TFP Measurement

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October 19, 2018

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 727073

Outline

1. The two fundamental results of growth accounting
   - The Solow residual
   - The Hulten aggregation theorem
2. Implementation and insights
   - Growth accounting in Europe and in the US
   - The ups and downs of US productivity growth
   - The IT Revolution and divergence
3. Improving measurement
   - Growth accounting and the business cycle
   - Limits of Hulten's theorem
   - Quality improvements and new products

1. The two fundamental results of growth accounting

The origins of growth accounting: Solow (1957)

- What are the sources of economic growth?
- Assume that there is an aggregate production function,

$$Y_t = Z_t F\left(K_t, L_t\right).$$

- Using a first-order Taylor approximation, we can write the growth rate of output as

$$\frac{Y_{t+1} - Y_t}{Y_t} \approx \frac{\dot{Y}_t}{Y_t}$$

- Then,

$$\frac{\dot{Y}_t}{Y_t} = \left(\frac{\partial F}{\partial K_t}\frac{K_t}{F}\right)\frac{\dot{K}_t}{K_t} + \left(\frac{\partial F}{\partial L_t}\frac{L_t}{F}\right)\frac{\dot{L}_t}{L_t} + \frac{\dot{Z}_t}{Z_t}$$

- We can decompose output growth into growth in labour, capital and a residual.
- But for this, we need to know the production function elasticities... How can we measure them?

The most fundamental result in growth accounting

- Assume production is done by a cost-minimizing firm.

$$w_t = P_t Z_t \frac{\partial F}{\partial L_t}$$

- This implies

$$\frac{\partial F}{\partial L_t} \frac{L_t}{F} = \frac{w_t L_t}{P_t Y_t}$$

$\Rightarrow$ The labour elasticity of the production function equals the (observable) labour share.

- The same thing is true for capital. Under perfect competition, we then have

$$\frac{\partial F}{\partial K_t} \frac{K_t}{F} = \frac{r_t K_t}{P_t Y_t} = 1 - \frac{w_t L_t}{P_t Y_t}$$

Insights

- Now, we can define the “Solow residual”, the part of output growth that is not explained by growth in production factors:

$$\frac{\dot{Z}_t}{Z_t} = \frac{\dot{Y}_t}{Y_t} - s_{K,t}\frac{\dot{K}_t}{K_t} - s_{L,t}\frac{\dot{L}_t}{L_t}.$$

Fact

The Solow residual accounts for the largest part of output growth over time.

- For instance, in the United States, it accounts for 80% of all growth in output per hour between 1948 and 2013 (Jones, 2016).
- “Productivity isn’t everything, but in the long run it is almost everything.” (Krugman, 1994).

Interpretation

- The Solow residual has been famously called “the measure of our ignorance” (Abramovitz, 1956).
- Indeed, it can capture many things:
  - Technological progress.
  - Changes in the organization of production.
  - Efficiency of the resource allocation.
  - Utilization rate of production factors.
- So, growth accounting is only the first step in analyzing the drivers of economic growth...
  - but it is a crucial first step, and it is important to get it right!

Growth accounting with different sectors: Hulten (1978)

- In the real world, there is no aggregate production function.
  - Instead, we consume a large number of different goods...
  - ... and many goods are only produced as intermediate inputs into other goods (e.g., steel).
- How do we do growth accounting in such a world? What is the right way to aggregate Solow residuals over many different activities?
- Hulten (1978) solved this issue by proving a fundamental aggregation result.

Hulten aggregation: setup

- Consumer preferences are given by

$$\mathcal{D}\left(C_{1t}, C_{2t}, \ldots, C_{Nt}\right)$$

- Production of every good uses labour and intermediate inputs.

$$Y_{nt} = Z_{nt} F_n \left(L_{nt}, K_{nt}, M_{n1t}, \ldots, M_{nNt}\right),$$

  where M_{nit} is the amount of good i used as an input in sector n at time t.

- We keep assuming perfect competition.
- What is real GDP (or aggregate production) in this economy?

Decomposing output growth

- Real GDP $\mathcal{Y}$ is defined as the aggregate utility of the representative consumer ($\mathcal{D}$ evaluated at equilibrium consumption).
  - This is equal to nominal income (nominal GDP) deflated with the ideal price index defined by $\mathcal{D}$.
  - We can normalize this price index to 1 for simplicity.
- Then, using the usual first-order approximation,

$$\frac{\mathcal{Y}_{t+1}-\mathcal{Y}_t}{\mathcal{Y}_t} \approx \frac{\dot{\mathcal{Y}}_t}{\mathcal{Y}_t} = \left(\frac{\partial \mathcal{Y}}{\partial Z_{1t}} \frac{Z_{1t}}{\mathcal{Y}}\right) \frac{\dot{Z}_{1t}}{Z_{1t}} + ... + \left(\frac{\partial \mathcal{Y}}{\partial Z_{Nt}} \frac{Z_{Nt}}{\mathcal{Y}}\right) \frac{\dot{Z}_{Nt}}{Z_{Nt}}$$

- How can we determine the elasticities of real GDP to industry productivities?

