Fraunhofer

# THE MACROECONOMIC EFFECTS OF THE FRAUNHOFER-GESELLSCHAFT

# The macroeconomic effects of the Fraunhofer-Gesellschaft

Torben Schubert

Fraunhofer Institute for Systems and Innovation Research ISI

Breslauer Straße 48

76139 Karlsruhe

March 2021

# Contents

## Tables

# 1 Introduction

The previous Fraunhofer Impact Study published in 2016 (Frietsch et al. 2016) demonstrated the strong macroeconomic effects of the Fraunhofer-Gesellschaft, particularly in terms of Gross Domestic Product (GDP) and tax revenues. Based on data up to 2014, one of the main findings was that revenue from one euro (€) of Fraunhofer third-party funds led to a GDP increase worth €18. Moreover, additional Fraunhofer researchers would increase GDP by about €1.9 million. Using these results, the resulting tax multipliers would lie between 1.7, when using the total Fraunhofer budget as a basis, and 3.3. The sizeable tax multipliers indicate that the Fraunhofer effects are not only large in absolute numbers, but also substantially exceed the costs the taxpayer would incur. Overall, the findings appear substantial but are generally in line with recent contributions showing that the social returns to innovation, even under conservative assumptions, are many multiples of the investment costs (Jones and Summers 2020).

Since the first impact study in 2017, four years have passed during which the Fraunhofer budget, based on the Pact for Research and Innovation (*Pakt for Forschung und Innovation*), has risen steadily. Since growth typically calls for readjustment (Penrose 1959; Grillitsch and Schubert 2020), it is far from clear whether Fraunhofer was able to translate the increased output proportionately into economic output. In other words, it is currently not clear whether the macroeconomic effects observed in the past are scalable with respect to the level of inputs. There is thus a need for a new study that compares how the macroeconomic effects have developed over time.

A second motivation for renewing the study design is methodological. Although the previous study worked with solid econometric panel estimators, it did not intensely analyze the robustness of the regression results with respect to different model specifications, including more in-depth questions about the role of endogeneity. A further issue was the use of third-party funds as a proxy for Fraunhofer activities, one criticism being that third-party funds reflect only a part of the Fraunhofer budget. This may lead to an over- and/or underestimation of the total macroeconomic effects. One the one hand, by ignoring a substantial part of the Fraunhofer budget, important impacts may be neglected. On the other hand, using third-party funds runs the risk of focusing on those activities that are closest to the economy. Overall, when calculating the macroeconomic effects, it seems more appropriate to focus on the total Fraunhofer budget.

Thirdly, the previous study only focused on GDP and tax revenues. One issue is that the mechanisms by which the Fraunhofer-Gesellschaft affects the economy are not clearly identified. In this study, we therefore assess a major potential mechanism by analyzing whether Fraunhofer affects local patenting activities, i.e. whether it has an effect on the technology generation.

The updated assessment of the macroeconomic effects of Fraunhofer seeks to address these two gaps. It provides additional evidence on the robustness of the results in terms of model specification and in terms of variable selection. In addition, it compares the effects obtained in 2016 using data up to 2014, with results obtained in 2020 using data up to 2018.

# 2 The economic value of public research

Previous scientific analyses have demonstrated that universities, and universities of applied sciences, have an overall positive effect on the economic and technological performance of their home regions. Most studies focused primarily on measuring demand-oriented, tangible effects, illustrated by monetary expenditure flows (for example, student consumption expenditure, university investment expenditure, etc.) within the framework of multiplier analyses (for example, Bürgel et al. 1996; Glückler et al. 2013; Kowalski et al. 2012). However, this approach ignores effects that are usually associated with intangible knowledge output. It is commonly assumed that they represent the more significant part of the economic effects of scientific institutions (Florax 1992) and are an inherent task of research organizations.

