would therefore expect that indeed the importance of capital investment as driver of productivity growth declined after 2000. Focusing on total factor productivities (TFP), we thus hypothesize

> ***H1: The elasticity of TFP-growth with respect to capital investment per employee declined after 2000.***

An important criticism of Gordon's version of depletion hypothesis relates to the fact that it implicitly assumes that that the depletion of technological opportunities occur in all sectors or at least that the depletion of technological opportunities in ICT could not be compensated by arising technological opportunities in other sectors. Several authors critically commented on this claim. In particular, Mokyr (2014) and Glaeser (2014) argue that technological opportunities in many sectors such as biosciences and medicine are far from depleting. In addition, ICT - although not revolutionizing office work or retail any longer - could be at the brink of radically changing production of manufacturing goods (Mokyr 2014, Sommer 2015). In fact, aggregated figures of R&D expenditures are difficult to reconcile with the claim that technological opportunities depleted generally because in many countries since the end of 1990ies R&D expenditures increased at a higher rate than GDP (compare Figure 2).

Figure 2: R&D expenditures as a share of GDP (top panel: US; bottom panel: world)



Source: World Bank

Generally, depleting technological opportunities would imply that R&D became "more expensive" leading to decreasing R&D expenditures relative GDP rather than rising ones. If at all, the (at least) constant R&D shares in the world are thus indicative of increasing technological opportunities associated with innovation and R&D activities. Although actual evidence over time is scarce, some authors indeed suggest that returns to R&D declined neither in terms of innovation output (Janz et al. 2001) nor in terms of productivity (Wang and Tsai 2004). Likewise, Ha and Howitt (2007) provide compelling time-series evidence that TFP-growth was stationary since the 1950ies, even though the growth-rates of R&D have fallen three-fold in the same period. Ha and Howitt (2007) take their finding as evidence of the Schumpeterian prediction that a constant fraction of R&D will lead to sustained TFP-growth, one implication of which is that the elasticity of TFP-growth with respect to R&D is constant. Madsen (2008, 2010) and Ang and Madsen (2011) present further evidence on the Schumpeterian growth models in showing that economic growth was strongly R&D-driven even after 2000 over a large set of OECD and Asian countries. We therefore expect that the elasticity of TFP-growth with respect to R&D and technology remained constant over the average of all sectors.

H2: The elasticity of TFP growth with respect to sectoral patent stocks and R&D expenditures remained constant over time.

3 Data and methodology

3.1 Construction of the dataset

The data for our analyses were collected from OECD databases (STAN, Main Science and Technology Indicators), the World Bank (population statistics) and the EPO Worldwide Patent Statistical database (PATSTAT) at the level of ISIC Rev. 4 sectors. In order to include all the data in one dataset, some of the data were aggregated to the level of a smallest common denominator for all variables in terms of ISIC Rev. 4 sectors. This implies that data for most of the manufacturing sectors is available at the 2-digit level, while the service sectors are only available in a more aggregated form.

To deal with missing data in our dataset, in particular in early time periods, we made use of ISIC Rev. 3 data. With the help of the concordance of the United Nations Statistics Division, some of the gaps within the data could be filled in case the concordance was unambiguous at the 2-digit level.[1] We collected information on sector-level value added, employment, R&D

1 An unambiguous concordance scheme between ISIC Rev.3 and ISIC Rev.4 that can be applied to OECD at the 2-digit level is not available. We thus resorted to the alternative of only assigning only 2-digit sectors that could unambiguously be assigned although this implies that data for some sectors is missing in the long time-series.

(BERD), capital investment, intermediate inputs, and several further sector and country controls such as exports and population. To eliminate the effects of inflation, we converted all monetary indicators to constant dollars.

The final challenge relates to patents, which are not available at the level of sectors but only at the level of technology classes according to the International Patent Classification (IPC). We approached this problem by matching PATSTAT to a snapshot of Bureau van Dijk's ORBIS database at the level of companies/patent applicants, to which the authors have offline access. With the help of this matched database, patent applicants in PATSTAT can be assigned an ISIC Rev. 4 class. However, the ORBIS database only delivers a snapshot of the current firm landscape. Firm entries and exits over time thus cannot be controlled. Aggregating the companies' patent filings at the sector level might thus induce a bias, due to the lower coverage of sector classifications in earlier years. To counter this effect, we generated a matrix of patent filings by sector and technology fields (WIPO35 list) in the time period from 2011-2013. Based on the matrix, we calculated the share of patents in a given technology field by economic sector. These shares can in a further step be applied to recalculate patents by technology fields to economic sectors across the whole time period. Here, we implicitly assume that the calculated shares are fixed across the whole time-period. This approach, however, also allows us to handle the break in series of the sector classification for the patent indicator. As a robustness check, we have compared the matrix in 2011-2013 to a matrix for 2001-2003. The differences are comparably small, backing our assumption that the shares can be applied across the whole time series.

3.2 Methodology

3.2.1 Calculating TFPs

Analyzing the phenomenon of secular stagnation requires an estimate of sectoral productivity. The simplest measure derivable from the dataset is a measure of labor productivity, which can be defined by the ratio of sector-level value added to employment. While simple to calculate, labor productivities have the disadvantage that they abstract from the use of other inputs, such as capital. In addition, if the production function relating sectoral inputs to outputs displays non-constant returns to scale, any changes in the input scale will change the maximum achievable productivity inducing further distortions. Because of the biases resulting from neglected inputs and unaccounted non-constant returns to scale, it is often more desirable to focus on total factor productivities (TFP).