Output elasticities (1/2)

- The economy we are considering is efficient (perfect competition and no distortions).
- Therefore, the first welfare theorem holds, and the efficient allocation of resources is the solution of the social planner problem:

$$\mathcal{Y} = \max \mathcal{D}\left(C_1, C_2, ..., C_N\right)$$
$$\text{such that}$$
$$\textstyle\sum_{n=1}^{N} L_n = L$$
$$\textstyle\sum_{n=1}^{N} K_n = K$$
$$Z_n F_n\left(L_n, K_n, M_{n1}, ..., M_{nN}\right) = C_n + \textstyle\sum_{i=1}^{N} M_{in}$$

- The Lagrangian of this problem is

$$\mathcal{D}\left(C_1, ..., C_N\right) - \lambda_L \left(\textstyle\sum_{n=1}^{N} L_n - L\right) - \lambda_K \left(\textstyle\sum_{n=1}^{N} K_n - K\right)$$
$$- \textstyle\sum_{n=1}^{N} \lambda_n \left(C_n + \textstyle\sum_{i=1}^{N} M_{in} - Z_n F_n\left(L_n, K_n, M_{n1}, ..., M_{nN}\right)\right)$$

Output elasticities (2/2)

- Applying the envelope theorem,

$$\frac{\partial \mathcal{Y}}{\partial Z_{nt}} = \lambda_n F_n \left(L_n, K_n, M_{n1}, ..., M_{nN} \right).$$

- This implies

$$\frac{\partial \mathcal{Y}}{\partial Z_{nt}} \frac{Z_{nt}}{\mathcal{Y}} = \frac{\lambda_n Y_n}{\mathcal{Y}}.$$

- Furthermore, can note that the Lagrange multiplier λ_n equals the price of good n, P_n, in a competitive economy.
  - To show this, note that the optimality conditions fulfilled by λ_n and P_n are the same.
- Therefore, we have

$$\frac{\partial \mathcal{Y}}{\partial Z_{nt}} \frac{Z_{nt}}{\mathcal{Y}} = \frac{P_n Y_n}{\mathcal{Y}}.$$

The Hulten theorem

Theorem

Up to a first-order approximation, output growth is given by

$$\frac{\mathcal{Y}_{t+1} - \mathcal{Y}_t}{\mathcal{Y}_t} \approx \sum_{n=1}^{N} \left(\frac{P_n Y_n}{\mathcal{Y}} \right) \frac{Z_{nt+1} - Z_{nt}}{Z_{nt}}.$$

- Growth in aggregate output is a weighted average of industry-level growth rates.
- The weight of an industry is given by the ratio of its sales over GDP (Domar weight).
- Note that these weights sum up to more than 1!
    - This is because input-output linkages introduce multiplier effects (see, e.g., Jones, 2011).

The Hulten theorem: interpretation

- Hulten's theorem is very powerful.
  - To calculate the aggregate impact of a change in productivity in one given industry (of firm), we just need to know its sales weight.
  - We do not need to know its position in the input-output structure...
  - ... and thus can do growth accounting without any information on how the input-output network looks like.
- At the industry-level, we can do Solow-style growth accounting:

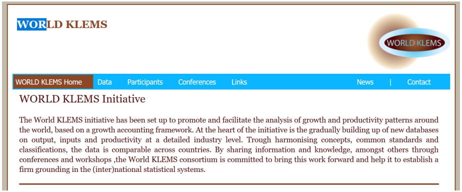
$$\frac{\dot{Z}_{nt}}{Z_{nt}} = \frac{\dot{Y}_{nt}}{Y_{nt}} - s_{Kn,t}\frac{\dot{K}_{nt}}{K_{nt}} - s_{Ln,t}\frac{\dot{L}_{nt}}{L_{nt}} - s_{Mn,t}\frac{\dot{M}_{nt}}{M_{nt}}$$

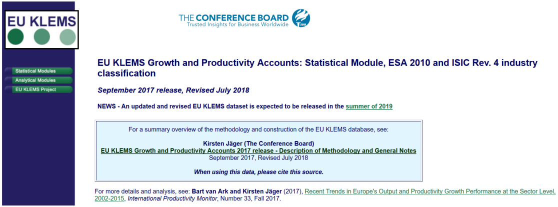
- But Hulten's theorem also has some limits (more on these later).

2. Implementation and insights

Growth accounting data (1/2)

- Researchers have constructed large growth accounting databases.



