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# How to Boost Productivity in the EU

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# How to Boost Productivity in the EU

*by Klaus Weyerstrass**

## Abstract

Advances in total factor productivity (TFP) are important for sustaining economic growth in modern economies, in particular in the face of a declining working-age population. In this Policy Brief, we identify investment in research and development, good governance, the capital intensity, a high share of information technology in the total capital stock, and the number of industrial robots per employee as conducive for TFP growth. Based on the empirical results, policies that are beneficial for capital formation in general, investment in computer technology, research and development as well as the use of industrial robots could boost TFP in Europe.

## Total Factor Productivity and its Importance for Economic Growth

Advances in productivity are decisive for maintaining and increasing the prosperity of modern economies (German Council of Economic Experts, 2015). In general, productivity is defined as output in relation to input. In analyses for the economy as a whole, output is generally measured by real GDP. In sectoral analyses, value added is the appropriate output indicator. Labour productivity is calculated as production per employee or per working hour. The productivity of capital, raw materials or energy can be calculated accordingly. After subtracting the contribution of the production factors, a residuum remains. With reference to the seminal work of Solow (1957), that part of real output that is not attributable to the other input factors is referred to as the Solow residual. Since it measures productivity that is not directly attributable to any of the production factors that are explicitly taken into account, it is called multifactor productivity (MFP) or total factor productivity (TFP). Solow (1957) refers to TFP as technical progress, which he regards as exogenously given and thus not explainable. Romer (1990), on the other hand, provides theoretical reasons for technical progress to be endogenous.

Although sporadic approaches exist that consider also raw material and energy, the vast majority of studies confine the input factors to labour and capital. Instead of using the number of workers or working hours, some authors adjust for the quality of labour by using information on the age

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or education profile of the workforce (see, e.g. Syverson, 2011, and Oulton, 2016). In the economic policy debate, particular attention is paid to labour productivity growth, as real wages should rise in line with labour productivity. When it comes to the determinants of labour productivity, Gomez-Salvador et al. (2006) point out that total factor productivity (TFP) is the most important factor influencing labour productivity.

When calculating TFP as the Solow residual, one has to weigh the other inputs. Most easily, this can be seen from the Cobb-Douglas (CD) production function:

$$Y = A \cdot K^{\alpha} L^{\beta}$$

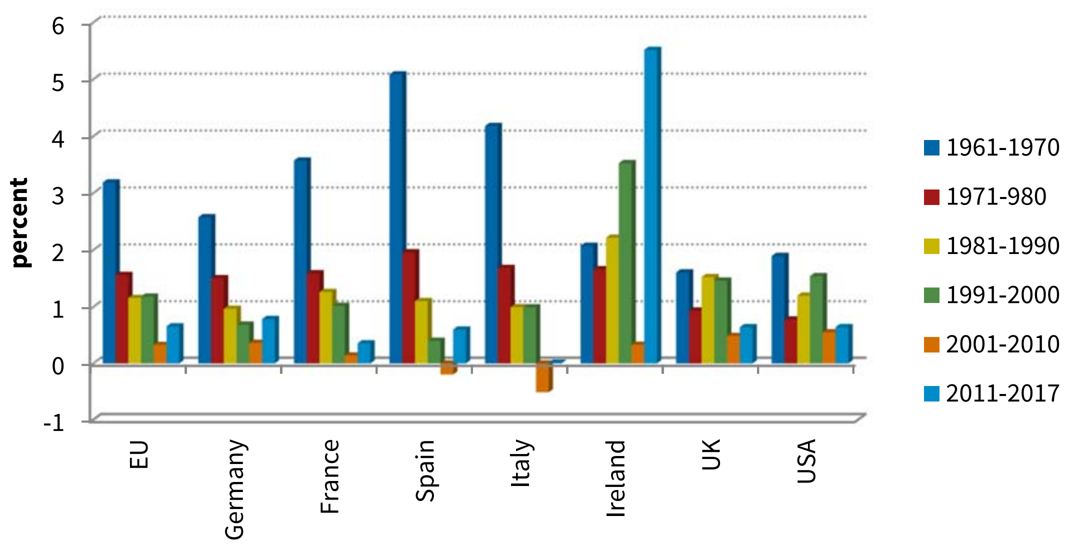
Y measures output (usually GDP), K stands for capital, and L for labour. α and β are the production elasticities, and A measures TFP. CD production functions are a first-order approximation to any production function. This, in combination with their relatively little demands to the data, make Cobb–Douglas-style approaches the most common in the literature. However, many researchers also use the translog form, which is a second-order approximation to general production functions and thus more flexible, but also more demanding of the data (Syverson, 2011). When estimating potential GDP, the European Commission assumes constant returns to scale (Havik et al., 2014). According to Havik et al. (2014), this assumption is broadly consistent with empirical evidence at the macro level. Under constant returns to scale, the nominal factor shares are stable over time. Under the additional assumption of perfect competition, the elasticities α and β can be estimated from the wage share and the profit share, respectively. The European Commission assumes the same Cobb-Douglas specification and the same values of 0.65 for labour and 0.35 for capital, respectively, for all EU countries (Havik et al., 2014). With these settings, TFP can be derived by re-arranging the above equation in the following way:

