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# Investment in Photovoltaics and Job Creation: Evidence from a Billion Dollar Program

February 23, 2016

We study the labor market effects of a €60 billion investment program in photovoltaics in Germany between 2003 and 2012. According to our estimates, the program created one job lasting one year for every €120,000 in investment. Gains were concentrated in the construction sector, with spillovers to local services. The effects are stronger in weaker economic times. To address endogeneity concerns, we exploit the fact that local investment was pre-determined by the amount of available rooftops and solar radiation in a region to construct an instrumental variable estimator.

**Keywords:** (Un)Employment, Job Creation, Local Multiplier

**JEL Classification:** E24, E62, R23

# 1 Introduction

Fostering employment is a key objective for governments around the world. Not only in times of crisis, governments resort to various kinds of fiscal interventions in order to spur job growth. Unfortunately, given the dearth of empirical evaluations of past policies, it is difficult to assess the labor market effects of a particular policy from an ex-ante perspective.

The reason is twofold: First, policies are usually not undertaken at random. Hence, in absence of quasi-random variation, observational data yields biased estimates. Second, the effectiveness of the same policy might depend on the state of the economy. During recessions, government action may be more effective than during a boom, as there is slack in the economy and government action does not crowd out private sector investment.

In this paper we evaluate the local job market impact of the German renewable energy act, a long-running, multi-billion euro program. This law mandated that electricity from photovoltaic systems can be sold to energy companies for an above-market, 20-year fixed feed-in tariff. Fixing the feed-in tariff is economically equivalent to a large subsidy for buying photovoltaic systems. This program worked: Although Germany's solar radiation is lower than anywhere in the US except Alaska and Seattle, German households spent more than €60 billion to buy photovoltaic systems for their rooftops between 2003 and 2012.

The particular design of this law allows us to estimate the causal impact of realized investment in photovoltaics on local employment both in boom and in bust. The resulting estimate is of key interest for the design of future stimulus policies – independent of whether the investment is implemented via a subsidy, a tax rebate or direct government purchases. The setting of the renewable energy act has several distinct advantages: First, given publishing requirements in the law, we have high-quality, geo-located data on more than 1.3 Million investment projects, including the date of commissioning. This is different from most of the existing literature, which focuses on the effects of transfers from federal to state government funds without clear evidence on when and where exactly funds were spent (e.g. Chodorow-Reich et al., 2012, Wilson, 2012).

Second, the particularities of the law allow us to address potential endogeneity issues: Most photovoltaic systems were financed via credit from (local) banks, and thus the credit availability within a region might have influenced both the labor market and the amount of photovoltaic investment. To address this problem, we exploit the fact that the profitability of investment is mechanically related to two predetermined variables: the solar radiation in a county and the availability of suitable rooftops for photovoltaic systems. Conditional on controlling for county characteristics, rooftop potential and solar radiation should be exogenous to local economic conditions, hence constituting a valid instrument. This allows us to assess the causal effect of investment on the labor market using an instrumental variable approach.

Third, the main characteristics of the renewable energy act were unchanged for ten years. We can therefore study whether the local employment multiplier differs with the state of the economy within a single program setting. With slack in the economy, the multiplier should be larger due to less crowding-out; However, there is no conclusive empirical evidence on this issue so far (e.g. Auerbach and Gorodnichenko, 2012a,b, Owyang et al., 2013).

In our empirical analysis, we study all 400 German counties from 2003-2012 in a yearly panel. Controlling for a range of county fixed effects and characteristics, our main 2SLS specification implies that €100,000 of investment in photovoltaics lead to 0.84 more employed individuals in a year. As we find small and insignificant results for unemployment, this suggests that the majority of additional employees may have been inactive or self-employed (self-employed individuals are not part of the main German employment statistics). Given our estimate, the cost per job-year (one job that lasts for one year) is  $\frac{€100,000}{0.84} = €120,000$ . However, this may not reflect the required investment to create one local job-year. Labor costs are only a small share of the total costs of photovoltaic systems as the majority is for capital goods (photovoltaic panels and construction inputs). We would expect only the labor share to remain within a county, as components are “imported” from other counties or from abroad. A back-of-the-envelope calculation using industry averages of cost shares suggests that around 30% of total investment accrue to

labor costs, implying that of the €120,000 in total investment costs, €36,000 remained in a county for job creation.

Separating our effect by industry, we find that most employment gains are concentrated in the construction sector, as expected by the nature of the program. Moreover, there seem to be some spillovers to employment in local service industries (restaurants, retail). We do not find a significant effect for employment in all other sectors. Furthermore, we find no evidence on spillovers across counties and our results are robust to the chosen specification and instrumental variables strategy.

In light of our long time frame, we split our sample according to whether a county is experiencing good or bad economic times. We use two separate definitions regarding the state of the local economy. The first definition assumes that a county has “slack” in the labor market if unemployment in that county in the previous year is above the *county* mean from 2003-2012. The second definition of “slack” is stated analogously as a year in which unemployment is above the *state* mean from 2003-2012. The first definition is a within-county comparison over time, the second also includes cross-county comparisons. In both these specifications, we find that the cost per job-year is lower in “slack” times, suggesting that the investment multiplier is larger during worse economic times.

## **Related Literature**

There is an active and expanding literature studying the effects of subnational government spending on local (labor market) outcomes. In contrast to aggregate time-series studies of national government spending (Ramey, 2011), studying the subnational level allows using plausibly exogenous cross-sectional variation to identify causal effects. Estimates of these local multipliers cannot be compared one-to-one to estimates of the global multiplier for national government spending. First, when looking at cross-regional variation in government spending, nationwide factors are differenced out, such as the federal tax policy or monetary policy. Second, spillovers on the regional level may lead to differences between global and local multipliers. Third, the benefactor of an increase in government spending does usually not (or only partially) bear the cost of increased government spending

in a cross-regional setting, leading to omission of any Ricardian effects. Although the relationship of local and global multipliers is not yet fully understood from a theoretical perspective, the study of local multipliers offers important insights in itself.<sup>1</sup> In many countries with a federal structure, such as the US or Germany, large portions of federal spending come in the form of regional transfers. The effects of these transfers are of first order importance, given that for example in Germany the constitution prescribes the federal government to create equal living conditions throughout the country. Furthermore, characteristics of local multipliers such as whether they differ in size in- and outside of recessions or the dynamics of spending shocks may very well transfer to global multipliers, adding to the importance.

This paper contributes to estimates of the local employment multiplier using cross-sectional variation. Conley and Dupor (2013), Feyrer and Sacerdote (2011), Chodorow-Reich et al. (2012) and Wilson (2012) study the American Recovery and Reinvestment Act (ARRA) on the US state level and find a cost per job-year between \$26,000 and \$212,000. Looking at spending shocks over longer time horizons, Suárez Serrato and Wingender (2014) find a cost per job-year of \$30,000 using exogenous changes in population statistics due to the decennial US census; Shoag (2015) finds a cost per job-year of \$35,000 using wind-fall investment returns to state pension funds as an instrument for US state government spending. At €120,000 per job-year (\$155,000 in 2012), our results are within the range found in the literature. Our study deviates from the aforementioned by studying one specific investment program, whereas these studies look at more general government (investment) expenditures.

Closely related to our paper is Buchheim and Watzinger (2016) who study the local employment effects of the German stimulus program in wake of the Great Recession. They find a cost per job-year of around €25,000. However, they look at a program focused on the renovation of schools, which may be more labor intensive than photovoltaic systems, hence having a higher share of investment remaining in a county.<sup>2</sup> In our back-of-the-

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<sup>1</sup> For an example of a model reconciling local and global multipliers, see Nakamura and Steinsson (2014).

<sup>2</sup> A very high tradable component may also explain why Mian and Sufi (2012) find no local labor market effects of the “cash for clunkers” program, as very few local jobs (e.g. in dealerships) are involved in the purchase of cars.

envelope calculation we find that in the case of photovoltaic systems around €36,000 remain in a county, which is close to the overall cost per job-year found in Buchheim and Watzinger (2016).

In addition, our paper addresses the question of whether the size of the multiplier differs with the state of the economy. This is addressed for the case of the global multiplier by e.g. Auerbach and Gorodnichenko (2012a,b). They use a regime-switching SVAR model and find that the multiplier is larger in recessions than in expansions. In contrast, Owyang et al. (2013) find no evidence for larger multipliers in recessions for the US. For the local multiplier, Shoag (2015) is to our knowledge the only one to address this question. He splits his sample according to whether there is “slack” in the local labor market and finds that the multiplier is larger in times of low employment. We undertake our analysis in the same spirit and also find that the multiplier is tentatively larger in weak economic times.

The remainder of this paper proceeds as follows: Section 2 describes the institutional background of the renewable energy act and Section 3 describes our data. We lay out the empirical approach in Section 4. First stage results are discussed in Section 5 and our main results can be found in Section 6. Section 7 presents robustness checks, Section 8 discusses further results and Section 9 concludes.

## 2 The German Renewable Energy Act

On April 1st 2000, the German Renewable Energy Act (*Gesetz für den Vorrang Erneuerbarer Energien*), was enacted. Its primary aim is to lower the carbon emissions of German energy production and its target is that 80 percent of German electricity consumption stems from renewable energy sources by 2050. In order to achieve this, the law granted one of the most generous remuneration schemes for investment in renewable energy production worldwide and has led to an unprecedented investment boom in renewable energy in Germany.<sup>3</sup> The key idea of the law is to make renewable energy systems an attractive

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<sup>3</sup> Although the law extends to all renewable energy sources (solar, wind, hydro, geothermal), we only study the case of investment in photovoltaic systems. Photovoltaics describes the direct production of electricity from solar energy using semiconducting materials. Solar energy is also utilized in the

investment opportunity by (a) mandating grid operators to purchase the produced electricity and (b) setting a 20-year fixed, above market price feed-in-tariff for the produced electricity.<sup>4</sup> This made investment in renewables a very safe investment opportunity, as investors knew the price they would receive for the next 20 years and were guaranteed that their produced electricity would also be bought. Furthermore, this implies that the profitability of a photovoltaic system solely depends on the amount of produced electricity, which in turn is a direct function of the available rooftop space and solar radiation in a location, giving rise to our IV-strategy.

In the period 2000 to 2012, the EEG underwent several major revisions. The most important one was in 2004, when the feed-in-tariff was raised by 26 percent and the prior existing cap on the amount of eligible systems was scrapped. Due to this major revision, we only study the period 2003 to 2012, although our results remain very similar if we extend our timeframe to 2000-2012. Figure 1 plots the evolution of investment in photovoltaics over time, showing how investment jumped from 2003 to 2004 and continued to rise until 2010, before dropping again after the government cut the feed-in-tariff for new systems in 2011 and 2012. At the peak in 2010, almost €15 billion (or 0.6 percent of GDP) were invested. From 2000 to 2012, this amounted to over €65 billion in total.

### 3 Data

In the following section we briefly describe the data used in this paper.

#### Investment data

The Renewable Energy Act mandates grid operators to collect and publish data on all renewable energy systems, including the capacity, location, and date of commissioning.

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form of solar thermal energy, where water is heated via solar energy. The hot water or steam is then either directly used or electricity can be produced by running turbines with the steam. We only study photovoltaic technology in this paper. This is due to the fact that our instrument should only be relevant for this technology.