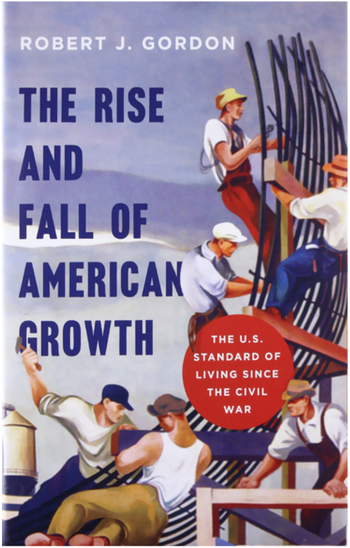


- Data is available without charge at worldklems.net and euklems.net.

Growth accounting data (2/2)

- KLEMS databases have the distinct advantage to have very disaggregated data on production factors.
  - Not just one type of labour, capital and materials, but up to 10 different types of capital and 18 different types of labour.
  - This allows separating the effects of composition changes (e.g., in the work force) from overall TFP.
- They also have limitations (see later), but they are the necessary starting point for any applied researcher working on productivity.

History of US productivity growth



Ups and downs: technological waves?

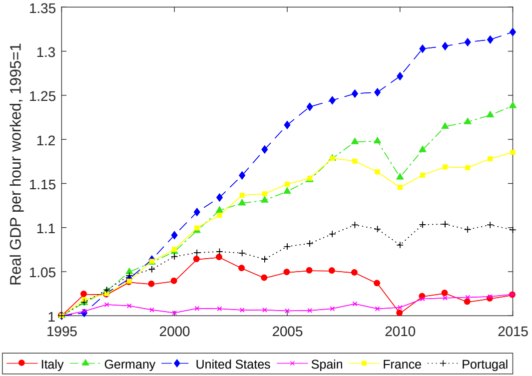
Source: Gordon (2016)

- Growth waves (in grey) correspond to the effects of major technological advancements.
  - Second Industrial Revolution: Electricity and the internal combustion engine.
  - Third Industrial Revolution: Information and Communication Technology.

Ups and downs: technological waves?

1. Technological progress is not constant, but occurs in waves/clusters (Schumpeter, 1916).
   - Some explanations of this have been proposed: complementarities in production (Shleifer, 1986), alternation between investment and innovation phases (Matsuyama, 1999).
2. It takes time for innovations to show up in productivity.
   - Technological Revolutions require large complementary investments, and firms do not directly know how to use them most efficiently (David, 1989, Brynjolfsson et al., 2018).
   - This is a common explanation for the "Solow paradox": in 1987, Solow famously claimed that "you can see the computer age everywhere, except in the productivity statistics".
   - The IT-driven productivity acceleration only occured towards the middle of the 1990s.

Recent country-level differences in productivity growth

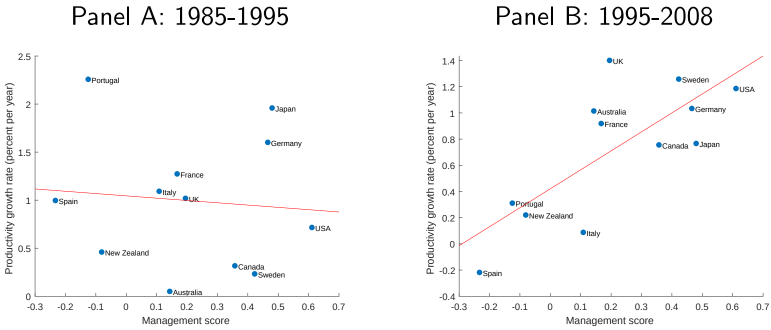


Source: Schivardi and Schmitz (2018)

Why has there been divergence?

- Divergence occured at about the same time that the impact of IT started to be felt in the US.
- TFP gaps have been particularly large in industries that have benefited a lot from IT in the US.
  - Wholesale and Retail trade (Amazon, Walmart...)
  - Business Services (IT Consulting...)
- Why has Europe (and Southern Europe in particular) adopted so little IT and benefited relatively little from the installed IT?

IT and management practices



Source: Schivardi and Schmitz (2018)

Why has there been divergence?

- Management practices have often been shows to be important for IT adoption and productivity gains from IT (e.g., Bloom et al., 2012).
- In Schivardi and Schmitz (2018), we use micro-level evidence on IT-management complementarity to calibrate a macro model.

	DEU	ITA	PRT	ESP
Productivity growth induced by IT	11.1%	5.9%	3.4%	2.5%
Share of actual divergence		35%	81%	47%

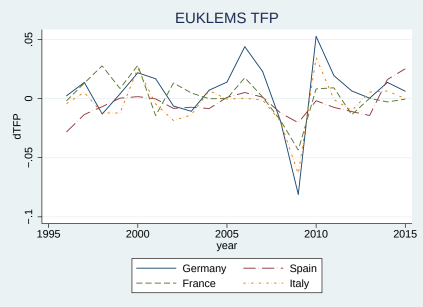
Source: Schivardi and Schmitz (2018)

3. Improving measurement

3.1. Growth Accounting over the Business Cycle

Factor utilization

- Factor utilization changes over the business cycle: even if firms have the same number of machines and of workers, they use them more or less intensively.
- This creates an important bias in TFP measures.