$$TFP = A = \frac{Y}{K^{0,35}\ L^{0,65}}$$

TFP is not only an essential determinant of labour productivity, but also of economic growth. The Joint Economic Forecast Group (2017) for Germany and Fortin et al. (2017) for Austria identify TFP as the most important driver of medium-term growth. Due to the eminent decline of the population in working age, TFP will play an increasingly important role in maintaining economic growth in the future.

In most EU countries, but also in the US, TFP growth has decreased over time. Also GDP growth decreased over the decades, but the decreasing trend in TFP is particularly accentuated. In the aftermath of the financial crisis of 2007-2009, TFP growth recovered somewhat in most EU countries, particularly so in Ireland[2] . On the other hand, in Italy TFP growth even became negative in the recent past. Given these empirical observations, the question arises what can be done to revitalise TFP growth and hence the growth potential in Europe.

Figure 1: TFP Growth in the EU and Selected Countries




Note: EU refers to EU28 from 1995 onwards, before 1995 calculated on the basis of growth rates of TFP for EU27 and EU15, respectively. Germany: Before 1991 West-Germany.

Source: AMECO database; own calculations and illustration

# Determinants of TFP – a Literature Review

A large body of literature has been devoted to the analysis of the drivers of total factor productivity. In the following, these factors are elaborated, based on Outlan (2016), Syverson (2011), Danquah et al. (2014), and UNIDO (2007) as well as other studies, cited below at the appropriate places.

One of, if not the, most important determinants of TFP is technical and scientific progress. Investment in research and development (R&D) is often identified as the main driver of TFP growth. Both company-owned R&D activities that lead to product or process innovations as well as research achievements of other companies (if these are generally accessible) and of universities or other research institutions are important. With regard to the research achievements of universities or universities of applied sciences, it is essential that the knowledge

[2] Irish GDP is to a large extent influenced by the presence of foreign companies and the resulting transfers of income between Ireland and the rest of the world