In a large-scale statistical study, Schubert and Kroll (2013; 2016) have therefore attempted to determine the effects of regional higher education, including knowledge-based or supply-oriented effects, using statistical methods from panel data econometrics. Schubert et al. (2013) have, in particular, classified the effects on regional GDP per capita as significant, with an annual effect of approximately €190 billion for Germany as a whole. Scientific studies that have chosen comparable methods include Goldstein and Renault (2004) for the USA, and Schlump and Brenner (2010) for Germany. In Egeln et al. (2015), an attempt was made to generalize the results of Schubert and Kroll (2013; 2016) for the four large non-university research networks and the Baden-Württemberg Innovation Alliance. It was shown that there are parallels between university and non-university research. However, it was not possible to completely replicate the analyses for the universities (universities and universities of applied sciences) due to data inconsistency of the individual non-university research consortia.

# 3 Data and methodology

Within the scope of this report was the update of the panel data for the Fraunhofer-Gesellschaft at institute level that were used in the previous impact study (Frietsch et al. 2016). These data calculate the economic effects of the Fraunhofer Institutes and compare them to the results of the previous study. The core indicators of the individual Fraunhofer Institutes were aggregated from the Fraunhofer SIGMA database at the regional level (NUTS 3) and merged with regional economic data provided by the Federal Statistical Office (DESTATIS). The dataset covers the 15-year period of 2003 until 2017 and therefore extends the time coverage of the previous study by three years. In the cross-sectional dimension, the dataset covers 400 NUTS 3 regions, implying that in total 6,000 time-year observations are included.[1]

Based on the derived panel data, econometrics methods were used to identify the systematic relationships between regional Fraunhofer activity and regional economic core variables. Generically, we use the following GDP formula:

$$\frac{GDP_{it}}{population_{it}} = \beta \frac{Fraunhofer_{it}}{population_{it}} + z_{it}\delta + u_{it}$$

(1)

In this formula, (1) relates to an indicator of per capita Fraunhofer activities, $Fraunhofer_{it}$, to GDP per capita, $z_{it}$ represents a vector of regional controls and $u_{it}$ a structural error term. Our main interest is clearly in the estimate of the coefficient$\beta$, which measures the GDP value of an additional one-unit increase in $Fraunhofer_{it}$ in monetary terms.

To analyze the impact of Fraunhofer on the local technology generation, we used the following semi-log formula:

$$\log(Pat_{it}) = \beta Fraunhofer_{it} + z_{it}\delta + u_{it}$$

(2)

Using a semi-log model is reasonable because patents differ dramatically in their economic value, making an assessment of the size in terms of levels meaningless. In the semi-log specification, $\beta$ represents the semi-elasticity of $Pat_{it}$ with respect to $Fraunhofer_{it}$: i.e. it gives the percentage increase in patents caused by a unit increase in $Fraunhofer_{it}$.

A key issue in estimating $\beta$ in equations (1) and (2) is whether the association is correlative or whether it represent causal effects. Several mechanisms pertinent to the economic

1 Rare missing values were inputted to create a balanced panel.

effects of Fraunhofer may inhibit a causal interpretation, which may result from e.g. unobserved heterogeneity and selection based on locational choice.

Unobserved heterogeneity occurs if regions differ in characteristics that are not captured by explicitly included regional control variables. As in the previous study (Frietsch et al. 2016), all models account for time-constant unobserved heterogeneity by considering the presence of fixed effects. We keep these models as our main focus in order to allow for a relatively direct comparison to the results from the previous studies.

With regard to locational choice, regions hosting Fraunhofer Institutes differ substantially from those that do not. If Fraunhofer Institutes choose to locate to regions that are *a priori* economically stronger, any observed associations between Fraunhofer presence and economic outcomes may be partly or even completely correlative. In particular, it stands to reason that the association between Fraunhofer activities and regional economic outcomes are overestimated. There are several econometric ways to account for such endogeneity biases. Firstly, if locational choice is determined by observable variables, sample balancing approaches are useful because they homogenize samples. One convenient way to achieve this is to use entropy-balancing (Hainmueller 2012), which provides an automatic procedure to derive regression weights, thus creating balanced samples that no longer differ in key control variables (for example, region size, share of agriculture etc.).