- Do we really believe that German TFP fell by 8% from 2008 to 2009?

Solving the measurement problem

- Solow (1957). "*Lacking any reliable year-by-year measure of the utilization of capital I have simply reduced the [capital stock] by the fraction of the labor force unemployed in each year, thus assuming that labor and capital always suffer unemployment to the same percentage. This is undoubtedly wrong, but probably gets closer to the truth than making no correction at all.*" Later, Costello (1993) and Burnside et al. (1995) instead used electricity consumption.

- Basu, Fernald and Kimball (2006) and Fernald (2014) developed a more sophisticated approach, accounting for
  1. Industry-level variation in production functions.
  2. Non-constant returns to scale.
  3. Fluctuations in factor utilization.

- For Europe, standard measures (OECD, European Commission, EU KLEMS) take into account 1, but not 2 or 3.

Our FRAME project

1. With Diego Comin, Javier Quintana and Antonella Trigari, we develop a procedure to adjust European TFP series for fluctuations in factor utilization.
   - Our procedure is similar in spirit to the one of Basu, Fernald and Kimball, but has also important differences, due to different labour market characteristics in the US and Europe.
2. We provide new annual time series for TFP growth at the aggregate and at the industry level for four European countries between 1995 and 2015.
   - Longer time span and quarterly data are work in progress.
3. We show that these new series provide a new perspective on European TFP dynamics around the Great Recession.

The BFK methodology

- Start from a usual growth accounting equation (at the industry-level). Redefine $K_{it} = A_{it}\widetilde{K}_{it}$ and and $L_{it} = E_{it}H_{it}N_{it}$ to get

$$dY_{it} = dX_{it} + dU_{it} + dZ_{it}.$$

$$dX_{it} = s_{Kit}d\widetilde{K}_{it} + s_{Lit}\left(dH_{it} + dN_{it}\right) + s_{Mit}dM_{it}\ ;\ dU_{it} = s_{Kit}dA_{it} + s_{Lit}dE_{it}$$

- Crucial feature: firms adjust all utilization margins simultaneously. Under some technical assumptions on adjustment costs, we get

$$dY_{it} = dX_{it} + \beta_i dH_{it} + dZ_{it},$$

  where β_i is a constant unknown parameter. Details

$\Rightarrow$ That is, BFK rely on the fact that (observable) changes in hours per worker are proportional to (unobservable) changes in capital utilization or worker effort.

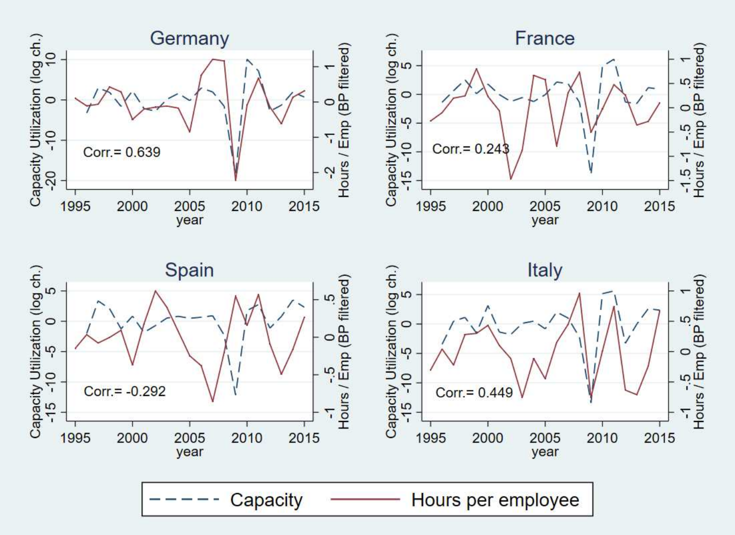
Econometric implementation and aggregation

- Hours per worker are detrended with a band-pass filter.
- β_is are estimated. There is a simultaneity problem, though: firms choose inputs knowing their productivity, so that dX_{it} and dH_{it} are correlated with the residual dZ_{it}.
- Therefore, BFK propose an IV approach, using
  - Oil price shocks.
  - Fiscal policy shocks.
  - Monetary policy shocks.
- Identification assumption: instruments are orthogonal to TFP shocks.

Are hours per worker always a good proxy for utilization?

- Many countries collect survey-based measures of capacity utilization (mostly in the manufacturing sector).
- For instance, the European Commission collects such a measure for every member state as a part of its Business and Consumer Surveys.
- The BFK methodology suggests that these measures should be positively correlated with hours per worker.
- Are they?