gained there is widely disseminated and applied in industry in order to become productive. In a study for the OECD countries, Guellec and van Pottelsberghe de la Potterie (2001) conclude that R&D financed from abroad is most important for long-term TFP growth, followed by R&D by domestic companies and finally public research. It should be noted that technical progress embodied in new capital goods is not attributed to TFP, but to the production factor capital. TFP is also influenced by gross fixed capital formation, in empirical studies usually measured as a share of GDP. Investment in fixed assets facilitates the emergence and dissemination of technological progress, since technological developments are generally tied up in new plants (Jäger et al., 2015). Learning, either in the form of "learning by doing" or learning from others, also supports TFP. Learning can also be due to positive external effects, i.e. the benefit of published findings of other companies or research institutions. It is not only domestic capital formation, but also foreign direct investment (FDI) that can boost TFP. FDI often goes hand in hand with a transfer of technology and management knowledge. The larger the difference in the level of development between the giving and the receiving economy, the larger the technological boost this will trigger. Developed economies can therefore expect FDI to have significantly less productivity-enhancing effects than emerging economies. Not only inward FDI, but also exports may influence productivity. Exporting companies are generally more productive than companies that produce exclusively for their domestic market. This can be attributed to the fact that the pressure of competition on foreign markets is often fiercer, which leads exporting companies to increase productivity. Graetz and Michaels (2015) find that robot densification is associated with increases in total factor productivity and wages.

Structural change in the economy can also affect TFP. A positive influence can be expected from a redistribution of input factors from less productive to more productive companies, or from a restructuring within companies. According to an OECD study (McGowan et al., 2017), part of the observed decline in productivity growth in many industrialised countries has been caused by a growing number of so-called zombie companies. Zombie firms are old companies that have permanent difficulties in servicing their loans. The existence of these zombie companies and the production factors captured by them prevent young and rapidly growing firms from entering the market. This prohibits faster productivity progress by means of “creative destruction”. According to the argumentation brought forward by McGowan et al (2017), these companies are artificially kept alive by public subsidies, aiming at protecting the lending banks from getting into solvency problems.

As mentioned above, in the production function the factor labour is most often measured by the number of persons employed or total hours worked. There are, however, approaches to measure the quality of the labour force directly. The wage structure is often used here, since higher education and knowledge are usually reflected in higher wages, at least if there is no oversupply of certain qualifications. However, if the labour factor is only recorded quantitatively, improvements in the education level are – strictly speaking incorrectly – not attributed to the production factor labour, but to the TFP. The educational attainment can be measured by the average number of school years or the share of persons with tertiary education.

Numerous studies theoretically and empirically investigated the influence of the use of information technology (IT) goods. A literature review can be found in Syverson (2011). Positive productivity effects of an increased use of IT can be attributed to the opportunities of processing larger quantities of information, and to the faster availability of information for planning production processes or transport, as well as to shorter changeover times in the production of various product variants.

Also the government may – positively or negatively – influence TFP. Positive effects might be expected from public spending on R&D, fast internet connections or education. However, in general a large government sector often entails tax distortions to finance expenditure. These distortions can hinder the efficient allocation of resources. This is particularly true when government spending is largely of a consumptive nature. Also the regulation of goods markets has an influence on productivity. Regulation that affects competition, for example by creating barriers to market entry, can contribute to lower productivity growth since such barriers reduce incentives for innovation activities by incumbent companies. Similarly, theoretical and empirical evidence suggests that state-owned enterprises have fewer incentives for productivity-enhancing innovation than privately owned enterprises.

In a recent paper by the Centre for Economics and Business Research in the UK, changing preferences of employees are blamed for the decline in productivity growth (Williams, 2017). The author argues that preferences have shifted away from high-paying jobs towards so-called "lifestyle jobs". This includes, for example, the creative industry. Such jobs bring, as the argument goes, more job satisfaction, but they are less productive than conventional jobs.

Finally, total factor productivity is influenced by measurement errors. The usual approach of attributing quality improvements of the factors labour and capital not to these input factors, but to TFP, is strictly speaking a measurement error. The same applies if intangible assets are not explicitly recognized but are also allocated to TFP. Too little recognition of quality improvement in the growth of the capital stock leads to an overestimation of the increase in capital goods prices and thus to an underestimation of real investment. An underestimation of the growth of the capital stock results in an overestimation of the contribution of TFP. However, it must be borne in mind that underestimating capital growth also leads to underestimating GDP growth. This results from the fact that GDP growth can be calculated as the weighted sum of the growth rates of the expenditure components, with the weights representing the shares of the individual components in GDP. The net error, i.e. the difference between the measurement error of the contribution of the capital stock on the factor input side and investment on the expenditure side, depends on the size of the weights (the investment share of GDP and the profit share as an approximation of the production elasticity of the factor capital) (Oulton, 2016).