<sup>4</sup> This feed-in-tariff was set to decrease by 5 percent each year for each new vintage of installed systems to take technological progress into account. This was specified in the law from the outset and common knowledge. See Figure 2 for the development of the feed-in-tariff over time.

This data is aggregated, cleaned, and validated by the *Deutsche Gesellschaft für Sonnenenergie* (DGS), which is the German section of the International Solar Energy Society. The accuracy and detail of the data is unique. Every entry has information concerning the exact address (street, number, zip code and municipality), the installed capacity, the type of system (solar, geothermal, hydro, wind), and the date of commissioning. As the date of commissioning was relevant for the feed-in-tariff (important especially at the end of the year before the tariff decreased) plant operators had every incentive to commission their system as soon as it was installed. Thus, we can say exactly when and where a system was installed and how large it is.

Photovoltaic systems can either be mounted on rooftops or can be mounted on the ground, so called greenfield systems. Since our instrument should only predict rooftop systems but not greenfield systems, we would like to exclude the latter to increase precision. As our data does not include information on the type of system, we resort to a size restriction and limit our attention to photovoltaic systems with a capacity of 500 kW<sub>p</sub> or less. Greenfield systems tend to be much larger than rooftop systems and our results are robust to varying the threshold.<sup>5</sup> The distribution in the size of photovoltaic systems with less than 500 kW<sub>p</sub> capacity can be seen in Figure A1. The vast majority of systems is actually much smaller than 100 kW<sub>p</sub>. Overall, we keep information on 94.8 percent or 1.3 million systems.<sup>6</sup>

We augment our data on the capacity and location of systems with the installation costs of a system at a given point in time, to arrive at our investment measure. Data for the period 2006-2012 is from Bundesverband Solarwirtschaft e.V. (2012), which is the German Solar Association, an industry trade body. Data for the period prior to 2006 is drawn from Janzing (2010). The price data of the German Solar Association is compiled by asking a representative sample of 100 companies that install photovoltaic systems each quarter about the total installation price they charge per kW<sub>p</sub>. The only time series available for our entire sample period is the one for prices of systems with less than 100 kW<sub>p</sub> capacity, which we hence use. Although there may very well be regional and idiosyncratic

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<sup>5</sup> A rule-of-thumb is that 1 kW<sub>p</sub> of capacity requires around 10m<sup>2</sup> of space, implying that 500 kW<sub>p</sub> require around 5000m<sup>2</sup> of rooftop space, a size only few roofs attain.

<sup>6</sup> Of the 5.2 percent of systems we drop, 40 percent are dropped due to our size restriction and 60 percent due to having some error as indicated by DGS, such as invalid address information.

differences in the price of photovoltaic systems (e.g. due to differences in local wage levels across Germany, different bargaining skills of the buyers), this is to our knowledge the most comprehensive and reliable source of price data on photovoltaic systems.<sup>7</sup> The development of the price index over time can be seen in Figure 2. The total price of a system has fallen by about 70 percent since 2000, from around €7000 per kW<sub>p</sub> to €2000 per kW<sub>p</sub>. The most rapid period of decline was in 2009/10, a development that is usually attributed to the influx of cheaper, imported photovoltaic panels from Asia.<sup>8</sup>

## Instrument

We use as instrument the interaction of solar radiation and the rooftop potential for photovoltaic systems. Data on solar radiation is taken from the PVGIS project of the European Union (Huld et al., 2012, Šúri et al., 2007). We have data on the ZIP code level and then use the mean of these values on the county level.

Obtaining a measure for rooftop potential is not as straightforward. This entails knowing the number of roofs, their angles and which direction they face on the county level. As this data is not directly measured, researchers interested in the total available potential for photovoltaic systems have resorted to estimating it. Most studies use some measure of the housing stock, invoke assumptions on the distribution of roof orientations, angles and sizes and extrapolate.<sup>9</sup> Examples for such studies are Kaltschmitt and Wiese (1993), Quaschnig (2000), Lödl et al. (2010) or Fraunhofer Institut für Windenergie und Systemtechnik (IWES) (2012). We follow the methodology employed by Lödl et al. (2010) for two reasons. First, this is a very recent and detailed study which should make the estimates more accurate. Second, the detailed description of the methodology allows us

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<sup>7</sup> A second source of prices for photovoltaic *panels* is pvXchange, a photovoltaic panel spot market for wholesalers (<http://www.pvxchange.com/priceindex/>, last accessed 21.02.2015). Rode (2014) confirms the reliability of the BSW price index with this source for the years 2006-9. Since pvXchange only lists the cost of *panels*, we cannot use this source to determine total investment in photovoltaic *systems*.

<sup>8</sup> <http://www.photovoltaik.org/wirtschaftlichkeit/photovoltaik-preise>, last accessed 21.02.2015.

<sup>9</sup> A different approach is used by <http://www.sun-area.net/index.php>. By using high-resolution laser-scans from flyovers with special aircraft, this approach allows the estimation of rooftop potential for every single building. Unfortunately, this endeavor has only been undertaken for few municipalities and counties in Germany.

to estimate rooftop potential on a county level. Lödl et al. (2010) use aerial maps of 4,500 dwellings in Bavaria to get an estimate for the average rooftop potential for different settlement types (very rural, rural, suburban, urban). They then categorize municipalities into these groups and estimate the rooftop potential by multiplying the amount of settlement area in a municipality with the average amount of rooftop potential per km<sup>2</sup> of settlement area in each category. They do this for the federal state of Bavaria and scale this to Germany as a whole by using the amount of constructed area in a state.

We follow the approach Lödl et al. (2010) for all German municipalities. Specifically, we categorize each of the roughly 11,000 municipalities<sup>10</sup> into the four categories proposed by Lödl et al. (2010) according to measures of population size, density, settlement area, living area and number of apartments per residential building. We then estimate the rooftop potential by using the values for rooftop potential per km<sup>2</sup> of settlement area that Lödl et al. (2010) determine from the aerial maps. We multiply these values with the settlement area in each municipality. In a last step we then aggregate this to the county level. A more detailed description of the instrument construction can be found in the Appendix.

## **Dependent and Control Variables**

Data on employment and unemployment for 2003-2012 is drawn from the Federal Employment Agency. This administrative data is collected to pay out unemployment benefits and to collect social security contributions and thus has minimal sampling error. The employment data encompasses all individuals that pay social security contributions, which are all employees except civil servants and self-employed persons.<sup>11</sup> We use the yearly mean of quarterly data (measured on the last day of the quarter). We normalize these numbers by the size of the working age population in 2004 unless noted otherwise. We define working-age as 15-65 year olds and obtain this data from the Federal Statistical Office. This is also the source for our control variables which are, unless otherwise noted, also normalized by the working age population measured in 2004. For the robustness check regarding our

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<sup>10</sup> Municipalities (*Gemeinden*) are the lowest administrative level in Germany and can vary in population size from 9 on an island in the North Sea to 3.4 Million in Berlin.

<sup>11</sup> As of 2011, there were roughly 1.9 Million civil servants and 4.5 Million self-employed individuals compared to 28.5 Million employees paying social security contributions (Destatis, 2012).

second instrument we use the number of residential buildings owned by individuals from the 2011 Census which is also provided by the Federal Statistical Office. Data on county types (non-city and city, where city is defined as a county consisting of a single municipality, so called *Kreisfreie Städte*) and on commuting zones (*Raumordnungsregionen*) is from the Federal Office for Building and Regional Planning.

## 4 Empirical Model

We aim to identify the effect of investment in photovoltaics on (un)employment by exploiting differences in the investment across German counties. In order to do this, we employ the following panel fixed effects model:

$$\frac{(Un)Employment_{c,t}}{N_{c,2004}} = \beta \frac{Investment_{c,t}}{N_{c,2004}} + CountyFE_c + DateFE_{c,t} + Controls_{c,t} + \epsilon_{c,t}$$

where (un)employment is the yearly mean of (un)employment in county  $c$  in year  $t$ ,  $N_{c,2004}$  is the working age population in county  $c$  in 2004, and investment is investment in photovoltaic systems in county  $c$  in year  $t$  measured in €100,000. *CountyFE* are time invariant county fixed effects for each of the 400 German counties.<sup>12,13</sup> *DateFE* are interactions of the year, state and county type of each county. German counties are either city type counties (*Kreisfrei*) or non-city type counties (*Landkreise*). The *DateFE* should absorb common shocks to each county type within each state in a given year. In our baseline specification, controls include population growth and construction of new buildings.

However, despite our various controls, endogeneity of investment remains a concern. A majority of photovoltaic investment was debt-financed and hence (unobserved) local economic conditions may affect both the local labor market and investment in photovoltaics via a local lending channel.<sup>14</sup> This would result in a biased estimate of our coefficient of

<sup>12</sup> Due to the major labor market reforms in Germany in 2005 (so called *Hartz Reformen*) we include to sets of county fixed effects, one for before and one for after 2005.

<sup>13</sup> In total, there are 402 counties in Germany. We drop Hamburg and Berlin, as these are city-states. Hence, they are fully captured by the Date FE and we omit them altogether.

<sup>14</sup> According to ZSW (2011, 2012, 2013), between 32.4 and 50.7 percent (2010 and 2012, respectively) of

interest,  $\beta$ . The direction of the bias is a priori unclear, as poor local economic conditions may make photovoltaic systems relatively more attractive due to their low risk, leading to a downward bias in  $\beta$ ; On the other hand, photovoltaic investment may suffer in poor economic conditions just as we expect other types of investment to do as well, leading to an upward bias in  $\beta$ . To circumvent this endogeneity issue, we exploit the institutional features of the renewable energy act. Due to the guaranteed feed-in-tariff and the purchasing requirement for grid operators, potential profits of a photovoltaic system solely depend on the amount of electricity it produces. This in turn is a direct function of the size of the system and the amount of solar radiation it receives. Hence, we use the interaction of rooftop potential and solar radiation as an instrument for investment in photovoltaics. Our faith in the relevance of our instrument is further motivated by the fact that many online calculation tools that potential investors consult prior to investing ask about exactly the features captured by our instrument: the size, angle, orientation and location of the roof in question.<sup>15</sup> To be a valid instrument, the interaction of rooftop potential and solar radiation needs to be exogenous. As the instrument is a pre-determined fixed characteristic of each county, it should only correlate with local labor market outcomes through investment in photovoltaics conditional on our rich set of county fixed effects and control variables.

The time invariance of our instrument has implications for our first stage regression. Since our instrument would be perfectly collinear with the county fixed effects, we interact the instrument with an indicator for each year, hence yielding as our first stage regression equation:

$$\frac{Investment_{c,t}}{N_{c,2004}} = \sum_{\substack{i=2004 \\ i \neq 2006}}^{2012} \gamma_i \frac{Rooftop\ potential_c \cdot Radiation_c}{N_{c,2004}} \cdot \mathbb{1}\{i = t\} + \\ + CountyFE_c + DateFE_{c,t} + Controls_{c,t} + u_{c,t}$$

All variables are defined as above. Due to the two sets of county fixed effects, we exclude

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total investment was financed via loans that were ultimately backed by the state-owned bank KfW.

<sup>15</sup> An example for this can be found at <http://energiertools.ea-nrw.de/tools/solarrechner/pvr/>, last accessed on 18 January 2016.

the interaction of the instrument with the indicators for 2003 and 2006.