Hours per worker and utilization in manufacturing



Hours per worker and utilization in manufacturing

- The situation is quite heterogeneous across countries:
  - In Germany, the two measures are highly correlated, while in Spain, they are not at all correlated.
  - France and Italy are somewhere in the middle.
- Why is that the case? Composition effects in dual labour markets could be part of the answer.
  - In Spain, many workers were employed on temporary contracts (with short hours) during the boom.
  - In the crisis, these were the first to get fired, and thus hours per worker increased through a composition effect. Evidence on dual labour markets
- In the presence of these composition effects, hours per worker are no longer a valid proxy for changes in factor utilization.
  - Formally, the β_i in the regression becomes time-varying.

An alternative approach

- Given the limitations of hours per worker, we propose to use an adjustment method using the survey-based measures of capacity utilization instead.
- That is, we specify
$$dY_{it} = dX_{it} + \widetilde{\beta}_i dT_{it} + dZ_{it},$$
- Our assumption is that there is a stable and linear relationship between changes in capacity utilization dT_{it} and changes in unobserved capital utilization and worker effort.
- We then estimate $\widetilde{\beta}_i$ using 2SLS.
    - As BFK, we restrict $\widetilde{\beta}_i$ to be the same across broad industry groups, to have more power.

Data

- All growth accounting data comes from EU KLEMS.
  - Annual industry-level data on inputs, outputs and factor shares from 1995 to 2015, for the four largest continental European countries (DE, ES, FR, IT).
  - We focus on the market economy (excluding public administration, health, education...).
- EU KLEMS considers 31 inputs (3 types of intermediates, 10 types of capital, 18 types of labour).
  - Different inputs are aggregated using their expenditure shares, e.g.,

$$dL_{it} = \sum_{l} \bar{w}_{lit} \left(dH_{lit} + dN_{lit} \right)$$

  - This already implements a direct control for composition effects.
- For capacity utilization, we use the European Commission's Harmonized Business and Consumer survey.
  - It is available for a line of manufacturing industries. For non-manufacturing industries, we use the manufacturing average.

Instruments

- We use three instruments.

1. Oil prices
   - Detrend natural logarithm of real oil prices with a band-pass filter (isolating components between 2 and 8 years)
   - Cyclical component in the series between years $t-2$ and $t-1$.
2. Economic Policy Uncertainty shocks (http://www.policyuncertainty.com/)
   - This is an index based on newspaper articles regarding policy uncertainty.
   - Increases in uncertainty are known to negatively affect investment, employment and output (Baker, Bloom and Davis, 2016).
3. Monetary shocks
   - European monetary policy shocks (Jarocinski and Karadi, 2018).
   - Identify surprise movements in Eonia interest rate swaps using ECB policy announcements.

Estimated β coefficients (BFK methodology)

	(1)		(2)		(3)		(4)	
	Germany		Spain		France		Italy	
	β	F-stat.	β	F-stat.	β	F-stat.	β	F-stat.
Durable Manufacturing	0.810***	33.4	-0.122	2.11	0.777***	9.46	0.596***	20.24
	(0.142)		(1.320)		(0.231)		(0.107)	
Nondurable Manufacturing	0.628***	38.7	-2.634	0.36	-0.251	7.16	0.434***	19.24
	(0.194)		(2.526)		(0.355)		(0.139)	
Non-manufacturing	0.424	15.6	-2.047**	2.52	0.020	1.07	-0.218	2.78
	(0.386)		(0.931)		(0.300)		(0.410)	
Observations	440		420		440		418	

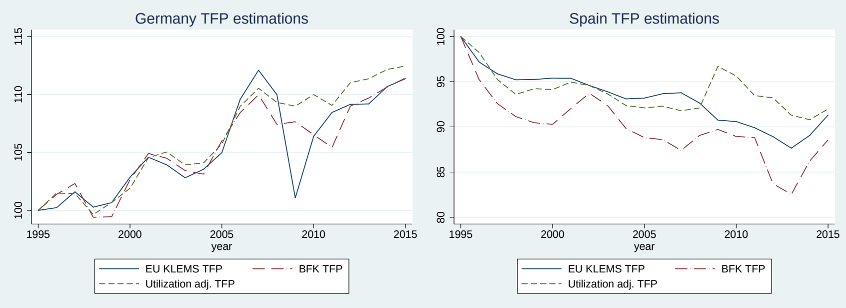
Standard errors in parentheses. * $p < 0.05$,** $p < 0.01$, *** $p < 0.001$

Estimated $\widetilde{\beta}$ coefficients (our methodology)