Assuming a Cobb-Douglas functional form, we can write the logarithmic production function of sector *i* in country *j* at time *t* taking labor, fixed capital and R&D as inputs as follows:

$$y_{ijt} = a_{ijt} + \alpha l_{ijt} + \beta c_{ijt} + \rho r_{ijt} \text{ (1)}$$

where y_{ijt} is logarithmic labor input, c_{ijt} is the logarithmic capital stock, r_{ijt} are logarithmic R&D expenditures. α, β, and ρ are the production elasticities of labor, capital and R&D. a_{ijt} is the logarithmic total factor productivity. Given observations on value added, labor, capital, and R&D, we can estimate Eq. (1) by some regression approach and we can derive the TFP as the exponentiated residual. Estimating Eq. (1), however, requires solving several problems. First, while capital investments are typically observable in the sector-level data, capital stocks are not. In a first step, we therefore constructed capital stocks by the perpetual inventory method using the following formula:

$$c_{ijt} = i_{ijt} + (1 - \delta)c_{ijt-1} \text{ (2)}$$

where i_{ijt} is investment δ is the depreciation rate of physical capital. Assuming a steady-state growth rate of capital g_{ij} we can obtain the initial capital stock through repeated substitution:

$$c_{ij0} = \frac{i_{ij0}}{g_{ij}+\delta} \text{ (3)}$$

We follow Bottazzi and Peri (2007) and set $\delta = 0.1$ and calculate g_{ij} as the growth rate investment in the first four years. The second problem concerns the specification of the TFP-term. Principally, the TFP contains all omitted factors not accounted for explicitly in the production function. In the most general case, we may therefore decompose TFP as follows:

$$a_{ijt} = e_{ij} + u_{ijt} \text{ (4)}$$

with e_{ij} containing all sector specific time constant effects (e.g. sector-specific persistent price shocks). h_t contains all time-varying factors which are common to all sectors (e.g. technology or demand shocks that apply to all sectors). u_{ijt} contains all time-varying factors specific to the sector (e.g. idiosyncratic productivity shocks, time-varying managerial capability). Consistent estimation of Eq. (1) depends on the assumptions made on the terms in Eq. (4). If we are willing to assume that all components of a_{ijt} are uncorrelated with the capital and labor inputs, Eq. (1) can consistently be estimated by pooled OLS or random effects. Such an assumption is quite restrictive. For example, if the demand in one sector is affected persistently by a negative price shock (e.g. decline of oil prices), firms may adjust their use of capital and labor in later periods. OLS-estimation of Eq. (1) will then lead to biased estimates. Nonetheless, we will use it as a point of reference. More robust estimates results from fixed effects regression, which can provide consistent estimates if u_{ijt} is purely random. The ability to eliminate any cross-sectional unobserved heterogeneity makes fixed-effects regression an attractive candidate for calculations of TFPs. We will therefore use it as a second method.

Despite the ability to sort out unobserved heterogeneity-issues, fixed effects will not deliver consistent estimates u_{ijt} if productivity shocks in any period are correlated with capital or labor input. A prime reason is the so-called transmission-bias, referring to the problem that past productivity shocks likely affect the firms' choice of input levels in the future. Since firms cannot freely adjust the present capital stocks, any correlation in the productivity shocks will imply inconsistency of pooled OLS or fixed effects regression (Eberhardt and Helmers 2010). In general, instrumental variable estimators can be used to identify the causal parameters in Eq. (1) but finding valid instruments in typical firm-level datasets is complicated. As a response, several authors have proposed structural estimators. These structural estimatorsderive the conditions under which variables, that are typically available in firm datasets, are valid instruments. Specifying explicitly the dynamic optimization problem of the firm, Olley and Pakes (1996) derive conditions under which past capital investment is correlated with the capital stock but uncorrelated with the current productivity shocks. The disadvantage of the Olley-Pakes-estimator is that it relies on the free adjustment of capital investment. However, if investment is lumpy to some degree, the estimator can be very biased in finite samples. Levinsohn and Petrin (2003) therefore provide a comparable estimator, which uses intermediate inputs instrument, which are typically less lumpy. Nonetheless, also the Levinsohn-Petrin-estimator (LP) relies on quite restrictive assumptions - e.g. that intermediate input use is a monotone positive function of only productivity shocks. It also assumes away fixed effects and therefore does not account for (time-constant) unobserved heterogeneity. In order to at least partly account for unobserved heterogeneity at the sectoral level, it is common to subdivide the TFP-regressions by sectoral subsamples (in our case high-tech manufacturing: NACE 20-35, low-tech manufacturing: NACE 10-19, other sector: all other NACE categories). We will see that the LP estimator will deliver quite unintuitive results in that it largely overrates the capital elasticity. Furthermore, the comparable ACF estimator (Ackerberg et al. 2015) does not solve the problem of inflated capital elasticities. It therefore remains dubious to rely too much on the results for the LP or the ACF estimator, which led us to focus on the FE and RE estimators apparently leading to realistic results. Nonetheless, in particular the results regarding the hypotheses do not critically depend on the choice of the estimator.