## 5 First Stage Results

Due to the two separate sets of county fixed effects for before and after 2005, the  $\gamma_i$ s in the first stage regression are not straightforward to interpret. Hence, we relegate the regression results to the Appendix (Table A1) and present mainly visual evidence on the relevance of our instrument in the main text. In Figure 3 we plot the residuals of regressing total investment from 2000 to 2012 on a full set of state-county type interactions in the left panel and the residuals of regressing our instrument on the same interactions in the right panel. In both panels, counties are colored according to quintiles and darker shades indicate higher values of the instrument and total investment, respectively. Most notably is the predictive power of the instrument, as can be seen by the high number of counties that exhibit both high (low) values of the instrument and total investment. This pattern is easily visible in the south-east and north-west of Germany. Additionally, we can see the large variation in total investment between counties, with an increase of around €1000 p.c. when we move from the 20th to the 80th percentile. The pattern apparent in the maps is even more striking in Figure 4, where the same residuals as in Figure 3 are plotted as a scatter plot. There is a strong positive association between our instrument and total investment. Furthermore, in Table 1 we present results from running our first stage regression only for the 2010 cross-section. After inclusion of our control variables, there is a highly significant positive correlation between the instrument and investment. This is underscored by the F-statistic on the instrument which is far above the levels conventionally assumed to be necessary to mitigate weak instrument concerns. In terms of magnitude of the coefficient, a back-of-the-envelope calculation implies that an additional €115,134 in remuneration potential per year leads to €100,000 in actual investment in a county.<sup>16</sup> The relevance of our instrument is also borne out in our main

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<sup>16</sup> We determine the remuneration potential by estimating the amount of produced electricity in a year and multiplying this with the feed-in tariff for a system commissioned in 2010. The exact calculation is  $0.125 \cdot 0.38 \left[ \frac{kWh}{m^2 \cdot year} \cdot GW_p \right] \cdot 0.3634 \left[ \frac{Euro}{kWh} \right] \cdot 1000000 \left[ \frac{kW_p}{GW_p} \right] \cdot 6.67 \left[ \frac{m^2}{kW_p} \right] = 115,134 \text{ [€]}$ .

first stage regression. At 23.28, the F-statistic on the joint significance of the instrument-year interactions is fairly high and above the critical value of 20.25 put forward by Stock and Yogo (2005) for 5 percent maximal IV relative bias with one endogenous variable and eight instrument (interactions).

## 6 Main Results

The effects of investment in photovoltaics on employment can be found in Table 2. Column 1 shows the results for OLS without control variables beyond county and date fixed effects. An additional €100,000 of investment in photovoltaics lead to 0.39 additional jobs that last for one year, so-called job-years. However, this is only marginally significant. Our standard errors are clustered on the level of 94 commuting zones (*Raumordnungsregionen*) to account for correlation across neighboring counties. Once we control for population growth (column 2) and new construction (column 3), the estimated coefficient is smaller and statistically insignificant. However, we are concerned that these estimates are biased due to the potential endogeneity of investment in photovoltaics. Columns 4 to 6 present the results for our 2SLS specification. The picture here is vastly different, with all estimates of  $\beta$  being highly statistically significant and economically meaningful. In our preferred specification with controls for population growth and new construction, an additional €100,000 lead to 0.84 additional job-years. For unemployment, the results are markedly different. As columns 3 and 6 in Table 3 show, the estimated coefficient is close to zero and insignificant in both the OLS and IV specification, although the coefficient changes sign and the IV estimate is in the direction we would expect. However, the difference in the results for employment and unemployment are not necessarily at odds with each other, as unemployment is not the only margin of adjustment for increased employment. The additional employees may have either been outside of the labor force or self-employed prior to their employment, as self-employed individuals are not part of the main German employment statistics.

The fact that in the employment specification the coefficients are much larger in the 2SLS specification than in the OLS specification indicate that investment is endogenous to

local economic conditions. Since OLS is biased towards zero, photovoltaic systems seem to be a substitute for other types of investment in difficult economic times. This is not unreasonable, as the renewable energy act made investment in photovoltaics essentially a risk-free investment opportunity.

An important quantity of interest in the evaluation and design of fiscal (stimulus) programs is the cost of creating an additional job. The cost per job-year for employment in case of investment in photovoltaics is  $\text{€}100,000 / 0.84 = \text{€}120,000$ . This is within the range found in the literature, where Buchheim and Watzinger (2016) estimate a cost per job-year of  $\text{€}18,000\text{-}36,000$  and Conley and Dupor (2013) estimate a cost per job-year of  $\text{\$}212,000$  ( $\text{€}165,000$  in 2012). However, given that we are interested in local job creation, another quantity of interest is the amount of *local* investment required to create one job. The costs of a photovoltaic system are comprised of the installation costs and the costs for the parts and components. We would only expect the former to constitute local investment, as only the labor is sourced from the county in question whereas the parts are imported from few locations with photovoltaic manufacturing worldwide. Unfortunately, we can only assess this in a back-of-the-envelope fashion. EuPD Research (2013) includes the break-down of the system costs according to parts and installation and reports that 19 percent of the total investment cost are for installation. Furthermore, based on conversations with industry experts we assume the mark-up on the components by the installation company to be on the order of 15 percent. Taken together, this implies that 30 percent (19 percent + 15 percent of 81 percent) of the total investment actually remains in a county, implying a local required investment of around  $\text{€}36,000$  per job. This is very close to the estimate in Buchheim and Watzinger (2016) who focus on a much more labor-intensive program than we do. Furthermore, this number can inform policy makers when thinking about the size of local stimulus packages.

## **Sector-specific Employment Effects**

As a first plausibility check on our estimates, we use sectoral employment data to ascertain in which sectors we find employment effects. Given that the photovoltaic system needs to

be connected to the grid by a licensed electrician, virtually all installation companies are electricians and we would hence expect results to be strongest for this group. Furthermore, if there are multiplier effects to other sectors we would expect these to exist in local service industries such as restaurants and retail trade. Hence, we split employment into three sectors (see Table A2 for details): Employment in treated sectors, employment in local services and employment in untreated sectors. We determine treated sectors in the following way: We take a random sample of the member firms of the German Solar Association. We then manually check via the homepage of these firms whether they are actually engaged in the installation of photovoltaic systems.<sup>17</sup> In a last step we then consult Creditreform company profiles, a commercial information provider, on the sectoral classification of these companies. The sectors we determine via this procedure includes construction sectors such as building installation and completion as well as certain wholesale categories or engineering activities. Since most electricians engage in a variety of activities and not only the installation of photovoltaic systems, this range of sectors is not surprising. Overall, 13 percent of all employment in 2003 falls into the (most likely) treated sectors. The local services sector includes all remaining wholesale and retail employment as well as hotels and restaurants (14 percent of employment in 2003). The remaining 74 percent of employment fall into the untreated sector.

We use the three groups as dependent variable in our main specification and report the OLS and IV results in Table 4. Since we only have sectoral employment data measured at the end of the second quarter, we report our baseline estimation with overall employment measured at the end of the second quarter in columns 1 and 5. The pattern is exactly the same as in our main results and the IV coefficient at 0.92 is slightly larger than when we use the yearly mean of employment. Looking at the different sectors, the majority of our effect falls on the treated sector, as we would expect. The coefficient for the local services sector is about one third as large, yet still statistically significant. For the untreated sector, the coefficient is of a similar magnitude, but we cannot reject the hypothesis that it is equal to zero. Taken together, we see these results as evidence that we are actually picking

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<sup>17</sup> The German Solar Association also includes producers of photovoltaic panels and service providers such as specialized cleaning companies or investment funds.

up the effects of photovoltaic investment in our main regressions and that investment in the local construction sector has spillovers in other local services such as restaurants and retail.

## **7 Robustness**

Our results are robust to including further control variables, choices of the specification and data choices. Furthermore, we present evidence that our results do not hinge on the specific construction of our instrument.

### **Inclusion of control variables**

We first assess the robustness of our main results to the inclusion of further control variables on the county level. For brevity, we only present the results for the employment specification, the results for unemployment are relegated to the Appendix (Table A3). In column 1 of Table 5 we only control for state-year interactions and do not include county type interactions, which yields our estimate almost unchanged. In column 2, we only include one set of county fixed effects, which leads to a rough doubling of our estimate; hence, controlling for two sets of county fixed effects yields much more conservative results. In column 3 we additionally control for a county specific trend in employment, leading to a somewhat smaller coefficient (0.52, significant on the 1 percent level). To account for local economic conditions, we control for GDP p.c. on the county level. This leads to an almost identical coefficient. In columns 5 and 6 we additionally control for characteristics of the employees in a county (education and sector), which yields somewhat larger coefficients. In the last column, we control for Bartik shocks. Bartik shocks are the predicted employment growth in a county based on the employment growth in all other counties within a specific sector. Controlling for this yields a smaller coefficient that is marginally significant (0.20).

## Robustness of the Chosen Specification

In Table 6 we evaluate the robustness of our results to specification choices for employment. The results for unemployment can be found in the Appendix in Table A4. For comparison reasons we repeat our baseline estimate in the first row. In the second row, we weight our regressions with the working age population in 2004 resulting in slightly larger coefficients compared to the baseline estimate. In the following two rows we do not standardize our variables with the working age population in 2004 and weight the regression in row 3 with  $1/$  the working age population in 2004. This results in coefficients more than twice the size of the baseline estimates. In the fifth row we re-run our baseline regression in first differences which results in slightly smaller coefficients. If we do not cluster our standard errors (row six) our estimates are more precise and especially our first stage F-statistic is much larger. In rows six and seven we study whether the choice of time period is driving our effect. If we limit our attention to 2006-2012 to circumvent issues of the far-reaching labor market reforms in 2005 driving results we find virtually unchanged coefficients. If we extend our period of study to the early years of the renewable energy act as well, our estimates are slightly larger, but still close to the original coefficients. In rows 8-11 we first split our sample into East and West Germany and into city-type counties (*Kreisfrei*) and non-city type counties. For West Germany and rural counties our results are very similar to the baseline estimates. However, for East Germany and city-type counties our estimates are vastly different and insignificant and our first stage regressions are much weaker, especially for city type counties. The imprecision of the results may be due to the much smaller sample size in these subsamples. Furthermore, the rationale for photovoltaic systems in large cities may be very different, as installing a system is much more difficult due to the prevalence of chimneys, skylights and the high number of renters in cities. Hence, other factors such as a desire to help the environment may be larger driver in cities than in more rural areas, a motivation our instrument does not capture as it is closely linked to the financial viability of a system. In the last four rows we assess the robustness of the results to using different definitions of county type beyond the city vs. non-city-type classification. Here we use the urbanization degrees as

classified by the German Federal Office of Building and Regional Planning on the basis of population densities. Regardless of the exact combination, our results remain very close to our baseline estimate, reassuring us in the robustness of our results.

## **Robustness to Data Choices**

In a second set of robustness checks we assess whether our results are driven by our sample choice or whether certain outliers are driving the results. In Table 7 we present our 2SLS estimate for (un)employment using all investment data including systems with a capacity of more than 500 kW<sub>p</sub> and those classified as invalid by the DGS. The second stage coefficient for unemployment is virtually unchanged and the coefficient for employment is somewhat smaller, but still highly significant. However, the first stage is much weaker as shown by the 1st stage F-statistic, implying that our instrument does a poor job at predicting very large systems. This is to be expected, as these systems are more likely to be greenfield systems, an issue we investigate in more detail below.