	(1) Germany		(2) Spain		(3) France		(4) Italy	
	β	F-stat.	β	F-stat.	β	F-stat.	β	F-stat.
Durable Manufacturing	0.338***	17.94	0.126	1.10	0.229***	7.97	0.329***	10.89
	(0.055)		(0.226)		(0.063)		(0.059)	
Nondurable Manufacturing	0.394***	14.78	0.260*	3.93	0.037	10.19	0.366***	3.95
	(0.112)		(0.146)		(0.098)		(0.122)	
Non-manufacturing	0.040	60.96	0.301***	12.00	0.203***	30.71	0.134***	26.99
	(0.040)		(0.105)		(0.052)		(0.051)	
Observations	440		420		440		418	

Standard errors in parentheses. * $p < 0.05$,** $p < 0.01$, *** $p < 0.001$

Properties of the new TFP series



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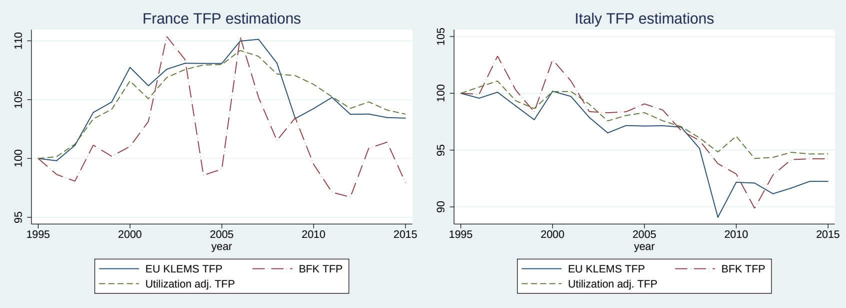


Properties of the new TFP series

	Growth rates		Correlations			
Germany	Mean	Std. Deviation	VA	$\mathrm{TFP}_{\mathrm{EU\ KLEMS}}$	$\mathrm{TFP}_{\mathrm{BFK}}$	$\mathrm{TFP}_{\mathrm{Survey}}$
VA	.0121	.0325	1			
$\mathrm{TFP}_{\mathrm{EU\ KLEMS}}$	.0050	.0253	0.93	1		
$\mathrm{TFP}_{\mathrm{BFK}}$	.0050	.0158	0.48	0.70	1	
$\mathrm{TFP}_{\mathrm{Survey}}$	.0051	.0119	0.37	0.59	0.89	1
Spain	Mean	Std. Deviation	VA	$\mathrm{TFP}_{\mathrm{EU\ KLEMS}}$	$\mathrm{TFP}_{\mathrm{BFK}}$	$\mathrm{TFP}_{\mathrm{Survey}}$
VA	.0169	.0312	1			
$\mathrm{TFP}_{\mathrm{EU\ KLEMS}}$	-.0076	.0099	0.35	1		
$\mathrm{TFP}_{\mathrm{BFK}}$	-.0086	.0198	0.10	0.51	1	
$\mathrm{TFP}_{\mathrm{Survey}}$	-.0073	.0172	-0.42	-0.06	0.32	1

Properties of the new TFP series

	Growth rates		Correlations			
France	Mean	Std. Deviation	VA	$\mathrm{TFP}_{\text{EU KLEMS}}$	$\mathrm{TFP}_{\text{BFK}}$	$\mathrm{TFP}_{\text{Survey}}$
VA	.0174	.0217	1			
$\mathrm{TFP}_{\text{EU KLEMS}}$	.0019	.0157	0.86	1		
$\mathrm{TFP}_{\text{BFK}}$	.0019	.0146	0.80	0.98	1	
$\mathrm{TFP}_{\text{Survey}}$	.0021	.0113	0.10	0.38	0.49	1
Italy	Mean	Std. Deviation	VA	$\mathrm{TFP}_{\text{EU KLEMS}}$	$\mathrm{TFP}_{\text{BFK}}$	$\mathrm{TFP}_{\text{Survey}}$
VA	.0049	.0283	1			
$\mathrm{TFP}_{\text{EU KLEMS}}$	-.0044	.0186	0.79	1		
$\mathrm{TFP}_{\text{BFK}}$	-.0038	.0137	0.66	0.94	1	
$\mathrm{TFP}_{\text{Survey}}$	-.0027	.0100	-0.11	0.16	0.39	1

Properties of the new TFP series

- With respect to the EU KLEMS TFP measure,
  - the mean of the series is roughly unchanged.
  - standard deviation is substantially lower (except in Spain).
  - the correlation with output is substantially lower.

- With respect to the BFK TFP measure,
  - series are highly correlated in countries in which hours per worker and capacity utilization are highly correlated (Germany, Italy).
  - in countries where this is not the case, the correlation is substantially lower (Spain, France).

A new perspective on Southern European TFP

- The long-run picture remains unchanged: low growth of TFP since the middle of the 1990s.
- However, previously, it looked as the TFP decline just continued unchanged through the crisis.
- Our measure suggests some evidence for selection/cleansing effects at the beginning, especially in Spain.
  - In later years, TFP does decline (negative effects of recessions on R&D and technology adoption: Comin and Gertler, 2006, Anzoategui et al., 2016).
  - Effects appear to be particularly strong in the construction sector. TFP by sector
- Maybe we need to better distinguish between the short and the long-run effects of recessions on productivity?