3.2.2 Explaining TFPs

Once TFPs have been derived either based on fixed effects or Levinsohn-Petrin regressions, testing the H1 and H2 is easy based on regular panel regressions taking TFP as the explained variable. In the most general form, we estimate the following model by fixed effects in various time periods, h, before and after 2000:

$$log\left(\frac{TFP_{ijt}}{TFP_{ijt-1}}\right) = \alpha_{1,h}\log(PATSTOCK_{ijt}/EMP_{ijt}) + \alpha_{2,h}\log(R\&D_{ijt-1}/EMP_{ijt-1}) + \alpha_{3,h}(INVEST_{ijt-1}/EMP_{ijt-1}) + x_{ijt}\beta_h + c_{ij} + v_{ijt} \quad (5)$$

$PATSTOCK$ is the patent stock calculated by a method identical to the capital stock.[2] $R\&D$ refers to R&D expenditures. EMP and $INVEST$ denote employment and investment. x is sector of further (logarithmic) control variables, in which we include the growth-rate of sector value added to account for cyclical patterns and employment to account for size. Most models also include general year dummies.

With respect to the hypotheses, if H1 is true we expect $\alpha_{3,until\ 2000} > \alpha_{3,after\ 2000}$. Finally, if H2 is true $\alpha_{1,h}$ and $\alpha_{2,h}$ should not differ substantially between the time periods. In specific, we choose three time periods, which roughly lead to comparable numbers of observations: 1993-1990, 2001-2004, and 2005-2011.

2 For the calculation of the patent stock, transnational patent filings, i.e. all filings at the EPO or via the PCT system (excluding double counts) were applied.

4 Results

4.1 The evolution of TFP measures

In Table 1, we present the country representation for which we were able to calculate TFP measures based on the FE approach. In total, we are able to cover 14 OECD countries. However, for three of them, namely GB, KR and SE, the sector-year-level observations were quite limited. Therefore, we will not present country level results for these three countries.

Table 1: Country coverage

	Obs.	Percent
AT	299	11.16
BE	213	7.95
CA	160	5.97
DE	381	14.22
ES	146	5.45
FI	358	13.36
FR	75	2.8
GB	2	0.07
IE	76	2.84
IT	330	12.32
KR	30	1.12
NL	316	11.8
SE	17	0.63
US	276	10.3
Total	2,679	100

If we disaggregate the observations by sector, information on the following ISIC Rev. 4 classifications could be collected. We will, however, only report sector level results on more aggregated levels. In particular, we will create a sector-classification for high-tech. manufacturing including sectors 20-33, low-tech. manufacturing including sectors 10-19, and other sectors including 01-09 and 35-99.

Table 2: Sector coverage

	Obs.	Percent
ISIC_01-03	149	5.56
ISIC_05-09	142	5.3
ISIC_10-12	111	4.14
ISIC_13	54	2.02
ISIC_14	52	1.94
ISIC_15	98	3.66
ISIC_16	138	5.15
ISIC_17	102	3.81
ISIC_18	102	3.81
ISIC_19	120	4.48
ISIC_20	147	5.49
ISIC_21	81	3.02
ISIC_22	162	6.05
ISIC_23	149	5.56
ISIC_24	121	4.52
ISIC_25	136	5.08
ISIC_26	97	3.62
ISIC_27	97	3.62
ISIC_28	145	5.41
ISIC_29	99	3.7
ISIC_30	114	4.26
ISIC_31-33	123	4.59
ISIC_35-99	140	5.23
Total	2,679	100

Table 3 presents summary statistics for the main variables used throughout the report as a point of reference. We will come back to discussing these figures after having presented the results from the TFP-regressions in Table 4 (RE/FE) and Table 5 (LP).

Table 3: Summary statistics

	Obs	Mean	Std. Dev.	Min	Max
TFP Growth Rate (RE)	2,679	0.0049	0.1241	-1.7496	0.9089
TFP Growth Rate (FE)	2,679	0.0057	0.1245	-1.7536	0.9132
TFP Growth Rate (LP)	2,679	-0.0063	0.1277	-1.8010	0.9136
Log Value Added	2,893	15.7345	1.9101	10.3981	23.2558
Log Employees	2,893	11.4427	1.9453	5.9216	18.6673
Log R&D Expenditures	2,893	11.6846	2.3365	5.0841	18.2757
Log Capital Stock	2,893	15.8950	2.0377	8.7861	23.4918
Log Intermediate Inputs	2,860	16.3689	1.8028	11.0271	22.8263
Patent Stock/Employee	2,893	0.0249	0.0395	0.0000	0.4137
Capital Investment/Employee	2,893	19.5579	28.7236	0.2441	320.9970
R&D Intensity	2,893	4.6329	10.6614	0.0005	179.9860
Log Value Added Growth	2,799	0.0253	0.1242	-1.7456	0.9260

When turning to the multivariate results we see that the estimated scale elasticities differ considerably between the RE and the FE approach on the one hand and the LP-approach on the other hand. Production elasticities of labor hover around 0.33-0.45 for RE and FE. Capital-elasticities are of approximately the same magnitude. The R&D elasticities are much lower with on average about 0.07, though much higher for HT-manufacturing with about 0.16. Both for RE and FE, the production functions display decreasing returns to scale. When focusing on the LP approach, the respective scale elasticities are 0.25 for labor, 0.06 for R&D and 0.90 for capital leading to production function with constant returns to scale. In particular, the high value for capital appears to be unreasonably large and inconsistent with economic theory: under constant returns to scale and full competition, it follows from Euler's theorem that the share of capital and labor income must be identical to the production elasticities. In most countries, the labor income as a share of GDP is around 0.6-0.7, while capital income is typically accounts for the rest. In Germany in 2012, the share of labor income for example was 0.68. Thus, the results from the LP-approach are very difficult to reconcile with economic theory and typically observable in macroeconomic capital and labor income shares. Furthermore, a robustness check using the ACF-estimator (Ackerman et al. 2015) as an IV-based close alternative delivered the same inflated result, which suggests that either the failure of the LP and the ACF-approach to account for constant unobserved heterogeneity or their quite restrictive consistency conditions caused the unreasonable results. In the following, we will therefore focus mainly on the RE and FE results, although we note that in particular for the results on the hypothesis-tests the choice of the TFP estimators does not appear to be crucial.