Furthermore, we investigate whether our results are driven by certain states. In Figure 5 we drop each state one-by-one and plot the resulting second stage coefficient and 95% confidence intervals for unemployment (panel a) and employment (panel b). Regardless of which state we drop, the overlap in confidence intervals for both dependent variables is very high. There is some movement in the coefficient on employment if we drop Lower Saxony or Bavaria, with an increase (decrease) in the case of dropping Bavaria (Lower Saxony). Since Bavaria exhibits a strong economic performance and a lot of investment in photovoltaics, it may be that it requires more funds to create a job there given the fairly high level of employment prevalent there. Dropping Bavaria would then result in the visible increase in the coefficient. Since Bavaria and Lower Saxony make up a large share of all German counties (almost 25 percent in the case of Bavaria), it is not surprising that our coefficients change somewhat if we drop a large share of our observations.

## Robustness of the Instrument

In a last set of robustness checks, we take a closer look at our instrument. First, we show that our instrument only predicts investment in rooftop systems and not greenfield systems. Second, we propose a second measure of rooftop potential to show that our results are not driven by the particular construction of our measure of rooftop potential. For a subset of our data we additionally know the type of system, i.e. whether a photovoltaic system is mounted on the ground (greenfield) or on a roof (rooftop). We limit our attention to greenfield systems and re-run our first stage regression with investment in greenfield systems from 2003 to 2012 as the dependent variable. Since the individual coefficients are difficult to interpret, we focus on the F-statistic on the instruments (Table 8) and see that whether or not we include our baseline controls, the F-statistic hovers at around 2, implying that our instrument does a very poor job at predicting investment in greenfield systems, as we would expect.

In order to check that the predictive power of our instrument for our main investment variable is not driven by the construction of our measure rooftop potential, we use a second measure of rooftop potential with a different motivation and taken from an entirely different source. We use the number of residential homes owned by a single person per capita (in contrast to homes owned by multiple persons, institutions, companies, etc.) as a measure for rooftop potential and interact this once more with radiation.<sup>18</sup> The rationale behind this instrument is as follows: An individual owner has much lower decision making costs in determining whether or not to install a photovoltaic system on her roof than if the building is owned by multiple people who all need to agree on the installation.<sup>19</sup> Thus, this not only measures the amount of rooftop space via the amount of housing, but the feasibly usable rooftop *potential*.<sup>20</sup> The information on the ownership structure

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<sup>18</sup> Note that the owner does not necessarily also occupy this building since he may own more than one residential building (or rent himself). This measure also encompasses apartment buildings owned by individuals.

<sup>19</sup> In case of multiple ownership, e.g. if in an apartment building each apartment is owned by a different individual, all owners together constitute a ownership association (*Wohnungseigentümergeinschaft*). This entity must decide on all matters pertaining to the building as a whole, such as whether or not to install a photovoltaic system. The installation of a photovoltaic systems usually needs unanimous consent of every owner, cf. [http://www.kanzlei-schultze.de/img-vioweb/ausgew\\_hlte\\_rechtsprobleme\\_bei\\_modernisierungsprojekten\\_in\\_weg.pdf](http://www.kanzlei-schultze.de/img-vioweb/ausgew_hlte_rechtsprobleme_bei_modernisierungsprojekten_in_weg.pdf), last accessed 04.03.2015.

<sup>20</sup> A similar line of reasoning is made by Comin and Rode (2013) for the share of single family and

of residential buildings is taken from the 2011 census in Germany. To show that this really captures rooftop *potential* and not merely rooftop *space*, we also use the number of homes owned by multiple persons as a measure for rooftop potential and see that this does not predict investment in photovoltaics. In Figure 6 we plot the residuals of regressing total investment p.c. from 2003 to 2012 as well as individual and group ownership times radiation on state-county type interactions. In panel (a) the positive association between individual ownership times radiation and total investment is clearly visible. In panel (b), the negative association between group ownership and total investment is clearly visible. This underscores our assertion that individual ownership is indeed a measure of rooftop *potential* and not merely of rooftop *space*.

For the number of houses owned by individuals to be a valid instrument, it must additionally be exogenous. We may be somewhat concerned given that the Census was conducted in 2011 and thus our data is measured well within our treatment period. Yet, the Census includes data on the age of residential building and at least 80 percent of all housing was built before 2000 in every county and around 90 percent on average. To account for any new housing, we include new construction as a control variable. This only mitigates our concerns if the composition of ownership is the same for new as for older buildings, a question which we have insufficient data to address. The results of the first stage regressions can be found in Table A5. The first stage F-statistic is 11.00, which is lower than with our main instrument but still indicates a reasonably strong instrument. Since the number of residential buildings owned by individuals is a much cruder proxy for rooftop potential than our main instrument, this drop in the predictive power is not surprising. The second stage results using the alternative measure of rooftop potential can be found in Table 9. For unemployment, coefficients are insignificant and essentially zero. For employment, the coefficient in our preferred specification is 1.23 (significant on the 1 percent level), which is about 50 percent larger than if we use our main measure of rooftop potential. Nevertheless, the results are in the same ballpark, which is reassuring given that the alternative measure of rooftop potential was taken from an entirely different source with a

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semi-detached homes.

different motivation.

## 8 Further results

### Geographic Spillovers

Given the close economic linkages between neighboring counties and the sizable number of commuters across county borders, it is possible that investment in one county also influences (un)employment in a neighboring county. Such spillovers of investment introduces measurement error in our investment measure and might bias our estimates towards zero. Furthermore, if the spillover investment is correlated with the level of investment in the county under consideration, we need to include the inflow of funds as an additional regressor to consistently estimate the coefficient of investment in photovoltaics. Since we only observe where the investment is installed and not where the installation company (the recipient of the investment) is located, we follow the approach of Acconcia et al. (2014) and include investment in neighboring counties as an additional control variable. Note that we instrument investment in neighboring counties with the instrument in neighboring counties, hence we now have two endogenous variables and two sets of instrument interactions. Results for employment can be found in Table 10, results for unemployment are relegated to the Appendix in Table A6. We define *neighboring counties* in four different fashions: in column 2 we consider all counties within the same commuting zone (CZ) to be neighboring. In column 3 we consider all counties in the same county region to be neighboring, although many county regions consist of only a single county. In columns 4 to 6 we define neighboring counties as the closest 5, 10 and 25 counties, respectively, as measured by the distance between the largest cities in each county. Across all definitions of neighboring counties, our coefficient of interest is very close to our baseline estimate. The coefficients on investment in neighboring counties are all very close to zero and almost all statistically insignificant. Overall, there is no evidence of spillovers into neighboring counties.

## Difference Over the Business Cycle

Keynesian theory implies that the multiplier of government spending should be larger in weaker economic times. Intuitively, if the economy is operating below full capacity, government spending will not crowd out private investment, resulting in larger multipliers. There is some empirical evidence on this issue, However, the literature so far has not yielded a consensus. Most studies study differences in the global, economy-wide multiplier using VAR-techniques. Examples include Auerbach and Gorodnichenko (2012b), Bachmann and Sims (2012) and Ramey and Zubairy (2014) for the US, Baum et al. (2012) for the G7 economies (excluding Italy), Ramey and Zubairy (2015) for Canada and Auerbach and Gorodnichenko (2012a) for a sample of OECD countries. Most studies find a larger multiplier in times of economic slack than in expansionary phases, for example Bachmann and Sims (2012) estimate a multiplier of 2 in recessions and of 1 in expansions. Auerbach and Gorodnichenko (2012a) find a maximum government spending multiplier of around 3.5 in recessions, whereas they cannot rule out a coefficient of zero during expansions . However, Ramey and Zubairy (2014), Owyang et al. (2013) do not find evidence of a larger output response to government spending shocks during recessions than in expansions ofr the US. For local multipliers, only Shoag (2015) to our knowledge addresses the question of whether or not the multiplier differs with respect to the economy.

The setting of the German Renewable Energy Act is ideally suited to study this question and to add to the empirical literature on this question. This is due to the fact that the main characteristics of the program were unchanged over the entire duration of the program. This makes us more confident to attribute any heterogeneity in the size of the multiplier to changes in economic conditions and not other concurrent developments. Furthermore, during the ten years we study, the German labor market changed dramatically with average unemployment falling from over 11 percent in 2005 to around 5 percent in 2012. In addition, there is considerable heterogeneity across German counties ranging from less than two percent in Bavaria to more than 18 percent in East Germany.

We follow the approach of Shoag (2015) in defining strong and weak economic conditions via local labor market conditions. We first define weak economic times such that there

is “slack” in the labor market if unemployment in a county in  $t - 1$  is above the *county* mean from 2003 to 2012. This compares counties to themselves over time. In our second definition, we define a county as experiencing “slack” if unemployment in the county in  $t - 1$  is above the *state* mean from 2003 to 2012. This not only compares counties with themselves over time but also uses cross-county comparisons. In columns (1) and (2) of Table 11 we present results for the first definition, using the employment rate as the dependent variable. Splitting the sample according to our measure of “slack”, we find that the coefficient in “slack” times is around twice as large as in good economic times. This is in line with the findings of the literature so far; Shoag (2015) finds that the multiplier is around twice as big in times of “slack”. Using our second definition (columns (3) and (4)), the difference is even larger, with the coefficient in “slack” times being multiple times as large as in times without “slack”. However, the first stage in “slack” counties is fairly weak. A qualitatively similar pattern is visible if we use unemployment as our dependent variable (Table A7); However, as in the main specification, none of the coefficients are statistically significant different from zero. Overall, we see this as tentative evidence for a larger multiplier in poor economic times.

## 9 Conclusion

In this paper we analyze the effects of investment in photovoltaics on local labor market outcomes in Germany. As investment is potentially endogenous, we use the interaction of predetermined rooftop potential and radiation as an instrument. Due to the structure of the renewable energy act with its generous fixed feed-in tariff, the instrument has high predictive power for investment in photovoltaics. Analyzing the causal effects of this investment, we find that €120,000 of investment create one additional job lasting for one year. A back-of-the-envelope calculation suggests that about €36,000 of this remained in the county of investment. Furthermore, effects are concentrated in the construction sector with some spillovers to local service industries and no detectable spillovers to neighboring counties. We find evidence that the multiplier is larger in weak economic times. Taken together, our results imply that a fiscal stimulus program with a focus on the non-tradable

sector could stabilize negative local economic shocks.

A key difference of this paper to the related literature on local employment multipliers, is in who undertakes the investment decision. Here, the government enticed consumers to purchase photovoltaic systems through a generous subsidy via the guaranteed feed-in tariff, whereas most of the literature focuses on government purchases or intra-governmental transfers. In our estimation of the labor market effects of this induced investment, we abstracted from the question of why and by whom this investment was undertaken. Thus our estimates can inform future stimulus policies independent of their actual implementation. Whether it would be more efficient if the government uses direct purchases, tax rebates or subsidies to induce local investment is an important question that we leave for future research.