Secondly, if locational choice depends on unobserved (and, in a fixed effects context, time varying) variables, entropy balancing will not eliminate all the bias resulting from locational choice. In this case, more general types of instrumental variables are needed. Since our dataset and estimation context is devoid of broad natural experiments, we resorted to using covariance restrictions to derive research instruments following the proposition of Arrelano and Bond (1991), Arrelano and Bover (1995), and Roodman (2009), based on the Generalized Methods of Moments (GMM) panel data models. The resulting instrumental variables usually do not have an easily identifiable narrative of their exogeneity, but the assumptions necessary for their exogeneity can be tested because the models are typically overidentified. Specifically, we run the GMM-type of models that treat the indicator of Fraunhofer activities as endogenous, drop the level equation, and collapse instruments in order not to weaken overidentification tests.

The next subsection briefly presents descriptive statistics on the overall estimation sample. These figures are mainly a point of reference for the reader. They do, however, show that regions hosting Fraunhofer Institutes differ fundamentally from those that do not, making the issue of locational choice highly relevant.

# 4 Descriptive analyses

The main descriptive results for the key variables used in this section are presented in Table 1 below, where the columns on the left show the results for the full sample and the columns on the right show the results for those regions with Fraunhofer activities. The average NUTS 3 region has a GDP per capita of €30,423, and applies for 194 patents annually. The regions hosting Fraunhofer Institutes differ in this respect by showing GDP per capita values of €38,544, with patent applications amounting to 399. Whether these differences reflect any causal effects of Fraunhofer activities remains unclear because the regions also differ in other characteristics. In total, regions have 203,593 inhabitants and a share of agricultural employment of 2.3%. Regions hosting Fraunhofer Institutes differ substantially, with a population of 396,251 and a share of agricultural employment of 0.91%. Overall, our results show that Fraunhofer Institutes cluster in regions that have higher economic power, are larger, less rural and more patent intensive. This implies that accounting for heterogeneity between regions and for locational choice may be highly relevant in identifying causal effects.

Table 1: Descriptive statistics for the regions

| | All regions | | | Regions with Fraunhofer Institutes | | |
|---|---|---|---|---|---|---|
| **Variable** | **Obs** | **Mean** | **Std. Dev.** | **Obs** | **Mean** | **Std. Dev.** |
| **GDP per capita** | 6000 | 30423.8 | 1.37E+04 | 825 | 38554.5 | 1.77E+04 |
| **DPMA-patents** | 6000 | 194.395 | 320.272 | 825 | 399.749 | 578.576 |
| **Fraunhofer budget (euro) per capita** | 6000 | 16.0454 | 82.6841 | 825 | 116.564 | 195.01 |
| **Fraunhofer scientists (head count) per capita** | 6000 | 0.000137 | 0.000625 | 825 | 0.000968 | 0.001422 |
| **Fraunhofer budget (euro)** | 6000 | 4.10E+06 | 1.70E+07 | 825 | 3.00E+07 | 3.80E+07 |
| **Fraunhofer scientists (head count)** | 6000 | 36.7925 | 153.553 | 825 | 261.401 | 335 |
| **Population** | 6000 | 203593 | 231676 | 825 | 396251 | 516927 |
| **Share agricultural employees (%)** | 6000 | 2.34413 | 2.03282 | 825 | 0.910151 | 1.2454 |
| **HT employees** | 6000 | 1140.1 | 545.877 | 825 | 1156.54 | 561.411 |

In the next subsection, we present the main regression results for equations (1) and (2), where we first start with the GDP results and then continue with the patent results.

# 5 Main results

Table 2 below shows the main results based on fixed effects (FE) regressions for GDP. The two columns on the left use contemporaneous values of the total Fraunhofer budget (Column 1) and the Fraunhofer researchers (Column 2). The two columns on the right repeat the same regressions but use the Fraunhofer indicators lagged by one period, in order to allow for lags between cause and effect.