3.2. Limits of Hulten's theorem

Limits of Hulten's theorem: first-order approximation

- Recall Hulten's aggregation theorem and its consequences: to assess the effect of a sector-level change in productivity, you only need to know the sector's ration of sales to GDP.
- But the theorem is based on a first-order approximation, and therefore only valid for small shocks!
- Baqaee and Farhi (2018a) derive a second-order approximation.
    - This shows that for large shocks, the network structure of the economy does matter!
    - For instance, compare shocks to oil and to retail trade.

Oil vs. Retail productivity shocks

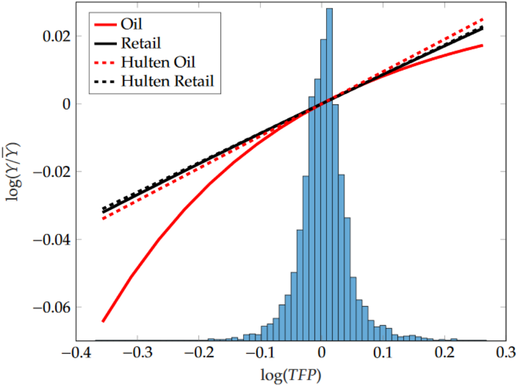
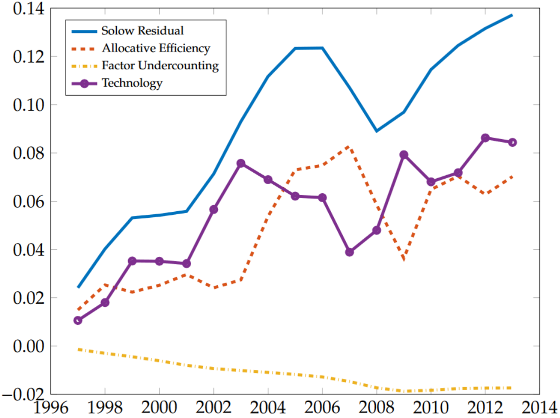


Figure 6: The effect of TFP shocks to the oil and gas industry and the retail trade industry. Both industries have roughly the same sales share, and so they are equally important up to a first-order approximation (dotted line). The nonlinear model is more fragile to both shocks than the loglinear approximation. The oil and gas industry is significantly more important than retail trade for large negative shocks. The histogram is the empirical distribution of sectoral annual TFP shocks pooled over the whole sample. The model has

Limits of Hulten's theorem: efficient economy

- Hulten's theorem assumes that the economy is efficient, without distortions.
  - In reality, of course, there are many distortions in the economy (e.g., market power).
- Baqaee and Farhi (2018b) derive a generalization of Hulten's theorem for an economy with distortions.
  - In this economy, the allocation of resources is no longer efficient: the equilibrium and the social planner solution no longer coincide.
- Therefore, productivity shocks have two effects: a direct effect (as before), and a change in the efficiency of the resource allocation.

Application to markups (United States)



- Sectors with high mark-ups have grown most over the last years.
- As they were too small to begin with, their expansion increased the aggregate Solow residual.

3.3. Quality improvement and new products

Output measurement problems

- To measure real output, statistical agencies need to disentangle
  - Price changes due to inflation.
  - Price changes due to changes in the quality of the underlying goods.
- This is a difficult task for "continuing" goods (e.g., safer and more comfortable cars).
  - Statistical agencies use hedonic regression models to get at this (i.e., try to estimate how much consumers value certain characteristics).
- Things are even harder for new goods which replace old ones (creative destruction).
  - How do you quantify the quality gain going from a cellphone to a smartphone?
  - Imputation: assume that inflation for creatively destroyed goods is equal to inflation for all other goods.

Output measurement problems

- When creatively destroyed goods have higher quality improvements than average, imputation creates a bias.

- Assume that nominal GDP raises by 4%.
  - 80% of goods are unchanged, but due to inflation, their prices increase by 4%.
  - 10% of all goods are improved by their current producers and experience a decrease in quality-adjusted prices by 6%.
  - The remaining 10% of goods replace old goods, and their quality-adjusted prices also fall by 6%.

  $\Rightarrow$ Assuming the ideal price index is a simple average of prices, the inflation rate is $0.8 \cdot 4\% + 0.2 \cdot (-6\%) = 2\%$, and true productivity growth is also 2%.

- However, imputation leads to a measured inflation rate of $8/9 \cdot 4\% + 1/9 \cdot (-6\%) = 2.9\%$, and a measured productivity growth of only 1.1%.