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## Figures

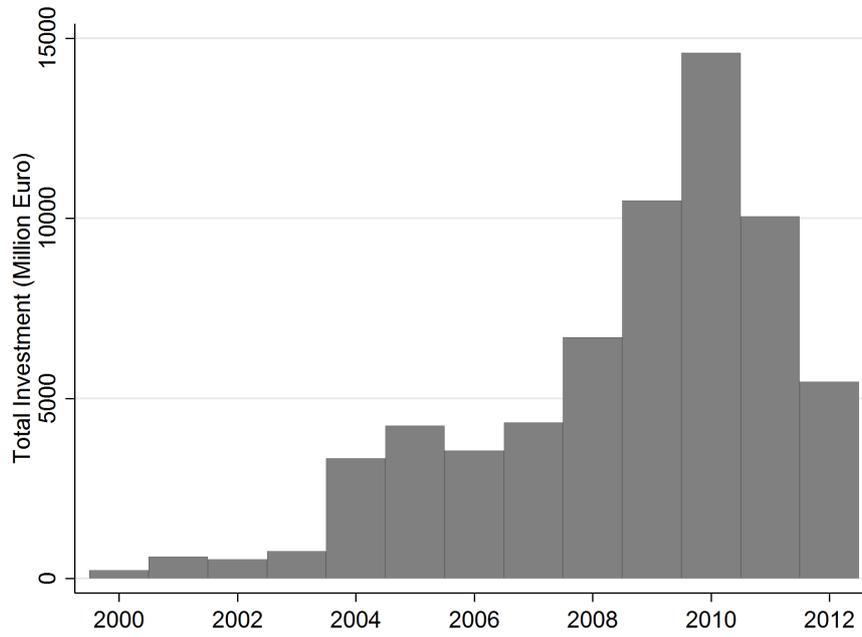


FIGURE 1 – TOTAL ANNUAL INVESTMENT

*Note:* Total new investment in photovoltaic systems in Germany by year. Note that this understates “true” investment as this is total investment limited to photovoltaic systems with fewer than 500 kW<sub>p</sub> capacity.

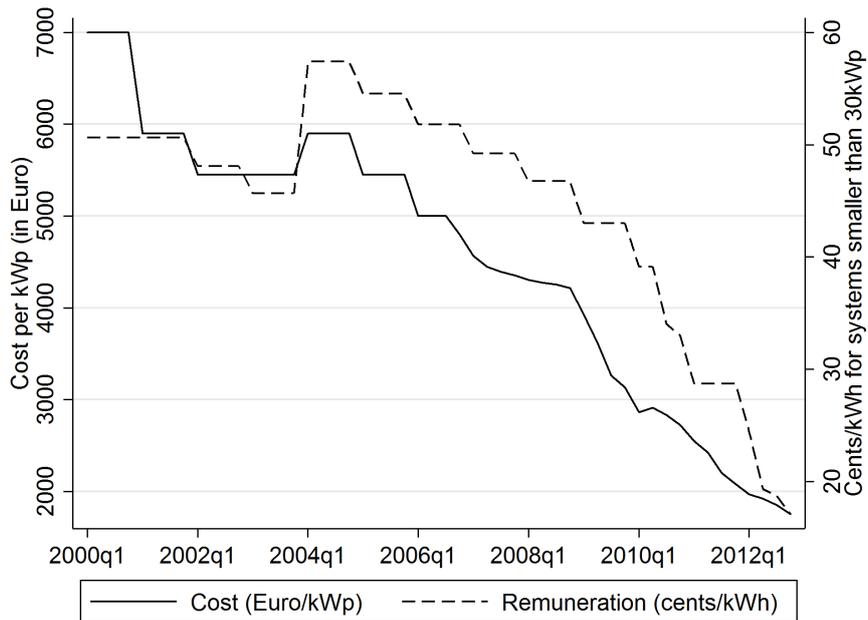


FIGURE 2 – REMUNERATION FOR PHOTOVOLTAIC ELECTRICITY AND COST OF PHOTOVOLTAIC SYSTEMS

*Note:* Cost is the total cost of a photovoltaic system (parts and installation) per  $\text{kW}_p$  for a system with a capacity of fewer than  $100 \text{ kW}_p$ . Data for 2000-2005 is drawn from Janzing (2010) and for 2006-2012 from Bundesverband Solarwirtschaft e.V. (2012). Remuneration is the legally guaranteed feed-in-tariff the owner of a photovoltaic system with fewer than  $30 \text{ kW}_p$  capacity receives for the following 20 years for every kWh of electricity he produces with a system commissioned in that year. This data is drawn from the Renewable Energy Act in its various versions.

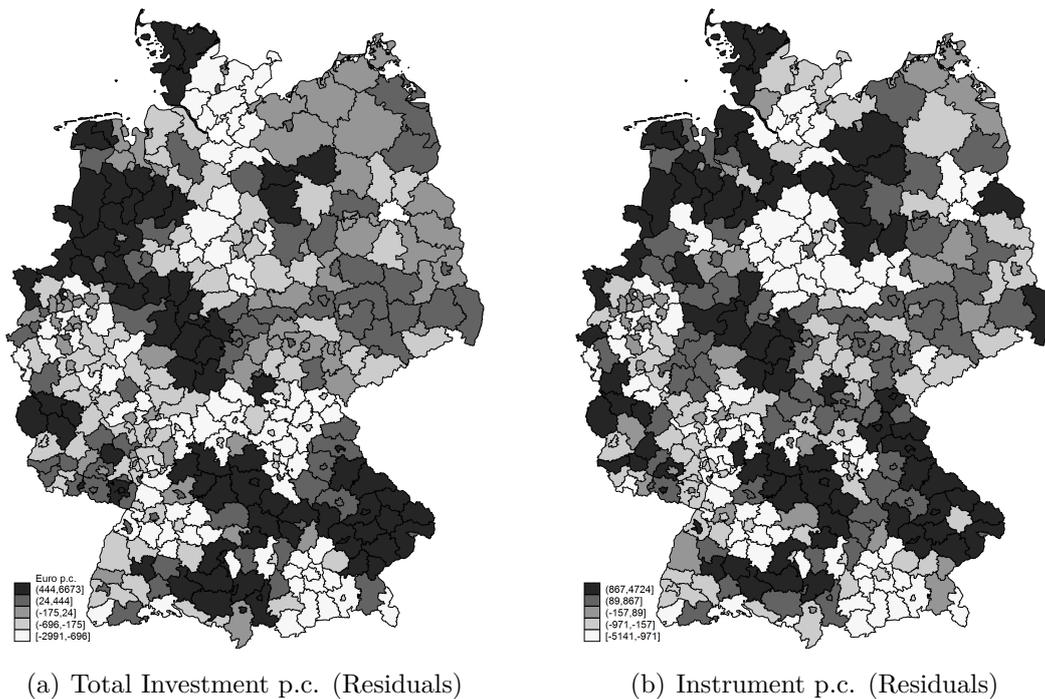


FIGURE 3 – GEOGRAPHIC DISTRIBUTION OF TOTAL INVESTMENT AND ROOFTOP POTENTIAL · RADIATION

*Note:* The map in the left panel shows the geographic distribution of total investment in photovoltaic systems p.c. from 2000 to 2012 net of an fixed effect for city type counties in each of the 14 states (Hamburg and Berlin are omitted). The map in the right panel shows the geographic distribution of rooftop potential · radiation p.c. net of a fixed effect for city type counties in each of the 14 states. The colors correspond to quintiles in investment (instrument) and darker colors indicate higher values of investment (the instrument). Per capita values are normalized with the working age population in 2004.

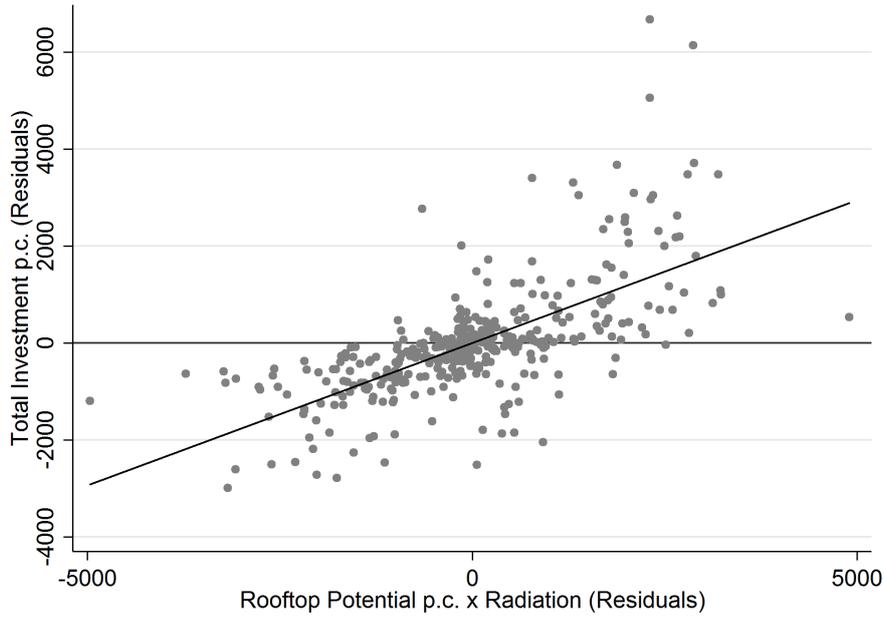
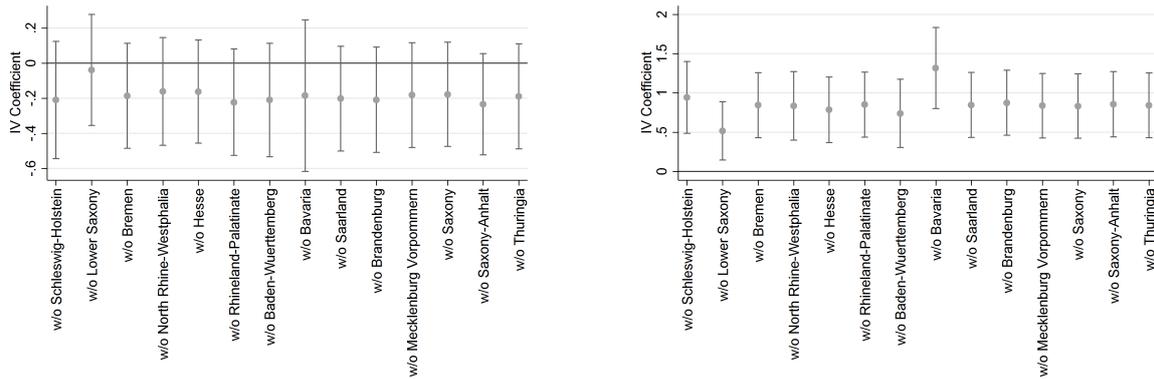


FIGURE 4 – TOTAL INVESTMENT P.C. AND INSTRUMENT P.C.

*Note:* Residuals of regressing total investment p.c. in a county and rooftop potential p.c.  $\times$  radiation on state and county type interactions. Per capita variables are normalized with the working age population in 2004. The solid line is a linear prediction of the residuals of total investment p.c. by regressing the residuals of total investment p.c. on the residuals of rooftop potential p.c.  $\times$  radiation.