Table 2: Baseline results (GDP per capita; FE-regressions)

| | (1)<br>GDP per capita | (2)<br>GDP per capita | (3)<br>GDP per capita | (4)<br>GDP per capita |
|---|---|---|---|---|
| Fraunhofer budget (euro) per capita | 21.1383*** | | | |
| | (8.82) | | | |
| Fraunhofer scientists (head count) per capita | | 3814657.2271*** | | |
| | | (7.31) | | |
| L. Fraunhofer budget (euro) per capita | | | 21.6754*** | |
| | | | (7.64) | |
| L. Fraunhofer scientists (head count) per capita | | | | 3795284.8571*** |
| | | | | (6.47) |
| Share agricultural employees (%) | -260.8402* | -290.9941* | -299.7970* | -329.4852* |
| | (-2.02) | (-2.24) | (-2.21) | (-2.42) |
| HT employees | 5.1728*** | 5.1554*** | 5.0603*** | 5.0642*** |
| | (6.05) | (6.02) | (5.67) | (5.66) |
| Constant | 30849.9380*** | 30736.1263*** | 31090.9305*** | 30950.5867*** |
| | (27.64) | (27.43) | (26.59) | (26.39) |
| Year dummies | Yes | Yes | Yes | Yes |
| Observations | 6000 | 6000 | 5600 | 5600 |
| R2 | 0.679 | 0.678 | 0.668 | 0.667 |

*t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Overall, the results are insensitive to the lag structure. Column 1 and Column 2 show that increasing the Fraunhofer budget by €1 is associated with an increase in GDP of between €21.13 and €21.67.[2] The same values for researchers (Columns 2 and 4) show that increasing the number of Fraunhofer employees by one will lead to an increase in GDP of

2 The levels interpretation is equivalent to the per capita interpretation because dependent and explanatory variables use the same normalization.

between €3.79 million and €3.81 million. The results suggest that the Fraunhofer effects on GDP are large and highly significant.

While it is technically possible to compare these figures to the previous study in order to study changes in the effects, it seems advisable to directly test for differences. One reason is that, although the methodology applied in the previous study is conceptually comparable, some differences remain. The first two columns of Table 2 differentiate the respective effects of the Fraunhofer budget and researchers by an early (before 2015) and a late (2015-2017) time period. Indeed, we see that the interaction for the late time period is significant and positive in both cases, which implies that Fraunhofer's leverage has substantially increased since the time it was studied in Frietsch et al. (2016). In fact, for the Fraunhofer budget, the increase corresponds to approximately 23% (=3.30/14.51*100). For the researchers, it even corresponds to 34% (=671,920/1,985,444*100). Thus, our results show that the macroeconomic effects of Fraunhofer on GDP are not only significantly positive but they have also increased substantially over time, even in a period where budgets have been on the rise.

The question remains whether the baseline results are subject to endogeneity biases resulting, in particular, from endogenous locational choice. Columns 3 to 6 in Table 3 below present the results for the GMM-type Arellano-Bond (AB) estimations and the entropy-balancing approach. While the size of the coefficients differs between the different methodologies, the coefficients remain significantly positive, not falling below a 1:19 ratio for the total Fraunhofer budget, and 1:2.97 million ratio for the Fraunhofer researchers.

Table 3: Robustness checks (GDP per capita)

| | (1) GDP per capita (late period) | (2) GDP per capita (late period) | (3) GDP per capita (AB) | (4) GDP per capita (AB) | (5) GDP per capita (entropy bal.) | (6) GDP per capita (entropy bal.) |
|---|---|---|---|---|---|---|
| Fraunhofer budget (euro) per capita | 14.5074*** | | 29.0855*** | | 18.9239*** | |
| | (4.03) | | (16.60) | | (4.69) | |
| Period: 2015-2017=0 # Fraunhofer budget (euro) per capita | 3.3049*** (2.60) | | | | | |
| Fraunhofer scientists (head count) per capita | | 1985444.6491** | | 6025237.8909*** | | 2977926.4897** |
| | | (2.91) | | (9.47) | | (2.92) |
| Period: 2015-2017=1 # Fraunhofer scientists (head count) per capita | | 671920.5150*** | | | | |
| | | (4.16) | | | | |
| Share agricultural employees (%) | -276.8893* | -310.4054* | -255.7719* | -351.0773*** | 964.9704** | 831.4576* |
| | (-2.14) | (-2.39) | (-2.48) | (-3.35) | (2.80) | (2.38) |
| HT employees | 5.1150*** | 5.0703*** | 1.0547 | 1.1132 | 4.3761 | 4.3572 |
| | (5.99) | (5.93) | (0.59) | (0.65) | (1.87) | (1.85) |
| Constant | 31025.7808*** | 31069.8084*** | NA | NA | 5238.2516 | 6415.9451* |
| | (27.78) | (27.70) | | | (1.68) | (2.04) |
| Year dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 6000 | 6000 | 5600 | 5600 | 6000 | 6000 |
| $R^2$ | 0.680 | 0.679 | | | 0.966 | 0.965 |
| *Hansen overid chi2(* | | | 13.16 | 9.41 | | |