Measuring creative destruction (1/3)

- Aghion et al. (2017) develop a simple framework to correct this bias. Assume

$$Y_t = \left(\int_0^N \left(q_t(j)\, y_t(j) \right)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}, \text{ with } \varepsilon > 1,$$

- Goods are produced with a linear production function $y_t(j) = l_t(j)$, and producers set a mark-up over their marginal cost, so that

$$p_t(j) = \mu w_t,$$

- For each good j, there is a probability λ_d that it gets improved through creative destruction, with a new producer displacing the previous one and improving its quality by a factor $\gamma_d > 1$. For all goods not improved by creative destruction, there is a probability λ_i that their current producers improve their quality by a factor $\gamma_i > 1$.

Measuring creative destruction (2/3)

- Goods are consumed by a representative consumer, who earns a wage income $w_t L$, equal to nominal GDP M_t. The ideal price index is

$$P_t = \left(\int_0^N \left(\frac{p_t(j)}{q_t(j)} \right)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}} .$$

- Therefore, real GDP growth is given by

$$\frac{Y_{t+1}}{Y_t} = \frac{M_{t+1}}{M_t} \frac{P_t}{P_{t+1}},$$

- The true price index holds

$$\frac{P_{t+1}}{P_t} = \frac{w_{t+1}}{w_t} \left(1 + \lambda_d \left(\gamma_d^{\varepsilon-1} - 1\right) + (1-\lambda_d) \lambda_i \left(\gamma_i^{\varepsilon-1} - 1\right)\right)^{\frac{1}{1-\varepsilon}} ,$$

- The statistical agency instead measures

$$\left(\widehat{\frac{P_{t+1}}{P_t}} \right) = \frac{w_{t+1}}{w_t} \left(1 + \lambda_i \left(\gamma_i^{\varepsilon-1} - 1\right)\right)^{\frac{1}{1-\varepsilon}} .$$

Measuring creative destruction (3/3)

- How can we recover the true inflation rate $\frac{P_{t+1}}{P_t}$?
- The market share of products $\mathcal{I}_t$ which have not been affected by creative destruction in period t is

$$S_{\mathcal{I}_t,t} = \int_{\mathcal{I}_t} \left(\frac{P_t}{\frac{p_t(j)}{q_t(j)}} \right)^{\varepsilon-1} dj.$$

- Then, defining $P_{\mathcal{I}_t,t}$ as the ideal price index for these prodcuts (the one observed by statistical agencies), it is easy to show that

$$\frac{S_{\mathcal{I}_t,t+1}}{S_{\mathcal{I}_t,t}} = \left(\frac{P_{t+1}/P_t}{P_{\mathcal{I}_t,t+1}/P_{\mathcal{I}_t,t}} \right)^{\varepsilon-1}.$$

- Using Census data, Aghion et al. can calculate $\frac{S_{\mathcal{I}_t,t+1}}{S_{\mathcal{I}_t,t}}$ (by making some additional assumption).
- Then, they just need to assume a reasonable value for ε and they get an estimate for missing growth!

Results

- Using $\varepsilon = 4$, the authors find that missing growth amounts to 0.64 percentage points per year in the United States between 1983 and 2013
  - The Bureau of Labor Statistics calculates a growth rate of 1.87% per year, the true growth rate should be 2.51%.
  - These estimates are roughly robust to assuming different values of ε, varying between 0.20 and 0.90 percentage points.
- Missing growth appears to be large.
  - Still, it is unlikely that the current phase of low productivity growth is due to mismeasurement.

Hours per worker and other adjustment margins

- BFK assume that capital utilization, effort and hours per worker all have a wage cost ("shift premium"). Total wage costs are then $w_t G(H_{it}, E_{it}) V(A_{it}) N_{it}$.
- Assuming N_{it} cannot be adjusted, cost minimization implies

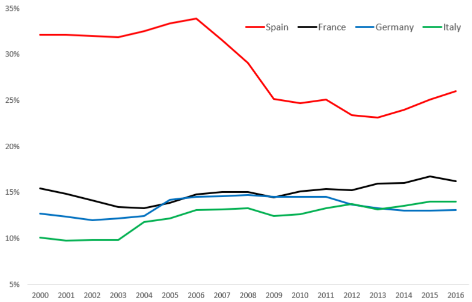
$$\frac{\partial G}{\partial H_{it}} \frac{H_{it}}{G} = \frac{\partial G}{\partial E_{it}} \frac{E_{it}}{G}.$$

- Thus, assuming the shape of G is such that there is a one-to-one mapping between E_{it} and H_{it}, we get up to a first-order approximation $E_{it} = \zeta H_{it}$, where ζ is a positive constant.
- Similarly, we can derive a relationship between A_{it} and H_{it}.

Back

Dual labour markets

Share of workers with a temporary contract



Source: OECD.

- The incidence of part-time work is higher among temporary workers (OECD, 2000; Eurofound, 2007). Back