Table 4: TFP regressions (RE and FE)

	(1) RE All firms	(2) RE HT Man.	(3) RE LT Man.	(4) RE Other Sectors	(5) FE All firms	(6) FE HT Man.	(7) FE LT Man.	(8) FE Other Sectors
Log Employees	0.4571***	0.4310***	0.4423***	0.3256***	0.3340***	0.2869***	0.3831***	0.1405**
	(29.39)	(19.43)	(16.92)	(7.74)	(11.68)	(6.34)	(8.29)	(2.19)
Log R&D Expenditures	0.0678***	0.1577***	0.0258**	0.0081	0.0667***	0.1653***	0.0087	0.0138
	(10.13)	(14.96)	(2.09)	(0.69)	(9.40)	(14.64)	(0.69)	(1.17)
Log Capital Stock	0.3863***	0.3074***	0.4561***	0.5125***	0.3509***	0.2866***	0.3623***	0.5162***
	(37.28)	(23.92)	(20.66)	(18.94)	(31.57)	(21.51)	(12.67)	(19.11)
Constant	3.5853***	3.9775***	2.9999***	3.8928***	5.5556***	5.8757***	5.1894***	6.0762***
	(21.26)	(16.06)	(10.58)	(8.47)	(15.78)	(10.79)	(7.59)	(8.63)
Observations	2,893	1,579	844	470	2,893	1,579	844	470
Within R^2	0.3889	0.4603	0.2157	0.325	0.391	0.463	0.217	0.593
#Groups	208.0000	108.0000	63.0000	37.0000	208.0000	108.0000	63.0000	37.0000
Chi2/F-stat	5,621.09	2,819.28	1,762.72	1,037.43	573.1542	422.6901	71.9351	208.9482
CRS-test pval	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: TFP regressions (LP)

	(1) LP All firms	(2) LP HT Man.	(3) LP LT Man.	(4) LP Other Sectors
Log Employees	0.2530***	0.2536***	0.2302***	0.1384
	(5.47)	(2.61)	(2.82)	(1.11)
Log R&D Expenditures	0.0633***	0.0542**	0.0292	0.0012
	(3.26)	(2.37)	(0.72)	(0.02)
Log Capital Stock	0.8921***	0.6647***	0.5354*	0.5137
	(4.04)	(4.36)	(1.81)	(0.62)
Observations	2,860	1,622	838	456
CRS-test pval	0.4166	0.8603	0.5975	0.6371

t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

When comparing how productivity developed over time, Table 6 gives of a slowdown after the 2000 both for FE and RE. For FE for example, we find 0.9% annual growth in 1993-2000, 0.5% annual growth in 2001-2004 and a further decline by 0.3% in 2005-2011. As concerns the results from the LP-model, we observe even negative growth rates in all periods although they moved closer to zero. As already stated, the LP model is unlikely to provide very credible accounts of the evolution of TFP given the unreasonable results for the output elasticity of capital. We therefore do not attach to much weight to the negative growth rates. Nonetheless, we find that none of the TFP-measures is in favor of substantially positive growth rates, which provides quite compelling evidence of the secular stagnation phenomenon in our dataset also when focusing on TFP-based measures. In fact, growth rates for the raw labor productivities are comparable in the trends to the RE/FE-effects TFP growth rates. In the period for 1993, the growth rate of labor productivity was about 3.8% and continuously dropped to 2.9% in 2005-2011. As Figure 4 - Figure 8 in the appendix show, these trends appear to be quite consistent over countries and broader sectors.

Table 6: TFP-growth rates over the years

	TFP Growth Rate (RE)	TFP Growth Rate (FE)	TFP Growth Rate (LP)
1993-2000	0.0057	0.0089	-0.0141
2001-2004	0.0051	0.0047	-0.0032
2005-2011	0.0040	0.0035	-0.0014

4.2 Explaining TFP-growth

The results on the evolution of TFP-growth provide additional support on the secular stagnation hypothesis by showing similarly slow sluggish growth also when focusing on total factor productivities rather than on raw labor productivities. However, the sources of the secular stagnation phenomenon, in particular the claim that technology development as a driver of TFP-growth became less important, are still under debate. A decisive question is therefore whether the elasticities of TFP-growth with respect to certain key innovation-related variables have changed over time. In particular, if the depletion hypothesis was true, we would expected the elasticity of TFP-growth with respect to innovation-related variables, such as R&D or patent, declined over time. In Table 7 (RE) and Table 8 (FE), we test whether declining trends in the elasticities can be observed. For the patent stocks, we find no significant relation to TFP-growth in any of the time periods and irrespective of whether we use the RE or the FE-based TFP-measure. When turning to the effects of R&D, we can observe a positive and statistically highly significant values for the TFP-growth elasticity, again irrespective of whether the TFP-growth measures variable was calculated using Random or Fixed Effects.[3] While the elasticities are with about 0.020-0.038 not overwhelmingly large, there is little evidence that the elasticities strongly declined over time. If at all, there was a slight dip in the second period from 2001-2004, which was followed by a recovery in the following period from 2005-2011. Thus, overall there seems little evidence of a general depletion of technological opportunities. Thus, we corroborate H2 for R&D.