*t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

We turn now to the Fraunhofer effects on regional patenting behavior, with the main results shown in Table 4 below. The results show largely significant semi-elasticities. The only effect not significant at the 5% level is that for the contemporaneous Fraunhofer researchers, which would be significant at the 10% level. While significantly positive, the effects are, however, smaller in size than for the GDP regressions. For example, taking the more robust effects of budget, an increase of €10 million would imply an increase in total regional patent applications by 3%, both for the contemporaneous and the lagged Fraunhofer budget.

Taking into account the average value of patents in regions hosting Fraunhofer activities, a €10 million increase would therefore lead to approximately 12 regional patent applications (399*0.03; see Table 1). This figure is not extremely large, but it should be considered as something additional to the GDP effects that already exist. The figure appears to be reasonably consistent with the results from the researcher regression. Increasing the regional Fraunhofer researchers by 100 will lead to an increase in patent stock by between 3% and 5%. Assuming that a Fraunhofer researcher (head counts) costs on average €100,000, a €10 million increase expenditure on wages for researchers will cause an increase of between 12 and 20 patents.

Table 4: Baseline results (patents; coefficients are semi-elasticities; FE regressions)

| | **(1)**<br>**Log patents** | **(2)**<br>**Log patents** | **(3)**<br>**Log patents** | **(4)**<br>**Log patents** |
|---|---|---|---|---|
| Fraunhofer budget (euro) | 0.0003$^{**1}$ | | | |
| | (2.58) | | | |
| Fraunhofer scientists (head count) | | 0.0003 | | |
| | | (1.68) | | |
| L Fraunhofer budget (euro) | | | 0.0003$^{**1}$ | |
| | | | (2.58) | |
| L. Fraunhofer scientists (head count) | | | | 0.0005$^{*}$ |
| | | | | (2.21) |
| Population | -0.0000 | -0.0000 | -0.0000 | -0.0000 |
| | (-0.41) | (-0.52) | (-0.47) | (-0.78) |
| Share agricultural employees (%) | -0.0372$^{**}$ | -0.0375$^{**}$ | -0.0356$^{**}$ | -0.0369$^{**}$ |
| | (-2.96) | (-2.98) | (-2.61) | (-2.69) |
| HT employees | -0.0003$^{**}$ | -0.0003$^{**}$ | -0.0003$^{**}$ | -0.0003$^{**}$ |
| | (-2.96) | (-2.97) | (-3.00) | (-2.99) |
| Constant | 4.9910$^{***}$ | 5.0075$^{***}$ | 5.0279$^{***}$ | 5.0630$^{***}$ |
| | (39.43) | (38.83) | (36.68) | (36.26) |
| Year dummies | Yes | Yes | Yes | Yes |
| Observations | 6000 | 6000 | 5600 | 5600 |
| $R^2$ | 0.010 | 0.009 | 0.010 | 0.010 |

*t* statistics in parentheses; $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$; 1 coefficient multiplied by 100,000 to make non-zero digits visible