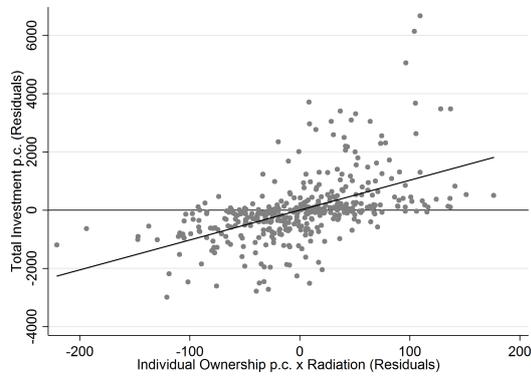


(a) Unemployment

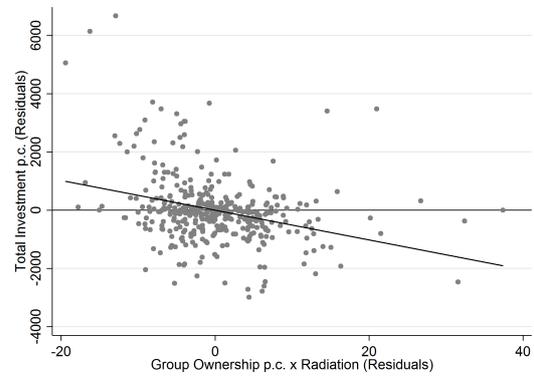
(b) Employment

FIGURE 5 – DROPPING INDIVIDUAL STATES

*Note:* Second stage coefficient on investment p.c. in regressions for 2003-2012, dropping the labeled state. All regressions control for state, year and county type interactions, population growth, new construction p.c. and county fixed effects with separate county fixed effects for the pre 2005 period. Dependent variable is the (un)employment rate in a county. All per capita variables are normalized with the working age population in 2004.



(a) Single Ownership



(b) Group Ownership

FIGURE 6 – TOTAL INVESTMENT P.C. AND ALTERNATIVE INSTRUMENTS

*Note:* Residuals of regressing total investment p.c. in a county and individual (group) ownership p.c.  $\times$  radiation on state and county type interactions. Per capita variables are normalized with the working age population in 2004. The solid line is a linear prediction of the residuals of total investment p.c. by regressing the residuals of total investment p.c. on the residuals of individual (group) ownership p.c.  $\times$  radiation.

## Tables

TABLE 1 – FIRST STAGE: 2010 CROSS SECTION

	Investment p.c.		
	(1)	(2)	(3)
Rooftop potential p.c. $\times$ radiation $\times$ 2010	0.39*** (0.05)	0.38*** (0.04)	0.38*** (0.04)
Population growth		0.03*** (0.01)	0.03*** (0.01)
Construction p.c.			0.09 (0.12)
State $\times$ Year $\times$ County Type	yes	yes	yes
F-statistic instruments	67.17	75.00	76.81
$R^2$	0.70	0.71	0.71
Observations	800	800	800

*Notes:* Regression for the years 2009-2010. The dependent variable investment p.c. is measured in €100,000 per capita. The year-instrument interactions for 2009 is dropped in order to accommodate the county fixed effects. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. We control for fixed effects for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 2 – THE TREATMENT EFFECT OF INVESTMENT ON EMPLOYMENT

	Employment Rate					
	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Investment p.c.	0.39*	0.20	0.20	0.79***	0.83***	0.84***
	(0.20)	(0.13)	(0.13)	(0.28)	(0.21)	(0.21)
Population growth		0.33***	0.33***		0.32***	0.32***
		(0.03)	(0.03)		(0.03)	(0.03)
Construction p.c.			0.25			0.25*
			(0.15)			(0.14)
State $\times$ Year $\times$ County Type	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes
F-statistic 1st stage				21.74	23.02	23.28
$R^2$	0.93	0.96	0.96	0.92	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000

*Notes:* The dependent variable is the employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 3 – THE TREATMENT EFFECT OF INVESTMENT ON UNEMPLOYMENT

	Unemployment Rate					
	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Investment p.c.	0.10 (0.09)	0.06 (0.09)	0.06 (0.09)	−0.19 (0.17)	−0.18 (0.15)	−0.19 (0.15)
Population growth		0.07*** (0.02)	0.07*** (0.02)		0.08*** (0.02)	0.08*** (0.02)
Construction p.c.			−0.08 (0.11)			−0.08 (0.10)
State × Year × County Type	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes
F-statistic 1st stage				21.74	23.02	23.28
$R^2$	0.96	0.96	0.96	0.95	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000

*Notes:* The dependent variable is the unemployment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 4 – SECTORAL EMPLOYMENT RESULTS

	Employment							
	OLS				2SLS			
	Baseline	Treated	Local	Untreated	Baseline	Treated	Local	Untreated
Inv. p.c.	0.22* (0.12)	0.19* (0.11)	0.14*** (0.04)	-0.11 (0.17)	0.92*** (0.23)	0.52*** (0.12)	0.18*** (0.07)	0.22 (0.24)
Pop. growth	0.32*** (0.03)	0.01 (0.01)	0.03*** (0.00)	0.28*** (0.02)	0.32*** (0.03)	0.01 (0.01)	0.03*** (0.00)	0.28*** (0.02)
Constr. p.c.	0.26* (0.14)	0.01 (0.14)	0.00 (0.08)	0.25 (0.17)	0.26* (0.15)	0.01 (0.14)	0.00 (0.08)	0.25 (0.17)
State $\times$ Year $\times$ County Type	yes	yes	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes	yes	yes
F-stat. 1 <sup>st</sup> stage					23.28	23.28	23.28	23.28
$R^2$	0.95	0.52	0.75	0.92	0.95	0.52	0.75	0.92
Observations	4000	4000	4000	4000	4000	4000	4000	4000

*Notes:* In columns (1) and (5), the dependent variable is the employment rate in a county from 2003-2012, measured at the end of the second quarter. In columns (2) and (6), the dependent variable is the number of employed p.c. in the construction and related sectors. In columns (3) and (7), the dependent variable is the number of employed p.c. in the wholesale, retail, hotel and restaurant sectors. In columns (4) and (8), the dependent variable is the number of employed p.c. in all remaining sectors. See Table A2 for details. Inv. p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Pop. growth is the working age population in a county at time  $t$  divided by the working age population in 2004. Constr. p.c. is new construction of residential and non-residential buildings. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 5 – EMPLOYMENT SPECIFICATION WITH CONTROL VARIABLES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Investment p.c.	0.77*** (0.18)	1.49*** (0.35)	0.52*** (0.19)	0.78*** (0.21)	0.96*** (0.24)	0.90*** (0.23)	0.20* (0.12)
Population growth	0.34*** (0.03)	0.36*** (0.02)	0.04*** (0.01)	0.31*** (0.03)	0.29*** (0.03)	0.28*** (0.03)	0.13*** (0.02)
Construction p.c.	0.34** (0.16)	-0.18 (0.22)	0.11 (0.09)	0.23 (0.14)	0.20 (0.15)	0.20 (0.15)	0.14 (0.12)
GDP p.c.				0.03*** (0.01)	0.03*** (0.01)	0.03*** (0.01)	0.02*** (0.00)
Share vocational					-0.07** (0.03)	-0.07** (0.03)	-0.03* (0.02)
Share university					0.25*** (0.06)	0.25*** (0.06)	0.21*** (0.04)
Share agriculture						0.17 (0.11)	0.09 (0.08)
Share manufacturing						0.09*** (0.03)	0.01 (0.02)
Bartik (treated)							0.53*** (0.05)
Bartik (local)							0.71*** (0.07)
Bartik (not treated)							0.53*** (0.04)
State × Year × County Type	no	yes	yes	yes	yes	yes	yes
State × Year	yes	no	no	no	no	no	no
Pre-2005 FE	yes	no	yes	yes	yes	yes	yes
Trend	no	no	yes	no	no	no	no
F-statistic 1st stage	32.43	25.60	20.71	22.98	22.32	21.26	19.23
$R^2$	0.94	0.92	0.98	0.95	0.95	0.96	0.97
Observations	4000	4000	4000	4000	4000	4000	3600

*Notes:* The dependent variable is the employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Control variables are described in the text. Trend denotes whether a county-specific trend is included in the regression. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005 in all columns except column 3) as well as for every state × year × county type combination (except for column 1). All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 6 – ROBUSTNESS: EMPLOYMENT

	Coeff.	SE	F-stat.	Obs.
Baseline	0.84***	0.21	23.28	4000
Weighted	0.95***	0.20	25.24	4000
Levels weighted 1/population	1.74***	0.31	20.64	4000
Levels not weighted	1.78***	0.54	23.01	4000
First Difference	0.61***	0.13	24.56	3600
No clustering	0.84***	0.13	68.23	4000
Only Post 2005	0.84***	0.21	24.79	2800
2000-2012	0.95***	0.23	24.79	5200
Only West	0.87***	0.21	22.79	3240
Only East	-2.86	2.04	14.79	760
Only City	1.89	1.68	5.05	1050
Only Rural	0.79***	0.20	25.03	2950
Alt. county type 1	0.85***	0.28	25.23	4000
Alt. county type 2	0.87***	0.21	27.05	4000
Alt. county type 3	0.87***	0.25	29.40	4000
Alt. county type 4	0.83***	0.25	23.47	4000

*Notes:* The dependent variable is the employment rate in a county from 2003-2012. In all regressions we control for population growth, new construction and county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination. F-stat. denotes the first stage F-statistic on the instrument interactions. In the baseline case, all variables are normalized by the working age population in 2004 and standard errors are clustered on the level of 94 commuting zones. In the weighted case, the regression is weighted by the working age population in 2004. In the levels specification, absolute levels instead of per capita normalized values are used. In the first difference specification, the second stage equation is estimated in first differences. In the no clustering case, robust standard errors are used. Only West limits the sample to the former West German counties and only East limits them to the states of the former German Democratic Republic. Only City denotes only city-type counties (*Kreisfrei*), whereas only rural denotes all non-city type counties. Alt. county type 1 denotes that instead of the city type county dummy (*Kreisfrei*) we control for every state  $\times$  year  $\times$  urbanization degree interaction where urbanization degree is one of four categories ranging from major city to rural, as classified by the German Federal Office of Building and Regional Planning on the basis of population densities (*Siedlungsstruktureller Kreistyp*). Alt. county type 2 denotes the interactions of state  $\times$  year  $\times$  major city. Alt. county type 3 denotes the interactions of state  $\times$  year  $\times$  major city  $\times$  rural. Alt. county type 4 denotes the interactions of state  $\times$  year  $\times$  city county type (*Kreisfrei*)  $\times$  rural. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 7 – SECOND STAGE WITH INVESTMENT DATA INCLUDING LARGE SYSTEMS

	Unemployment p.c. (1)	Employment p.c. (2)
Investment p.c. (all data)	−0.21 (0.13)	0.54*** (0.19)
Population growth	0.07*** (0.01)	0.33*** (0.03)
Construction p.c.	−0.08 (0.10)	0.26* (0.15)
State × Year × County Type	yes	yes
Pre-2005 FE	yes	yes
F-statistic 1st stage	11.48	11.48
$R^2$	0.95	0.95
Observations	4000	4000

*Notes:* The dependent variable is the (un)employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012, where large systems and system information not deemed valid by the DGS are not dropped. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 8 – FIRST STAGE: ONLY GREENFIELD SYSTEMS