For a panel of 32 countries (the 28 EU countries plus Switzerland, USA, Canada, Japan and South Korea), Weyerstraß (2018) identifies significantly positive influences of the number of patents (or, in alternative specifications, spending on R&D), the investment share in GDP, the industry share in GDP, openness, economic freedom, and a positive regulatory environment on TFP. Negative influences are found for the share of public consumption in GDP and for the share of services.

## Determinants of TFP – Empirical Investigation with a Focus on Information Technology

Based on the literature review as well as Weyerstraß (2018), for the present Policy Brief a panel econometric analysis of the determinants of TFP was performed. A panel model analyses cross-section data (in our case for a panel of countries) over time. In addition to the existing literature, a special focus was laid on the influence of investments in information and communication technologies (ICT). Two variables were included. Firstly, in line with Graetz and Michaels (2015), industrial robots per employee were taken. Secondly, Eurostat data on the capital stock were taken, differentiated by asset types. The Eurostat database provides data on total ICT capital as well as data on computer hardware, computer software and databases as well as telecommunication equipment.

The endogenous variable, i.e. the variable explained in the model, is total factor productivity calculated on the basis of the production function mentioned above. Before estimating the equations, it has to be decided whether the level or the growth rate of TFP should be taken as the endogenous variable. In the literature, both approaches can be found, e.g., Miller and Upadhyay (2000) as well as Dettori et al. (2012) use the level of TFP, while Danquah et al. (2014) explain TFP growth. When the level of TFP is explained, any effect of the explanatory variables causes a long-run level shift of TFP.

The following explanatory variables were taken into account (a list of the variables and the sources can be found in Table 2 in the appendix): number of patents, share of industry or services in value added, share of industry in GDP, public consumption as share of GDP, openness of the economy, regulatory quality, detailed capital stock data, number of industrial robots. The analysis was performed for a panel of the current 28 EU member states, but due to limited data availability Estonia, Cyprus and Poland were excluded. Hence, the basic panel consisted of 25 countries. In the models including the robots density, i.e. robots per employee, or a breakdown of the capital stock, the panel was much smaller due to limited availability of the respective data.

The panel OLS models include fixed effects for countries and time periods. Time dummies capture the influence of aggregate trends, while the country dummies control for country heterogeneity in the development of TFP. Table 1 shows a summary of the significant factors in different specifications of the panel model. The detailed results can be found in the appendix. There, Table 3 displays the basic model without data on ICT capital and robot density, Table 4 contains results for models including data on ICT capital, and Table 5 shows models including data on both ICT capital and robot density. In the first set of estimations, three different models were tested, while in the second and the third set of estimations four models were investigated. The variables were included in logarithms, so the resulting coefficients can be interpreted as elasticities. The only exception is the regulation index, which can be negative. In this case, the coefficients are semi-elasticities.

**Table 1: Summary of Significant Results**

Dependent Variable: log (TFP)

| Variable | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Constant | ✓ | ✓ | ✓ |
| log (PATENTS) | ✓ | ✓ | |
| log (INDUSTRY SHARE) | ✓ | ✓ | |
| log (SERVICES SHARE) | | | |
| log (INVESTMENT SHARE) | ✓ | ✓ | ✓ |
| log (PUBLIC CONSUMPTION SHARE) (negative) | ✓ | ✓ | ✓ |
| QUALITY OF REGULATION INDEX | ✓ | | ✓ |
| log (INTELL. PROPERTY / TOTAL CAPITAL) | | ✓ | ✓ |
| log (OTHER MACHINERY/ TOTAL CAPITAL) | | ✓ | ✓ |
| log (TRANSPORT EQUIPMENT / TOTAL CAPITAL) | | ✓ | ✓ |
| log (CONSTRUCTION / TOTAL CAPITAL) | | ✓ | |
| log (COMPUTER HARDWARE / TOTAL CAPITAL) | | ✓ | |
| log (COMPUTER SOFTWARE / TOTAL CAPITAL) | | ✓ | |
| log (ROBOTS / EMPLOYEE) | | | ✓ |
| No. of countries | 25 | 16 | 13 |
| Estimation period | 1996 - 2016 | 1985 – 2016 | 1996 – 2016 |