Table 5: Robustness checks (Patents; coefficients are semi-elasticities; FE regressions)

| | (1) Log patents (late period) | (2) Log patents (late period) | (3) Log patents (AB) | (4) Log patents (AB) | (5) Log patents (entropy bal.) | (6) Log patents (entropy bal.) |
|---|---|---|---|---|---|---|
| Fraunhofer budget (euro) | 0.0000 | | 0.0000 | | 0.0003$^{*1}$ | |
| | (1.54) | | (1.51) | | (2.34) | |
| Fraunhofer budget (euro) # Period: 2015-2017 | 0.0000 | | | | | |
| | (0.98) | | | | | |
| Fraunhofer scientists (head count) | | 0.0002 | | 0.0002$^{**}$ | | 0.0003 |
| | | (0.83) | | (2.90) | | (1.33) |
| Fraunhofer scientists (head count) # Period: 2015-2017 | | 0.0000 | | | | |
| | | (0.65) | | | | |
| Population | -0.0000 | -0.0000 | -0.0000 | -0.0000$^{*}$ | -0.0000 | -0.0000 |
| | (-0.66) | (-0.59) | (-1.73) | (-2.37) | (-0.20) | (-0.41) |
| Share agricultural employees (%) | -0.0381$^{**}$ | -0.0379$^{**}$ | -0.0514$^{*}$ | -0.0400 | -0.0508 | -0.0549 |
| | (-3.03) | (-3.00) | (-2.06) | (-1.75) | (-1.28) | (-1.39) |
| HT employees | -0.0003$^{**}$ | -0.0003$^{**}$ | 0.0000 | 0.0001 | -0.0002 | -0.0002 |
| | (-2.95) | (-2.98) | (0.16) | (0.70) | (-0.89) | (-0.93) |
| Constant | 5.0205$^{***}$ | 5.0204$^{***}$ | NA | NA | 5.1240$^{***}$ | 5.1705$^{***}$ |
| | (38.59) | (38.48) | | | (15.30) | (15.21) |
| Year dummies | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 6000 | 6000 | 5600 | 5600 | 6000 | 6000 |
| $R^2$ | 0.010 | 0.009 | | | 0.966 | 0.966 |
| *Hansen overid chi2(9)* | | | 13.75 | 9.52 | | |

*t* statistics in parentheses; $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$; 1 coefficient multiplied by 10,000 to make non-zero digits visible

When referring to the sensitivity of the results (Table 5 above), it becomes clear that the effects are not only smaller but also less robust. Columns 1 and 2 show that there are no significant changes between the late periods, where in fact, probably due to multicollinearity, the significance disappears altogether. While this may be the result of overfitting the model, in the AB regressions the Fraunhofer budget loses its significance, while in the entropy balancing approach the Fraunhofer researchers do not. Results do, however, remain significant for researchers in the AB regression (Column 4) and for budgets in the entropy-balancing approach. Overall, there is thus some evidence that Fraunhofer stimulates local technology generation, measured in terms of local patents. The effects are, however, smaller in terms of size, and less robust with respect to models that approach the issue of endogeneity biases more seriously.

# 6 Excursus: a note on panel unit roots and cointegration

All models so far are applicable under regular panel data settings. In particular, they are reliant on fixed-T-large-N asymptotes, which imply that all-time series are stationary. The fixed-T-large-N framework is clearly a reasonable choice because our cross-section dimension is substantially larger (N=400) than our time-series dimension (T=15). At the same time, it is accepted that several of our variables (patents, GDP per capita) are usually found to be non-stationary. Since Fraunhofer budgets and employee figures have been continuously on the rise in the last two decades, it stands to reason that these time series may also be non-stationary. It is well known that regressing a non-stationary variable on another one produces spurious regression results (Granger et al. 1974). Differencing (integrating) time series is an appropriate way to make them stationary.

However, if time series are cointegrated, the quick-fix solution of regressing the integrated time series on one another is consistent but the coefficients are often undesirable because of poor identification in finite samples. Conceptually, cointegration implies that the cointegrated variables are bound together by an economic relationship in the long run.[3] Since Fraunhofer budgets have grown, based on the Pact for Research and Innovation by a fixed rule, which was arguably fiscally implementable because of a growing economy, there are good reasons to suspect that GDP, patents and Fraunhofer activities are not only non-stationary but also cointegrated. Because of that, we probed our results using cointegration analysis.