When additionally considering the TFP-growth elasticity with respect to sectoral per-employee capital-investment (columns 4-8 in Table 7 and Table 8) we can observe a consistent drop in the coefficients. While in 1993-2000 the elasticity was around 0.022-0.024 both for RE and FE, the elasticities where not significant in the two ensuing periods anymore. To the degree that we consider capital investments as linked to embodied technological change, our results are consistent with a modified version of the depletion hypothesis: we find little support that the effectiveness of genuine innovation activities as a driver of TFP-growth has declined. We do however find some evidence that the effectiveness of embodied technological change driven by capital investments has declined. As argued in Figure 1, the lower relevance of capital investments as a driver of TFP-growth is also consistent with macroeconomic observations on the relative prices of capital investment, which declined sharply throughout the 1990ies but changed only little afterwards.

3 Indeed, the main results are robust for the LP-estimator (not presented).

Table 7: FE-regressions: drivers of TFP-growth (RE-based TFP-measures)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All years	1993-2000	2001-2004	2005-2011	All years	1993-2000	2001-2004	2005-2011
Log Patent Stock/Employee	0.0053	-0.0111	-0.0129	0.0391	-0.0001	-0.0075	-0.0119	0.0374
	(0.75)	(-0.50)	(-0.31)	(1.16)	(-0.02)	(-0.34)	(-0.28)	(1.11)
L.Log R&D Intensity	0.0210***	0.0377***	0.0237***	0.0273***	0.0210***	0.0383***	0.0237***	0.0274***
	(10.75)	(7.12)	(5.67)	(8.23)	(10.80)	(7.26)	(5.68)	(8.24)
Log Employees	-0.0410***	-0.0513	-0.2181***	-0.0895**	-0.0421***	-0.0506	-0.2208***	-0.0897**
	(-4.13)	(-1.45)	(-4.62)	(-2.37)	(-4.27)	(-1.44)	(-4.67)	(-2.38)
Log Value Added Growth	0.9572***	0.9910***	0.9734***	0.9615***	0.9544***	0.9939***	0.9749***	0.9610***
	(131.35)	(61.52)	(66.42)	(112.38)	(131.60)	(61.88)	(66.12)	(111.69)
L.Log Capital Investment/Employee					-0.0220***	0.0243***	0.0077	-0.0045
					(-5.97)	(2.85)	(0.92)	(-0.64)
Constant	0.4640***	0.4966	2.4023***	1.1568***	0.5111***	0.4568	2.4189***	1.1631***
	(4.67)	(1.39)	(5.94)	(3.70)	(5.17)	(1.28)	(5.98)	(3.72)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,679	930	719	1,030	2,679	930	719	1,030
R^2	0.892	0.845	0.899	0.952	0.893	0.846	0.900	0.952
#Groups	203.0000	180.0000	183.0000	199.0000	203.0000	180.0000	183.0000	199.0000
F-stat	963.1060	402.0247	675.9390	1635.1315	933.9212	369.7381	591.3722	1485.4626

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: FE-regressions: drivers of TFP-growth (FE-based TFP-measures)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All years	1993-2000	2001-2004	2005-2011	All years	1993-2000	2001-2004	2005-2011
Log Patent Stock/Employee	0.0067	-0.0001	-0.0091	0.0292	0.0025	0.0032	-0.0081	0.0277
	(1.02)	(-0.01)	(-0.23)	(0.89)	(0.37)	(0.15)	(-0.20)	(0.85)
L.Log R&D Intensity	0.0197***	0.0367***	0.0207***	0.0265***	0.0197***	0.0372***	0.0207***	0.0266***
	(10.84)	(7.40)	(5.18)	(8.23)	(10.87)	(7.53)	(5.19)	(8.24)
Log Employees	-0.0276***	-0.0265	-0.1565***	-0.0643*	-0.0285***	-0.0259	-0.1591***	-0.0645*
	(-2.98)	(-0.80)	(-3.47)	(-1.76)	(-3.09)	(-0.79)	(-3.52)	(-1.76)
Log Value Added Growth	0.9677***	0.9952***	0.9831***	0.9714***	0.9655***	0.9978***	0.9845***	0.9710***
	(142.52)	(65.96)	(70.18)	(117.09)	(142.58)	(66.30)	(69.86)	(116.38)
L.Log Capital Investment/Employee					-0.0171***	0.0221***	0.0075	-0.0039
					(-4.98)	(2.76)	(0.93)	(-0.57)
Constant	0.3182***	0.2705	1.7207***	0.8288***	0.3548***	0.2343	1.7369***	0.8342***
	(3.44)	(0.81)	(4.45)	(2.73)	(3.84)	(0.70)	(4.49)	(2.75)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,679	930	719	1,030	2,679	930	719	1,030
R^2	0.907	0.862	0.908	0.956	0.908	0.864	0.908	0.956
#Groups	203.0000	180.0000	183.0000	199.0000	203.0000	180.0000	183.0000	199.0000
F-stat	1138.0094	462.6323	748.7189	1789.4403	1097.9482	425.0389	655.0665	1625.4603