Panel OLS with country and time fixed effects. Sources: Eurostat, AMECO, OECD, own presentation

Among the basic variables, investment exerts a robust positive influence on total factor productivity. On the other hand, in all finally chosen specification, large government intervention as measured by the share of public consumption in GDP is detrimental to TFP. Also intellectual capital either captured via the number of patents or via the stock of intellectual property capital, is found to robustly positively affect TFP.

Regarding the complete regression results as reported in the appendix, in the first model (1a) the factors identified in the literature as influencing TFP were included, but not all coefficients were significant. In In the third model, those variables that were not significant were excluded. The results in Table 1 confirm theoretical considerations and previous empirical studies. The number of patents per million inhabitants, the share of industry in value added, the share of investment in GDP, and good governmental regulation positively influence total factor productivity, while a large public sector is detrimental for TFP. A positive influence of openness could not be established in the present study. If, alternatively, the share of exports in GDP was included (model 1b), this variable was significantly positive, but in this case the industry share became insignificant. Therefore, it was decided to exclude any measure of economic openness in the final model 1c. According to the empirical results, the positive influence of the share of investment in GDP and the negative influence of the share of public consumptions are larger than the positive effect of the number of patents. This is somewhat surprising, as it should in particular be research and development and the resulting patents that stimulate multifactor productivity. However, the comparatively large negative effect of public consumption might be a proxy for government intervention in general. Large government (consumptive) expenditures have to be financed by taxes which are in general more or less distortive. These distortions then impede such private activities that stimulate productivity. Regarding the quite small positive effect of patents it has to be borne in mind that for patents to affect TFP it needs time, but particularly due to the relatively short time period lags could not be taken into account in the present panel regressions. Dettori et al. (2012) find somewhat larger effects of intangible capital, which includes human capital, knowledge capital and life-long learning. Miller and Upadhyay (2000) identify, among others, an effect of trade openness of comparable size as the present study.

If the capital stock is taken into account in addition to the variables from the basic model, it turns out that both the total capital intensity, i.e. the capital-labour ratio, is conducive to TFP. Interesting, the R&D capital stock (as share of the total capital stock) is significantly negative (model 2a). This might be due to multicollinearity with the number of patents per million inhabitants. Also the regulation index becomes negative, hence the latter and the R&D capital stock were taken out in model 2b. In contrast, the expected positive influence of information and communication (ICT) capital can be confirmed. Also all other capital asset, including transport equipment and also buildings, positively influence TFP. In models 2c and 2d, instead of total ICT capital, the constituting asset classes computer hardware, software and databases, and telecommunication equipment are included. The regulation index remains insignificant, and also for telecommunication capital as share of total capital, no significant influence on TFP could be found.

Finally, in models 3a to 3d, in addition to the variables from the basic model and the capital stock data, the robot density, defined as industrial robots per employee, was included. Due to limited availability of data on the number of robots in the IFR database, in this case the panel shrinks to 13 countries. It turns out that the robot density significantly stimulates TFP in addition to ICT and other capital and many of the basic factors. However, some of the basic variables change compared to the basic models. As an example, instead of a positive effect from the industry share in value added, now a negative influence of the services share is found.

## Summary and Conclusions

Total factor productivity is an important driver of long-term economic growth. Hence, policies that boost TFP would be conducive to the growth potential in the EU. In all industrialised countries, TFP growth has slowed down over the last decades. Although it is not unusual that growth is slower the higher the level of income already is, in some countries the slowdown was more pronounced than in others and the severe economic and financial crisis had a lasting negative impact on TFP growth. In some countries, e.g. in Italy, TFP growth has still not recovered, and in most of the other EU countries the recovery has been more or less sluggish.