Table 6 below presents the relevant test statistics needed to corroborate that the conditions under which cointegration analysis is applicable are met. In the left column we see that the

3 Technically, cointegration means that for j non-stationary variables of the same integration order, there exists a real-valued vector of length j, such that the linear combination of the variables based on that vector is stationary. That vector is called a cointegrating vector.

null hypothesis of non-stationarity can be rejected for any of the time series. The inverse normal test statistic is not significant for any of the relevant variables. In addition, the right column shows that the relevant variables are indeed cointegrated because the null hypothesis of no cointegration is rejected with a high degree of confidence. All tests are fairly general and allow for trend stationarity and a lag-structure of two. Thus, regressions are an appropriate choice to estimate the long-term relationship between Fraunhofer activities and the regional economic outcomes under consideration.

Table 6: Panel unit root and cointegration tests

| | **Inverse normal panel unit root stat.** | **Panel t cointegration stat.** |
|---|---|---|
| *Null hypothesis* | *All panels have unit roots* | *No cointegration* |
| GDP per capita | 11.4 | |
| Log patents | 9.22 | |
| Fraunhofer budget (euro) per capita | 1.92 | |
| Fraunhofer budget (euro) | 2.46 | |
| Fraunhofer scientists (head count) per capita | 2.53 | |
| Fraunhofer scientists (head count) | 3.18 | |
| GDP p.c.~ Fraunhofer budget p.c.~ Fraunhofer scientists p.c. | | -16.05*** |
| Log patents~ Fraunhofer budget~ Fraunhofer scientists | | -23.05*** |

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

We used the Dynamic OLS estimator proposed by Kao and Chiang (2000), and one lead and one lag to account for the short-term dynamics, but did not observe changes when allowing for more leads and lags. The results can be found in Table 7 below, and they largely confirm those obtained from the regular panel models presented in the previous section. For all variables and outcomes, the effects are positive and significant. It should be noted, however, that for patents as the dependent variable, the models were not well behaved in their most general form because of singular variance matrices. For these two models, Table 7 presents only restricted versions, which include either a linear time trend instead of year dummies (Column 4) or no time controls (Column 3). In Column 3, we even observed issues due to multicollinearity, which forced us to drop some of the control variables. Overall, the results for the patent regressions should therefore not be overinterpreted.

Table 7: Estimation of the long-run cointegration relationship (Dynamic OLS)

| | (1) GDP per capita | (2) GDP per capita | (3) Log patents | (4) Log patents |
|---|---|---|---|---|
| Fraunhofer budget (euro) per capita | 26.0691*** | | | |
| | (5.23) | | | |
| Fraunhofer scientists (head count) per capita | | 3367523.2137** | | |
| | | (3.00) | | |
| Fraunhofer budget (euro) | | | 0.0002***1 | |
| | | | (7.41) | |
| Fraunhofer scientists (head count) | | | Dropped multi-collinearity | 0.0018*** |
| | | | | (5.10) |
| Share agricultural employees (%) | -2824.8269*** | -2809.2996*** | -0.1513 | -0.1255*** |
| | (-10.13) | (-10.02) | (.) | (-5.23) |
| HT employees | -0.3660 | -0.4349 | Dropped multi-collinearity | 0.0006*** |
| | (-0.19) | (-0.23) | Dropped multi-collinearity | (3.69) |
| Linear time trend | | | | -0.0107*** |
| | | | | (-4.06) |
| Year dummies | Yes | Yes | No | No |
| Observations | 4800 | 4800 | 4800 | 4800 |
| $R^2$ | 0.831 | 0.828 | 0.260 | 0.451 |

*t* statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; 1 coefficient multiplied by 10,000 to make non-zero digits visible

Nonetheless, for GDP per capita, the models worked well and also corroborate the previous findings in terms of extent. In particular, Column 1 shows that a €1 increase in the Fraunhofer budget implies a €26 increase in GDP. In regard to Fraunhofer researchers, the results are slightly lower than before: one additional head count implies a €3.3 million increase in GDP.