	Inv. p.c. (Greenfield)		
	(1)	(2)	(3)
Rooftop potential p.c. $\times$ radiation $\times$ 2004	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Rooftop potential p.c. $\times$ radiation $\times$ 2005	0.03 (0.02)	0.04 (0.02)	0.03 (0.03)
Rooftop potential p.c. $\times$ radiation $\times$ 2007	-0.01 (0.02)	-0.01 (0.02)	-0.01 (0.02)
Rooftop potential p.c. $\times$ radiation $\times$ 2008	-0.01 (0.03)	-0.01 (0.03)	-0.02 (0.03)
Rooftop potential p.c. $\times$ radiation $\times$ 2009	0.31** (0.13)	0.31** (0.13)	0.30** (0.13)
Rooftop potential p.c. $\times$ radiation $\times$ 2010	0.24** (0.11)	0.24** (0.10)	0.24** (0.11)
Rooftop potential p.c. $\times$ radiation $\times$ 2011	0.24 (0.17)	0.24 (0.17)	0.24 (0.17)
Rooftop potential p.c. $\times$ radiation $\times$ 2012	0.24** (0.12)	0.27** (0.11)	0.27** (0.11)
Population growth		-0.01** (0.01)	-0.01* (0.01)
Construction p.c.			-0.09 (0.08)
State $\times$ Year $\times$ County Type	yes	yes	yes
Pre-2005 FE	yes	yes	yes
F-statistic instruments	1.97	2.60	2.38
$R^2$	0.03	0.03	0.03
Observations	4000	4000	4000

*Notes:* Regression for the years 2003-2012. The dependent variable investment in greenfield systems p.c. is measured in €100,000 per capita. The year-instrument interactions for 2003 and 2006 are dropped in order to accommodate the two sets of county fixed effects. A separate fixed effect for before 2005 is estimated due to far reaching labor market reforms in 2005. We control for fixed effects for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 9 – SECOND STAGE ALTERNATIVE INSTRUMENT

	Unem.			Empl.		
	(1)	(2)	(3)	(4)	(5)	(6)
Investment p.c.	0.01 (0.24)	0.03 (0.24)	0.02 (0.24)	1.11*** (0.43)	1.19*** (0.34)	1.23*** (0.35)
Population growth		0.07*** (0.02)	0.07*** (0.02)		0.32*** (0.03)	0.32*** (0.03)
Construction p.c.			-0.08 (0.10)			0.26* (0.14)
State × Year × County Type	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes
F-statistic 1st stage	11.23	10.87	11.01	11.23	10.87	11.01
$R^2$	0.95	0.95	0.95	0.92	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000

*Notes:* The dependent variable is the (un)employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 10 – SPILLOVERS FROM NEIGHBORING COUNTIES: EMPLOYMENT

	(1)	(2)	(3)	(4)	(5)	(6)
Investment p.c.	0.84*** (0.21)	0.85*** (0.21)	0.83*** (0.21)	0.98*** (0.21)	0.92*** (0.21)	0.86*** (0.20)
Spillover CZ		-0.00 (0.04)				
Spillover county region			-0.03 (0.09)			
Spillover 5 closest				-0.05* (0.03)		
Spillover 10 closest					-0.02 (0.01)	
Spillover 25 closest						-0.00 (0.01)
Population growth	0.32*** (0.03)	0.32*** (0.03)	0.32*** (0.03)	0.32*** (0.03)	0.32*** (0.03)	0.32*** (0.03)
Construction p.c.	0.25* (0.14)	0.25* (0.14)	0.25* (0.14)	0.25* (0.14)	0.25* (0.14)	0.25* (0.14)
State × Year × County Type	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes
F-statistic instruments	23.28	23.49	12.71	19.77	16.82	14.52
$R^2$	0.95	0.95	0.95	0.95	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000

*Notes:* The dependent variable is the employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Spillover CZ is investment in all other counties within the same commuting zone (*Raumordnungsregionen*) the county lies in; in total, there are 94 commuting zones. Spillover county region is investment p.c. in all other counties within the same county region (*Kreisregionen*); in total, there are 360 county regions. Spillover 5 closest, 10 closest and 25 closest is investment p.c. in the five, ten and 25 geographically closest counties, respectively. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE 11 – SLACK VS. NON-SLACK TIMES: EMPLOYMENT

	County Mean		State Mean	
	Slack	No Slack	Slack	No Slack
Investment p.c.	0.98* (0.48)	0.55* (0.28)	2.78*** (0.77)	0.35 (0.19)
Population growth	0.36*** (0.03)	0.21*** (0.02)	0.29*** (0.03)	0.25*** (0.03)
Construction p.c.	-0.09 (0.10)	1.17*** (0.28)	0.13 (0.15)	0.57* (0.23)
Controls	yes	yes	yes	yes
State $\times$ Year $\times$ County Type	yes	yes	yes	yes
County FE	yes	yes	yes	yes
F-stat. 1 <sup>st</sup> stage	17.13	34.79	7.85	38.26
$R^2$	0.92	0.92	0.93	0.96
Cluster	94	94	89	93
Observations	2044	1956	1929	2017

*Notes:* The dependent variable is the employment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. In columns (1) and (2), slack is defined as unemployment in  $t - 1$  in a county above the county-mean in the unemployment rate from 2003-2012. In columns (3) and (4), slack is defined as unemployment in  $t - 1$  above the mean of the state of the county from 2003-2012. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004 and all regressions. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

# Appendix

## Figures

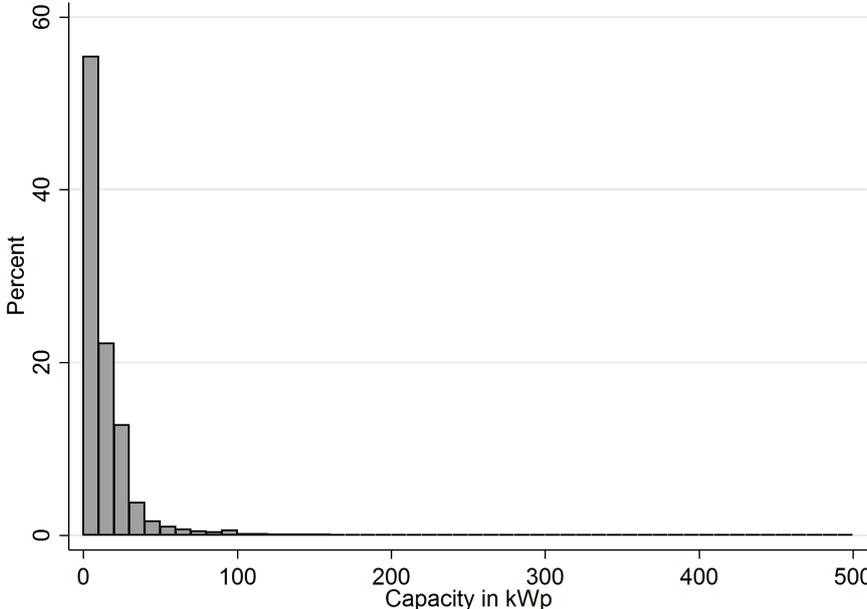


FIGURE A1 – DISTRIBUTION OF CAPACITY

*Note:* Distribution of capacity for photovoltaic systems with fewer than 500 kW<sub>p</sub> capacity (about 95 percent of a total of 1.3 Million systems).

## Tables

TABLE A1 – FIRST STAGE

	Investment p.c.	
	Coeff.	SE
Rooftop potential p.c. $\times$ radiation $\times$ 2004	0.30***	(0.05)
Rooftop potential p.c. $\times$ radiation $\times$ 2005	0.36***	(0.05)
Rooftop potential p.c. $\times$ radiation $\times$ 2007	0.08**	(0.04)
Rooftop potential p.c. $\times$ radiation $\times$ 2008	0.33***	(0.09)
Rooftop potential p.c. $\times$ radiation $\times$ 2009	0.76***	(0.12)
Rooftop potential p.c. $\times$ radiation $\times$ 2010	1.15***	(0.13)
Rooftop potential p.c. $\times$ radiation $\times$ 2011	0.59***	(0.06)
Rooftop potential p.c. $\times$ radiation $\times$ 2012	0.16***	(0.03)
Population growth	0.00***	(0.00)
Construction p.c.	0.03	(0.02)
State $\times$ Year $\times$ County Type	yes	
County FE	yes	
F-statistic instruments	23.28	
$R^2$	0.80	
Clusters	94	
Observations	4000	

*Notes:* Regression for the years 2003-2012. The dependent variable investment p.c. is measured in €100,000 per capita. The year-instrument interactions for 2003 and 2006 are dropped in order to accommodate the two sets of county fixed effects. A separate fixed effect for before 2005 is estimated due to far reaching labor market reforms in 2005. We control for fixed effects for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A2 – CLASSIFICATION OF EMPLOYMENT INTO TREATED, LOCAL SERVICES AND UNTREATED SECTORS

	Comprises (NACE Rev. 1.1 Code)	Share 2003
Treated sectors	Manufacture of electrical machinery and apparatus, n.e.c. (31) Manufacture of electronic valves and tubes and other electronic components (321) Manufacture of instruments and appliances for measuring, checking, testing, navigating (332) Production and distribution of electricity (401) Building installation (453) Building completion (454) Wholesale of machinery, equipment and supplies (518) Other wholesale (519) Other retail sale of new goods in specialized stores (524) Research and experimental development on natural sciences and engineering (731) Architectural and engineering activities (742) Technical testing and analysis (743)	13 %
Local services	Wholesale and retail trade (G), except wholesale of machinery, equipment and supplies (518), other wholesale (519) and other retail of new goods in specialized stores (524) Hotels and restaurants (H)	14%
Untreated sectors	All others	74%

*Note:* The classification into treated sectors was undertaken as follows: First, a random sample of member firms of the German Solar Association that install photovoltaic systems was taken. Second, for these firms the sectoral classification was checked with Creditreform firm profiles, a commercial provider of firm solvency data. All different classifications that were listed for this sample were subsequently categorized as treated.

TABLE A3 – UNEMPLOYMENT SPECIFICATION WITH CONTROL VARIABLES

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Investment p.c.	-0.08 (0.14)	-0.70*** (0.27)	0.09 (0.09)	-0.17 (0.15)	-0.28* (0.17)	-0.27 (0.17)	-0.27 (0.18)
Population growth	0.08*** (0.02)	0.10*** (0.02)	0.02*** (0.01)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)
Construction p.c.	-0.13 (0.10)	0.10 (0.13)	-0.11 (0.08)	-0.07 (0.10)	-0.09 (0.10)	-0.08 (0.10)	-0.11 (0.11)
GDP p.c.				-0.01** (0.00)	-0.01** (0.00)	-0.01** (0.00)	-0.01** (0.00)
Share vocational					0.06*** (0.01)	0.06*** (0.01)	0.06*** (0.01)
Share university					0.05 (0.05)	0.05 (0.05)	0.06 (0.05)
Share agriculture						-0.09 (0.11)	-0.14 (0.14)
Share manufacturing						-0.02 (0.03)	-0.01 (0.03)
Bartik (treated)							-0.01 (0.05)
Bartik (local)							0.03 (0.07)
Bartik (not treated)							-0.02 (0.03)
State × Year × County Type	no	yes	yes	yes	yes	yes	yes
State × Year	yes	no	no	no	no	no	no
Pre-2005 FE	yes	no	yes	yes	yes	yes	yes
Trend	no	no	yes	no	no	no	no
F-statistic 1st stage	32.43	25.60	20.71	22.98	22.32	21.26	19.23
$R^2$	0.95	0.92	0.97	0.95	0.95	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000	3600

*Notes:* The dependent variable is the unemployment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Control variables are described in the text. Trend denotes whether a county-specific trend is included in the regression. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005 in all columns except column 3) as well as for every state × year × county type combination (except for column 1). All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A4 – ROBUSTNESS: UNEMPLOYMENT