In the literature, numerous factors were identified that are conducive to TFP growth. To mention are, e.g. a large share of industry as opposed to services in value added, investment, research and development, good governance as well as openness to foreign direct investment and international trade. In the present study, in addition the capital intensity, a high share of information technology in the total capital stock, as well as the number of industrial robots per employee could be identified as conducive for TFP growth. Due to limited data availability, the influence of the robot density is less robust than the positive effect of the industry share in value added, R&D spending (measured as R&D spending or by the number of patents). Also the negative influence of a large government sector is robust across the various models. The capital intensity and the share of ICT capital in total capital are found to be beneficial for TFP in most model specifications. Based on the empirical results, policies that are beneficial for capital formation in general, investment in computer technology, R&D as well as the use of industrial robots would boost TFP in Europe.

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# Appendix

In this appendix, the variable definitions and the detailed regression results are documented. The "Regulatory quality" index, published by the World Bank, is a measure of companies' confidence in the quality of contract enforcement, ownership rights, police and the courts, and the probability of crime and violence. As in Graetz and Michaels (2015), data on robots were taken from the database of the International Federation of Robotics (IFR), which compiles information from national robot federations on industrial robots. Most data are available at least from 1985 onwards, but the time series on robots and on the regulation index start only in 1993 and in 1996, respectively.

**Table 2: List of Variables**

| Variable | Description | Source |
|---|---|---|
| **TFP** | Index of total factor productivity | AMECO database |
| **PATENTS** | Number of triadic patent applications (patent applications in the USA, the EU and Japan) per million inhabitants | OECD |
| **INDUSTRY** | Share of industry in value added | Eurostat |
| **SERVICES** | Share of services in value added | Eurostat |
| **INVEST** | Gross fixed capital formation as a percentage of GDP | Eurostat |
| **G** | Public consumption as a percentage of GDP | Eurostat |
| **EXPORTS** | Exports as a percentage of GDP | Eurostat |
| **OPEN** | Degree of openness, defined as the average of the share of exports and imports in GDP | Eurostat |
| **REGULATION** | Regulatory quality Index | World Bank |
| **KTOT** | Capital stock; total assets | Eurostat |
| **KICT** | Capital stock; information and communication technology | Eurostat |
| **KCOMP** | Capital stock; computer hardware | Eurostat |
| **KTELECOM** | Capital stock; telecommunications equipment | Eurostat |
| **KR&D** | Capital stock; research and development | Eurostat |
| **KSOFT** | Capital stock; computer software and databases | Eurostat |
| **KTRANS** | Capital stock; transport equipment | Eurostat |
| **KMOTHER** | Capital stock; other machinery equipment | Eurostat |
| **KCONST** | Capital stock; construction | Eurostat |
| **ROBOTS** | Number of industrial robots | Internat. Federation of Robotics (IFR) |
| **EMP** | Number of employees | Eurostat |