# 7 Conclusion

In this report, we updated the macroeconomic analyses of the effects of Fraunhofer, as detailed in Frietsch et al. (2016). We have used more recent data and, in several ways, improved the methodology. Our results corroborate the substantial macroeconomic effects on GDP, in which a one euro increase in budget implies a 21 euro increase in GDP in the baseline model. Moreover, we show that the effects increase substantially over time, with the GDP multiplier in 2015-2017 around 23% larger than in the period up to 2014. The result is robust with respect to the possible effects of selection biases, endogeneity biases, stationarity/cointegration, or lag structures.

# 8 References

Bürgel, H.D., Binder, M., Schultheiß, R. (1996): *Die Universität Stuttgart als Wirtschaftsfaktor für die Region Stuttgart*. Stuttgart.

Egeln, J., Köhler, C., Niefert, M., Schliessler, P., Kroll, H., Schubert, T. (2015): *Wirkungen der öffentlichen Finanzierung von Wissenschaft und Forschung in Baden-Württemberg auf die wirtschaftliche Entwicklung des Landes*, Endbericht zum Projekt. Ministerium für Wissenschaft, Forschung und Kunst des Landes Baden-Württemberg (MWK).

Engle, R.F. Granger, C.W. (1987): Co-integration and error correction: representation, estimation, and testing. *Econometrica,* 55, 251-276.

Florax, R.G.M. (1992): *The university: A regional booster? Economic impacts of academic knowledge infrastructure*. Avebury, Aldershot.

Frietsch, R., Lutz, J., Neuhäusler, P. Schubert, T., Lerch, C., Bethke, N., Rothengatter, O. (2017): *Der Beitrag der Fraunhofer-Gesellschaft zum Deutschen Innovationssystem.* Endbericht zum Projekt, Karlsruhe: Fraunhofer ISI.

Glückler, J., Panitz, R., Wuttke, C. (2013): Die wirtschaftliche Bedeutung der Landesuniversitäten für das Land Baden-Württemberg, http://www.lrk-bw.de/images/PDF/2013-LRK-Endbericht.pdf

Goldstein, H., Renault, C. (2004): Contributions of universities to regional economic development: A quasi-experimental approach, *Regional studies*, 38, 733-746.

Granger, C.W., Newbold, P. (1974): Spurious regressions in econometrics. *Journal of Econometrics*, 2, 111-120.

Grillitsch, M., Schubert, T. (2020): Does the timing of integrating new skills affect start-up growth? *Strategic Entrepreneurship Journal.*

Jones, B.F., Summers, L.H. (2020): *A Calculation of the Social Returns to Innovation*, working paper No. w27863. Cambridge, MA: National Bureau of Economic Research.

Kao, C., Chiang, M.H. (2000): “On the estimation and inference of a cointegrated regression in panel data”, *Advances in Econometrics,* 15, 179-222.

Kowalski, J., Meyborg, M., Dziembowska-Kowalska, J., Häußling, R., Schaffer, A. (Hrsg.). (2012): Karlsruher Institut für Technologie – Impulsgeber für Karlsruhe und die Region. Online: https://www.google.de/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCIQFjAA&url=http%3A%2F%2Fwww.ksp.kit.edu%2Fdownload%2F1000030730&ei=BGRMVemwE4rkUq-WgOAI&usg=AFQjCNFzFKxlhl0U7GsLiCsl1eIYC8ZETQ&bvm=bv. 92765956,d.d24.

Penrose, R. (1959): The apparent shape of a relativistically moving sphere. *Mathematical Proceedings of the Cambridge Philosophical Society*, 55, 137-139.

Schubert, T., Kroll, H. (2013): *Endbericht zum Projekt Hochschulen als regionaler Wirtschaftsfaktor Karlsruhe*. Online: http://www. stifterverband. de/ wirtschaftsfaktorhochschule/regionale_bedeutung_von_hochschulen.

Schubert, T., Kroll, H. (2016): Universities' effects on regional GDP and unemployment: The case of Germany. *Papers in Regional Science*, 95, 467-489.

Schlump C., Brenner, T. (2010): University education, public research and employment growth in regions: An empirical study of Germany. *Berichte zur deutschen Landeskunde*, 84: 115–136.