5 Conclusion

Based on techniques for the calculation of total factor productivities, we provided new evidence of the secular stagnation hypothesis, which claims that growth rates of productivities have declined over time and are unlikely to return to the levels before the 1990ies. Several candidate explanations have been proposed to explain stagnating productivity levels, which vary widely and relate to monetary and fiscal policies (Summers 2014, Krugman 2014) or changes in the welfare system (Glaeser 2014). As of recent, Gordon (2014, 2015) suggested that stagnating productivities could be the result of depleting technological opportunities. We contribute to the debate by providing empirical evidence on several of its aspects. First, we focus on TFP-measures rather than the raw labor productivities for a set of 11 OECD countries. Indeed, using a wide range of techniques, we can robustly show that the TFP-growth rates were very low throughout the period from 1993-2011 not exceeding rates of 0.9 % per annum on average. Furthermore, we observe a considerable decline in the rates after 2000, where annual growth remained at around 0.3%. The stagnating trends appear to be robust over countries and sectors. Second, we investigated the technological depletion hypothesis in detail. Our results show that the importance of own R&D activities as a driver of TFP-growth did not tremendously change over time. While that observation seems to contradict the depletion hypotheses at least in a very broad definition, we do however note that the role of capital investments as way to induce capital-embodied technological change almost vanished after 2000. While in the 1990ies we find a positive elasticity of capital investment on TFP-growth, we do not find a significant effect afterwards. Relying on macroeconomic evidence on the relative prices, capital investment and Gordon's (2015) depletion hypotheses, our results are therefore consistent with the claim that advances in capital goods, in particular ICT, lost their potential to drive total factor productivities in other sectors after the 1990ies. This argument however shall not hide that, considering for example the digitization of production, ICT may not be an important technological component in many future technologies but at least the induced sharp decline in prices for ICT equipment seems to be largely over after the turn of the millennium.

In summary, we interpret our results as being largely consistent with the technological depletion hypothesis, with some needs for clarification though. As Gordon (2015) claimed, we find evidence of declining potentials to benefit from capital-embodied technical change. However, there is little evidence that general intrasectoral R&D expenditures or patenting did not promote TFP-growth after 2000. Thus, our results do not support the notion of consistently depleting technological opportunities across sectors. Overall, while we may enter an extended period where firms find it difficult to sustain high productivity growth mainly based on capital-embodied technical change, intramural innovation has, if at all, increased in importance.

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7 Appendix

Overall the trends across the RE, FE, and LP-methods are fairly comparable even though they might somewhat in level. For most countries the growth rates were slightly higher in the in the early 1990nds. A more sizeable downward sloping trend is observable for Italy, which corresponds well the Italian economic stagnation since the early 1990ies. Furthermore, all countries display a display a sizeable dip around 2009, which most likely can be interpreted as a crisis-phenomenon.

Figure 3: The evolution of TFP-growth by country (RE)

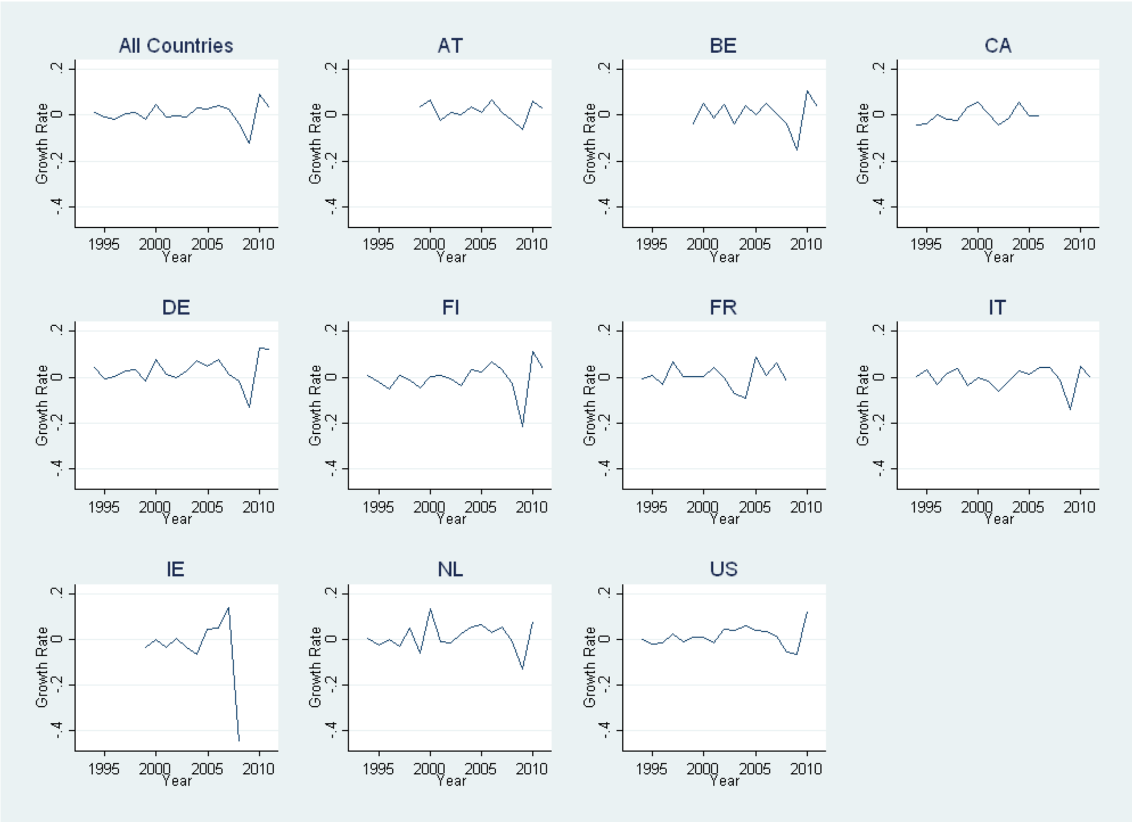

Figure 4: The evolution of TFP-growth by country (FE)