	Coeff.	SE	F-stat.	Obs.
Baseline	-0.19	0.15	23.28	4000
Weighted	-0.24	0.16	25.24	4000
Levels weighted 1/population	-0.73***	0.20	20.64	4000
Levels not weighted	-0.76**	0.31	23.01	4000
First Difference	0.05	0.08	24.56	3600
No clustering	-0.19*	0.10	68.23	4000
Only Post 2005	-0.21	0.17	24.79	2800
2000-2012	-0.13	0.15	24.79	5200
Only West	-0.25*	0.15	22.79	3240
Only East	4.29	3.45	14.79	760
Only City	0.75	1.74	5.05	1050
Only Rural	-0.21	0.14	25.03	2950
Alt. county type 1	0.01	0.18	25.23	4000
Alt. county type 2	-0.22	0.16	27.05	4000
Alt. county type 3	-0.07	0.16	29.40	4000
Alt. county type 4	-0.06	0.18	23.47	4000

*Notes:* The dependent variable is the unemployment rate in a county from 2003-2012. In all regressions we control for population growth, new construction and county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination, unless otherwise noted. F-stat. denotes the first stage F-statistic on the instrument interactions. In the baseline case, all variables are normalized by the working age population in 2004 and standard errors are clustered on the level of 94 commuting zones. In the weighted case, the regression is weighted by the working age population in 2004. In the levels specification, absolute levels instead of per capita normalized values are used. In the first difference specification, the second stage equation is estimated in first differences. In the no clustering case, robust standard errors are used. Only West limits the sample to the former West German counties and only East limits them to the states of the former German Democratic Republic. Only City denotes only city-type counties (*Kreisfrei*), whereas only rural denotes all non-city type counties. Alt. county type 1 denotes that instead of the city type county dummy (*Kreisfrei*) we control for every state  $\times$  year  $\times$  urbanization degree interaction where urbanization degree is one of four categories ranging from major city to rural, as classified by the German Federal Office of Building and Regional Planning on the basis of population densities (*Siedlungsstruktureller Kreistyp*). Alt. county type 2 denotes the interactions of state  $\times$  year  $\times$  major city. Alt. county type 3 denotes the interactions of state  $\times$  year  $\times$  major city  $\times$  rural. Alt. county type 4 denotes the interactions of state  $\times$  year  $\times$  city county type (*Kreisfrei*)  $\times$  rural. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A5 – FIRST STAGE: ALTERNATIVE INSTRUMENT (OWNERSHIP OF INDIVIDUALS)

	Investment p.c.		
	(1)	(2)	(3)
Individual ownership p.c. × radiation × 2004	4.80*** (1.13)	4.74*** (1.13)	4.75*** (1.13)
Individual ownership p.c. × radiation × 2005	6.07*** (0.94)	5.98*** (0.94)	6.06*** (0.94)
Individual ownership p.c. × radiation × 2007	1.87** (0.77)	1.88** (0.78)	1.88** (0.77)
Individual ownership p.c. × radiation × 2008	6.68*** (1.78)	6.68*** (1.79)	6.74*** (1.78)
Individual ownership p.c. × radiation × 2009	13.18*** (2.70)	13.15*** (2.72)	13.25*** (2.71)
Individual ownership p.c. × radiation × 2010	18.87*** (3.04)	18.83*** (3.05)	18.90*** (3.04)
Individual ownership p.c. × radiation × 2011	9.45*** (1.69)	9.43*** (1.72)	9.46*** (1.71)
Individual ownership p.c. × radiation × 2012	2.52*** (0.81)	2.26*** (0.84)	2.29*** (0.83)
Population growth		0.00** (0.00)	0.00** (0.00)
Construction p.c.			0.04 (0.03)
State × Year × County Type	yes	yes	yes
Pre-2005 FE	yes	yes	yes
F-statistic instruments	11.23	10.86	11.00
$R^2$	0.75	0.75	0.75
Observations	4000	4000	4000

*Notes:* Regression for the years 2003-2012. The dependent variable investment p.c. is measured in €100,000 per capita. Individual ownership are all residential buildings owned by one private individual, as taken from the 2011 Census. The year-instrument interactions for 2003 and 2006 are dropped in order to accommodate the two sets of county fixed effects. A separate fixed effect for before 2005 is estimated due to far reaching labor market reforms in 2005. We control for fixed effects for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A6 – SPILLOVERS FROM NEIGHBORING COUNTIES: UNEMPLOYMENT

	(1)	(2)	(3)	(4)	(5)	(6)
Investment p.c.	-0.19 (0.15)	-0.16 (0.16)	-0.20 (0.15)	-0.24* (0.14)	-0.24 (0.14)	-0.24* (0.14)
Spillover CZ		-0.02 (0.03)				
Spillover county region			0.13** (0.06)			
Spillover 5 closest				0.02 (0.02)		
Spillover 10 closest					0.01 (0.01)	
Spillover 25 closest						0.00 (0.01)
Population growth	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)	0.08*** (0.02)
Construction p.c.	-0.08 (0.10)	-0.09 (0.10)	-0.07 (0.10)	-0.08 (0.10)	-0.08 (0.10)	-0.08 (0.10)
State × Year × County Type	yes	yes	yes	yes	yes	yes
Pre-2005 FE	yes	yes	yes	yes	yes	yes
F-statistic instruments	23.28	23.49	12.71	19.77	16.82	14.52
$R^2$	0.95	0.95	0.95	0.95	0.95	0.95
Observations	4000	4000	4000	4000	4000	4000

*Notes:* The dependent variable is the unemployment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. Spillover CZ is investment in all other counties within the same commuting zone (*Raumordnungsregionen*) the county lies in; in total, there are 94 commuting zones. Spillover county region is investment p.c. in all other counties within the same county region (*Kreisregionen*); in total, there are 360 county regions. Spillover 5 closest, 10 closest and 25 closest is investment p.c. in the five, ten and 25 geographically closest counties, respectively. Population growth is the working age population in year  $t$  divided by the working age population in 2004. Construction p.c. is new construction of residential and non-residential buildings in a county. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state × year × county type combination. All variables are normalized by the working age population in 2004. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A7 – SLACK VS. NON-SLACK TIMES: UNEMPLOYMENT

	Slack	No Slack	Slack	No Slack
Investment p.c.	-0.04 (0.27)	0.20 (0.11)	-1.15 (0.72)	0.03 (0.08)
Population growth	0.08*** (0.02)	0.04*** (0.01)	0.04 (0.02)	0.03** (0.01)
Construction p.c.	0.05 (0.11)	0.02 (0.12)	-0.00 (0.14)	0.04 (0.10)
Controls	yes	yes	yes	yes
State $\times$ Year $\times$ County Type	yes	yes	yes	yes
County FE	yes	yes	yes	yes
F-stat. 1 <sup>st</sup> stage	17.13	34.79	7.85	38.26
$R^2$	0.92	0.83	0.93	0.93
Cluster	94	94	89	93
Observations	2044	1956	1929	2017

*Notes:* The dependent variable is the unemployment rate in a county from 2003-2012. Investment p.c. is investment in €100,000 p.c. in photovoltaic systems in a county from 2003-2012. In columns (1) and (2), slack is defined as unemployment in  $t - 1$  in a county above the county-mean in the unemployment rate from 2003-2012. In columns (3) and (4), slack is defined as unemployment in  $t - 1$  above the mean of the state of the county from 2003-2012. In all regressions we control for county fixed effects (a separate set of fixed effects for before 2005 is estimated due to far reaching labor market reforms in 2005) as well as for every state  $\times$  year  $\times$  county type combination. All variables are normalized by the working age population in 2004 and all regressions. Standard errors are clustered on the level of 94 commuting zones. \*\*\*, \*\*, \* denote significance on the 1 percent, 5 percent and 10 percent level, respectively.

TABLE A8 – CATEGORIES OF MUNICIPALITIES

Category	Very Rural	Rural	Suburban	Urban
Population	$\leq 2000$	$\leq 5000$	$\leq 20000$	$> 20000$
Population Density (per km <sup>2</sup> )	$\leq 100$	$\leq 200$	$\leq 300$	$> 300$
Settlement Area (in km <sup>2</sup> )	$\leq 0.4$	$\leq 0.8$	$\leq 1.5$	$> 1.5$
Living Area p.c. (in m <sup>2</sup> )	$> 48$	$> 45$	$> 42$	$\leq 42$
Number of Apartments	$\leq 1.4$	$\leq 1.6$	$\leq 1.8$	$> 1.8$
Number of Municipalities	4899	4454	1973	966

*Note:* Thresholds for categorization of municipalities in one of four categories (very rural, rural, suburban, urban) and total number of municipalities in each category. Thresholds and categories are taken from Lödl et al. (2010).

## Estimating Rooftop Potential

Lödl et al. (2010) estimate the feasible rooftop potential in Germany in four steps. First, they digitalize aerial maps of 4,500 dwellings in the state of Bavaria to obtain average measures of rooftop potential for different settlement types (very rural, rural, suburban, urban). Second, they categorize all municipalities in Bavaria into their four settlement types. Third, they multiply the settlement area in each municipality with the average measures of rooftop potential per km<sup>2</sup> of settlement area to obtain their overall measure of rooftop potential. In a last step, they extrapolate their results for Bavaria via the housing stock to all other German states. In total, they estimate that there are 161 GW<sub>p</sub> of rooftop potential in Germany.

We follow the approach of Lödl et al. (2010) in the following way. First, we categorize all 11,000 municipalities in Germany into one of the four settlement types. We use the same indicators as Lödl et al. (2010), which are population, population density, settlement area, living area p.c. and the number of apartments per building. The thresholds for the individual categories can be found in Table A8. Since a municipality may be in one category for some indicators and in another category for other indicators, we need to decide on an aggregation rule. We therefore assign one point each for each characteristic that falls into the very rural category, two for each that falls into the rural category, three for each in the suburban and four for each in the urban category. Thus, a municipality can reach between 5 and 20 points. All municipalities with more than 17 points are classified as urban, 13 to 16 points are suburban, 8 to 12 are rural and less than 8 are very rural. The number of municipalities in each category can be found in Table A8. The vast majority of municipalities is very rural or rural.

In a second step, we then multiply the settlement area in each municipality with the constants found by Lödl et al. (2010) for each category and aggregate this to the county level. Overall, we estimate a rooftop potential of 123 GW<sub>p</sub> for Germany as a whole. This is in line with other exercises; Kaltschmitt and Wiese (1993) estimate 53 to 116 GW<sub>p</sub>, Quaschnig (2000) 120 GW<sub>p</sub> and Lödl et al. (2010) 161 GW<sub>p</sub>. Despite using the same method as Lödl et al. (2010), we estimate a rooftop potential that is about 25 percent

smaller. The reason for this is threefold. First, they extrapolate the values from Bavaria to Germany via the housing stock. This induces measurement error, as for example in North Rhine-Westphalia the housing stock is very large but rooftop potential may be low due to the high degree of urbanization.<sup>21</sup> Second, we omit Berlin and Hamburg from our data for which Lödl et al. (2010) estimate a rooftop potential of 2.4 and 1.8  $\text{GW}_p$ , respectively. Third, they do not specify their tie-breaking rule for a municipality that has, for example, 2 urban indicators and 2 suburban ones (and 1 rural or very rural one). Hence, we might categorize some municipalities in a different way.

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<sup>21</sup> For Bavaria, our estimate is less than 6 percent smaller whereas for mostly urban North Rhine-Westphalia it is only 57 percent of the Lödl et al. (2010) estimate.