Table 3: Determinants of TFP – Models without ICT

| Dependent Variable: log (TFP) | | | | | | |
|---|---|---|---|---|---|---|
| | Model 1a | | Model 1b | | Model 1c | |
| **Variable** | **Coefficient** | **t-Statistic** | **Coefficient** | **t-Statistic** | **Coefficient** | **t-Statistic** |
| **Constant** | 4.228*** | 47.081 | 4.278*** | 44.646 | 4.186*** | 51.051 |
| **log (PATENTS)** | 0.015*** | 3.275 | 0.014*** | 3.063 | 0.015*** | 3.334 |
| **log (INDUSTRY)** | 0.048* | 1.844 | 0.039 | 1.482 | 0.056*** | 2.248 |
| **log (INVEST)** | 0.119*** | 6.063 | 0.133*** | 6.137 | 0.114*** | 5.951 |
| **log (G)** | -0.343*** | -9.344 | -0.327*** | -8.542 | -0.354*** | -9.997 |
| **log (OPEN)** | 0.038 | 1.165 | | | | |
| **log (EXPORTS)** | | | 0.057* | 1.855 | | |
| **Regulation** | 0.043** | 2.476 | 0.043** | 2.485 | 0.045*** | 2.578 |
| **Adjusted $R^2$** | 0.679 | | 0.680 | | 0.678 | |
| **Country fixed effects** | Yes | | | | | |
| **Period fixed effects** | Yes | | | | | |
| **Estimation period** | 1996 - 2016 | | | | | |
| **No. of countries** | 25 | | | | | |
| **No. of observations** | 514 | | | | | |

*,**,***: Significance at the 10, 5, 1 percent level

Fixed effects panel OLS. Sources: Eurostat, AMECO, OECD, own estimations and presentation

## Table 4: Determinants of TFP – Models including ICT Capital

| Dependent Variable: log (TFP) | Model 2a | | Model 2b | | Model 2c | | Model 2d | |
|---|---|---|---|---|---|---|---|---|
| Variable | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. |
| Constant | 6.719*** | 17.294 | 5.867*** | 14.907 | 6.600*** | 18.158 | 6.412*** | 23.113 |
| log (Patents) | 0.017*** | 3.071 | | | 0.019*** | 3.587 | 0.016*** | 3.262 |
| log (Industry) | 0.067** | 2.154 | | | 0.071** | 2.020 | 0.070** | 2.574 |
| log (Invest) | 0.164*** | 6.415 | | | 0.146*** | 5.870 | 0.168*** | 8.128 |
| log (G) | -0.314*** | -5.801 | -0.324''' | -5.694 | -0.329*** | -5.527 | -0.376*** | -8.068 |
| Regulation | 0.003 | 0.141 | 0.047** | 2.273 | 0.011 | 0.592 | | |
| log (KTOT/EMP) | 0.066** | 2.085 | 0.101*** | 2.902 | 0.021 | 0.683 | | |
| log (KICT/KTOT) | 0.097*** | 5.864 | 0.125*** | 7.089 | | | | |
| log (KR&D/KTOT) | -0.018*** | -4.286 | | | | | | |
| log (KIPP/KTOT) | 0.162*** | 6.202 | 0.084*** | 4.648 | 0.043** | 2.157 | 0.046*** | 2.752 |
| log (KMOTHER/KTOT) | 0.388*** | 8.201 | 0.305*** | 6.276 | 0.315*** | 7.359 | 0.305*** | 8.042 |
| log (KTRANS/KTOT) | 0.083*** | 3.033 | 0.094*** | 3.303 | 0.058** | 2.192 | 0.057** | 2.387 |
| log (KCONST/KTOT) | 2.599*** | 6.931 | 2.434*** | 6.590 | 2.424*** | 7.139 | 2.221*** | 7.376 |
| log (KCOMP/KTOT) | | | | | 0.057*** | 5.775 | 0.052*** | 9.949 |
| log (KSOFT/KTOT) | | | | | 0.057*** | 3.728 | 0.056*** | 4.190 |
| log (KTelecom/KTOT) | | | | | 0.035** | 2.417 | | |
| Adjusted $R^2$ | 0.833 | | 0.789 | | 0.846 | | 0.902 | |
| Country fixed effects | Yes | | | | | | | |
| Period fixed effects | Yes | | | | | | | |
| Estimation period | 1996 - 2016 | | 1996 - 2016 | | 1996 - 2016 | | 1985 - 2016 | |
| No. of countries | 16 | | 16 | | 16 | | 16 | |
| No. of observations | 313 | | 313 | | 313 | | 357 | |

*,**,***: Significance at the 10, 5, 1 percent level

Fixed effects panel OLS. Sources: Eurostat, AMECO, OECD, own estimations and presentation