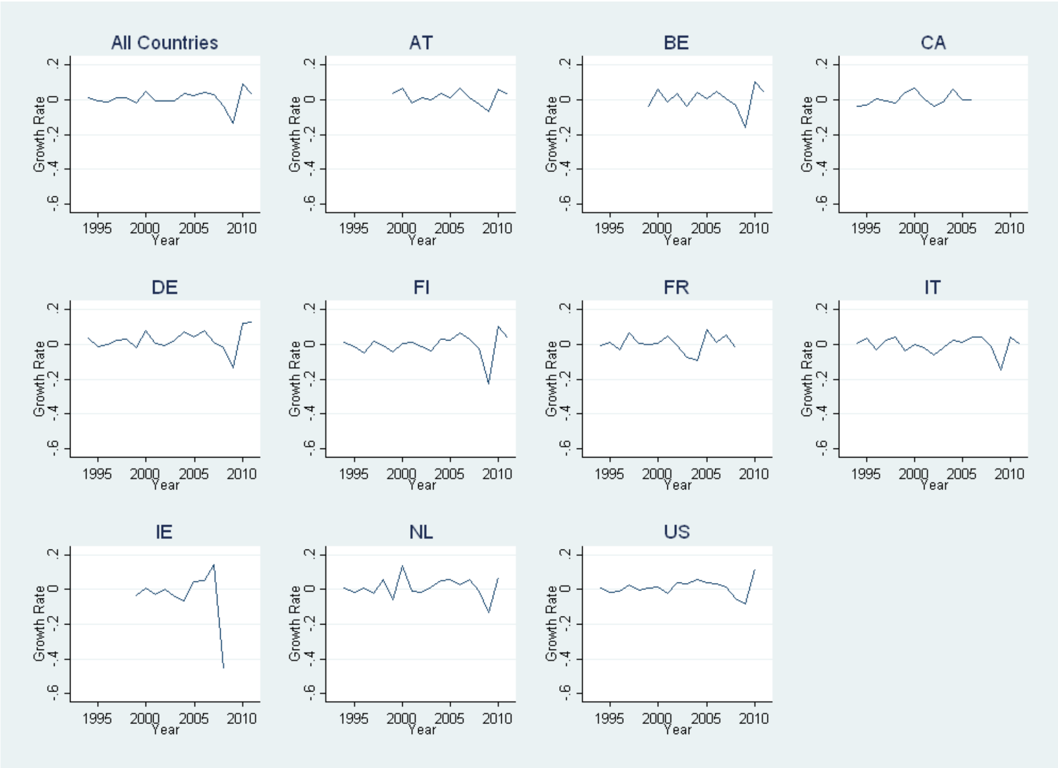

Figure 5: The evolution of TFP-growth by country (LP)

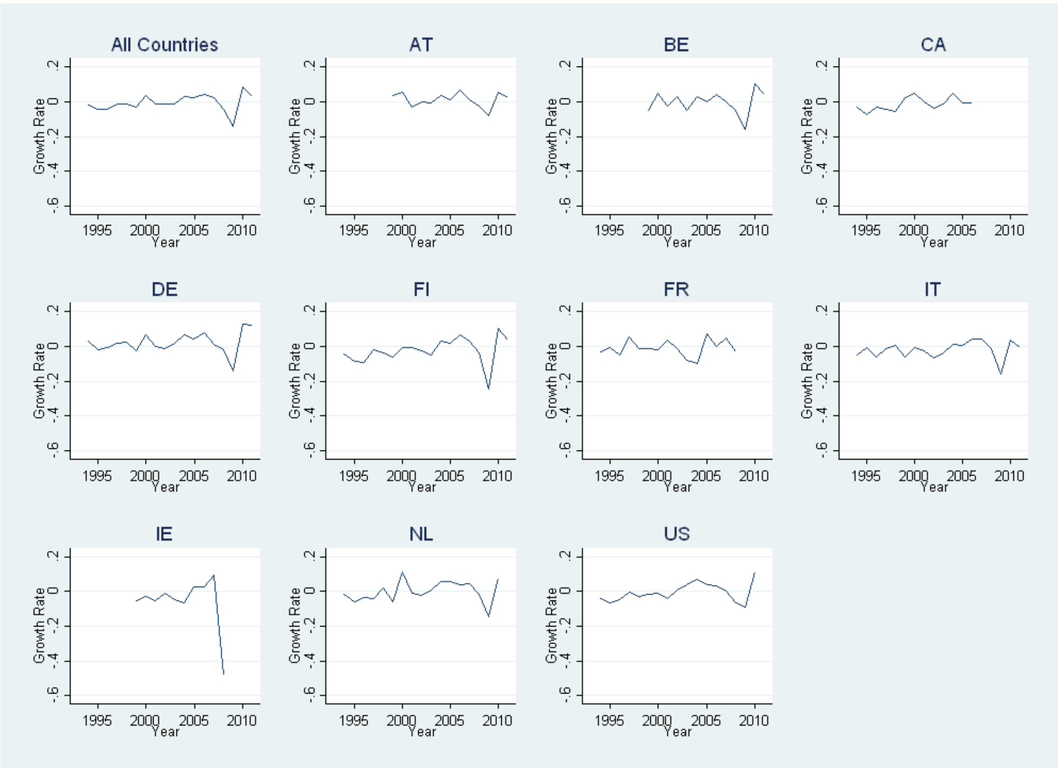

Figure 6: The evolution of TFP-growth by sector (RE)

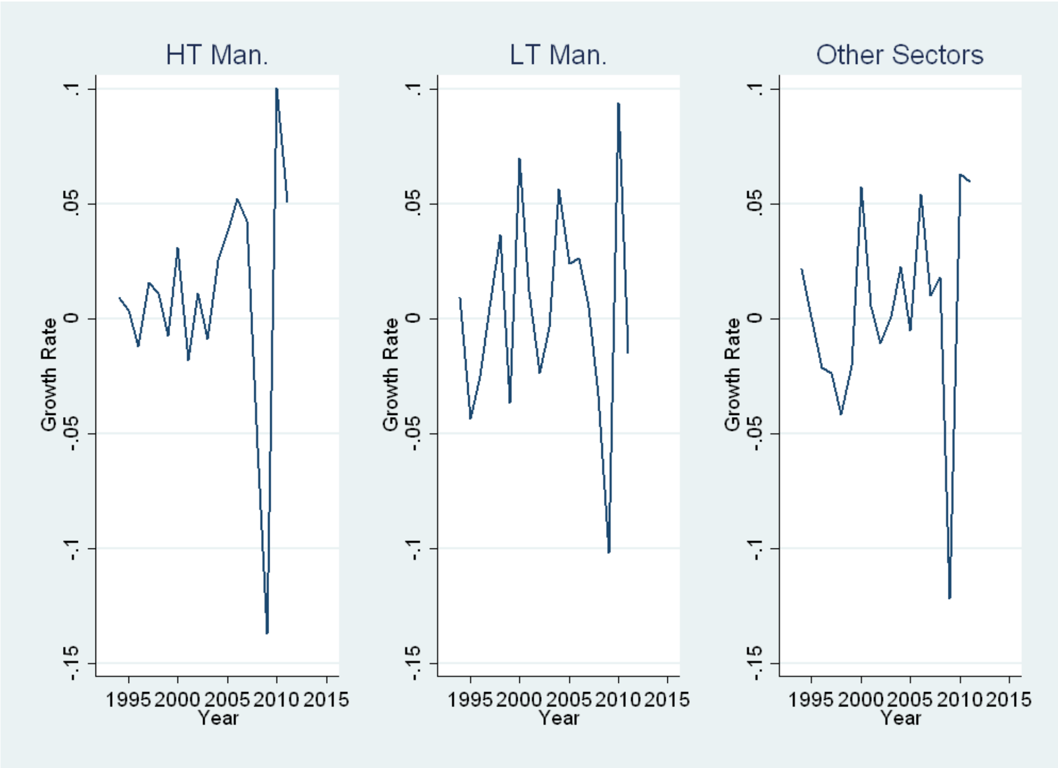

Figure 7: The evolution of TFP-growth by sector (FE)

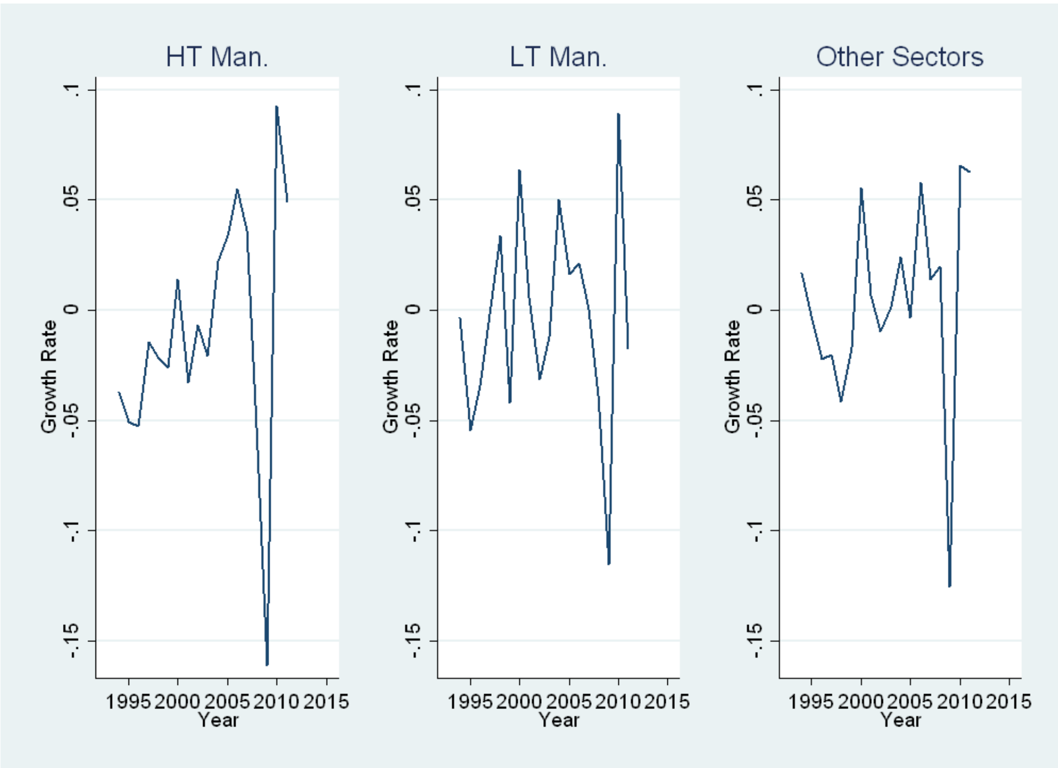

Figure 8: The evolution of TFP-growth by sector (LP)