Table 5: Determinants of TFP – Models including ICT Capital and Robot Density

Dependent Variable: log (TFP)

| | Model 3a | | Model 3b | | Model 3c | | Model 3d | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Coeff.** | **t-stat.** | **Coeff.** | **t-stat.** | **Coeff.** | **t-stat.** | **Coeff.** | **t-stat.** |
| **Constant** | 6.005*** | 12.580 | 5.807*** | 13.762 | 5.845*** | 14.016 | 6.709*** | 26.198 |
| **log (Industry)** | -0.005 | -0.107 | | | | | | |
| **log (services)** | | | -0.623*** | -4.103 | -0.581*** | -3.878 | | |
| **log (Invest)** | 0.094*** | 3.443 | -0.137** | -2.199 | | | 0.172*** | 7.115 |
| **log (G)** | -0.331 | -6.096 | 0.100*** | 6.079 | -0.167*** | -2.584 | -0.364*** | -7.589 |
| **Regulation** | 0.023 | 1.345 | | | 0.098*** | 5.902 | 0.058*** | 3.568 |
| **log (KTOT/EMP)** | 0.086* | 1.766 | 0.133** | 2.262 | 0.130** | 2.229 | | |
| **log (KICT/KTOT)** | 0.067*** | 4.527 | 0.099*** | 6.304 | | | | |
| **log (KR&D/KTOT)** | -0.202*** | -5.966 | | | | | | |
| **log (KIPP/KTOT)** | 0.361*** | 9.038 | 0.178*** | 6.585 | 0.159*** | 5.259 | 0.165*** | 6.901 |
| **log (KMOTHER/KTOT)** | 0.353*** | 6.806 | 0.356*** | 6.759 | 0.342*** | 6.600 | 0.361*** | 7.649 |
| **log (KTRANS/KTOT)** | 0.014 | 0.534 | | | | | | |
| **log (KCONST/KTOT)** | 3.147*** | 7.540 | 3.074*** | 9.417 | 3.277*** | 10.075 | 3.380*** | 11.832 |
| **log (KCOMP/KTOT)** | | | | | 0.074*** | 6.244 | 0.065*** | 7.172 |
| **log (KSOFT/KTOT)** | | | | | 0.018 | 1.230 | | |
| **log (KTelecom/KTOT)** | | | | | 0.013 | 0.773 | | |
| **log (ROBOTS/EMP)** | 0.072*** | 9.855 | 0.051*** | 7.137 | 0.056*** | 7.581 | 0.081*** | 12.452 |
| **Adjusted $R^2$** | 0.847 | | 0.794 | | 0.806 | | 0.831 | |
| **Country fixed effects** | Yes | | | | | | | |
| **Period fixed effects** | Yes | | | | | | | |
| **Estimation period** | 1996 - 2016 | | | | | | | |
| **No. of countries** | 13 | | | | | | | |
| **No. of observations** | 249 | | | | | | | |

*,**,***: Significance at the 10, 5, 1 percent level

Fixed effects panel OLS. Sources: Eurostat, AMECO, OECD, IFR, own estimations and presentation

## EconPol Europe

EconPol Europe - The European Network for Economic and Fiscal Policy Research is a unique collaboration of policy-oriented university and non-university research institutes that will contribute their scientific expertise to the discussion of the future design of the European Union. In spring 2017, the network was founded by the ifo Institute together with eight other renowned European research institutes as a new voice for research in Europe.

The mission of EconPol Europe is to contribute its research findings to help solve the pressing economic and fiscal policy issues facing the European Union, and thus to anchor more deeply the European idea in the member states. Its tasks consist of joint interdisciplinary research in the following areas

1) sustainable growth and 'best practice',

2) reform of EU policies and the EU budget,

3) capital markets and the regulation of the financial sector and

4) governance and macroeconomic policy in the European Monetary Union.

Its task is also to transfer its research results to the relevant target groups in government, business and research as well as to the general public.