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Abstract

Using European Commission real-time data, we show that potential output (PO) estimates were substantially and persistently revised downwards after the Great Recession. We decompose PO revisions into revisions of the capital stock, trend labor, and trend total-factor productivity (TFP). Initially, trend TFP revisions contribute most to the overall PO revisions while all three components are almost equally important in the longer run. Revisions of the capital stock happen quickly while revisions of trend labor, mainly driven by revisions of the non-accelerating wage rate of unemployment (NAWRU), are made gradually. The relative contributions of the components to overall PO revisions differ systematically across countries. This suggests that heterogeneous policies are needed to push different countries back to their previous growth paths.

JEL-Codes: E320.

Keywords: potential output, trend, output gap, hysteresis, EC.

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1 Introduction

Estimates of potential output (PO) were substantially revised downwards for many European countries after the Great Recession that started in 2008/09. Ten years later, they still remain below their pre-recession trends. In this paper, we use real-time estimates of PO and its components published by the European Commission (EC) to analyze in detail how much, how fast, and how persistently those estimates have been revised downwards. Furthermore, we investigate whether we can identify important cross-country differences in terms of the magnitude of revisions or the relative contribution of revisions to individual components of PO.

The Great Recession was triggered by the bursting of the US housing market bubble that started in 2006. As private investment and consumption growth slowed down, the US economy slipped into a tough recession. The crisis spread to other countries both through the financial system and via trade linkages, eventually evolving into a full-blown global economic crisis. World gross domestic product (GDP) contracted in 2009 for the first time since 1991. Even more importantly: the recession was exceptionally long and the recovery process was slow. The Washington Post (2018) summarizes that the "recession profoundly shaped the decade that followed." In Europe, the sovereign debt crisis prolonged the recession. Real GDP of the euro area, for example, did not return to its pre-crisis peak of 2008Q1 until the end of 2014. Although the unemployment rate for the euro area has decreased since 2014, it is still about half a percentage point higher than before the recession. For some of the heavily hit countries in the euro area the situation is much worse. Overall, this suggests that the Great Recession affected the production capacities of many economies substantially and persistently.

PO is a measure that is commonly used to quantify these long-term production capacities. In modern macroeconomics, it is an important factor when deciding on monetary or fiscal policy. Measurement error can lead to poor policy decisions. Since PO is defined to proxy the sustainable long-run level of output, it should in principle be independent of cyclical (temporary) fluctuations. However, it reacts to supply shocks that lead to a reassessment of trend total-factor productivity (TFP). Moreover, PO revisions could be driven by demand shocks in the presence of hysteresis. Such hysteresis effects can potentially work through the different components of PO. If the hysteresis effects caused

structural changes in the labor market, we would expect revisions of the trend of aggregate labor input. If they worked through a depreciation of the capital stock or a decline of investment in physical capital, we would expect estimates of the capital stock to be revised. Finally, if they caused a decline in R&D investment, we would expect revisions of trend TFP. A third explanation for PO revisions is that previous estimation errors are simply corrected. In this paper, we use real-time data on PO revisions made by the EC to quantify how much revisions of each component of PO contributed to the overall PO revision for the member countries of the European Union (EU) in the decade following the Great Recession.

We document three main findings. First, revisions of estimates of PO and components were substantial and permanently lowered after the Great Recession. Second, the size of the revisions and the the relative contribution of component revisions differ systematically between country groups. Third, revisions of the trend of aggregate labor input are predominantly driven by revisions of the non-accelerating wage rate of unemployment (NAWRU), but also migration within the EU can explain a substantial part of those revisions.

Our paper contributes to two strands of the literature. First, it is related to research on the long-term economic effects of recessions and financial crises. Cerra and Saxena (2008, 2017) show that *output* follows a permanently lower growth path after financial crises or currency crises between 1960 and 2001. Reinhart and Rogoff (2009, 2014) extend their results by showing that financial crises negatively affect a large set of variables, such as employment and government debt. Blanchard et al. (2015) find that regular recessions tend to dampen the output level as well. Later studies present evidence that revisions of *potential* output exhibit a similar pattern in response to recessions and financial crises. Using ex-post data, Martin et al. (2015) show for 23 countries of the Organisation for Economic Co-operation and Development (OECD) for a sample of 40 years that PO growth decreases permanently after recessions. Benati (2012) provides evidence that PO estimates are persistently lower in four major economies following the Great Recession by applying a structural vector autoregression framework to ex-post data. Using a comprehensive real-time data set on PO level estimates, Dovern and Zuber (2019) show that downward revisions of PO estimates after recessions are substantial for a sample of 26 advanced economies between 1989 and 2017. Ball (2014) finds similar effects on PO

after the Great Recession by comparing pre-crisis PO forecasts with ex-post estimates. Coibion et al. (2018) document that experts revised estimates of PO growth downwards in response to the Great Recession due to both transitory and permanent economic shocks. This paper contributes by systematically documenting revisions of PO *level* estimates for all EU countries after the Great Recession.

Second, this paper contributes to the discussion on which components drive the decline of PO estimates after recessions. To our knowledge, there exist only a few studies which focus on the PO components. Using ex-post data in a production function approach, Furceri and Mourougane (2012) show for 30 OECD countries between 1960 and 2008 that the reduction in the capital stock accounts for most of the permanent decrease of PO after financial crises. Similarly, Haltmaier (2012) provides evidence that the capital-output ratio is the single most important contributor to lower trend output per capita after general recessions for a sample of ten OECD countries while declines in trend employment and participation rates contributed to a fall of trend output only in some of the countries. With special focus on the Great Recession in the US, Hall (2014) documents that a deterioration of the capital stock and lower TFP were the main drivers of permanently lowered trend GDP.[1] Our paper is the first that systematically analyzes the contributions of the revisions of components to the overall PO revision for a comprehensive real-time data set and a large country sample. By tracking revisions in real time, we provide information on the relationship of component revisions across time and how experts exactly revise their estimates.

The remainder of this paper is structured as follows. We present our data and explain the methodology behind the PO estimates in Section 2. Section 3 contains our empirical results. We first focus on revisions of PO estimates and then analyze the contributions of the component revisions to the revisions of overall PO. Section 4 concludes.

2 Data

2.1 Real-Time Vintages

Our main real-time data are from two sources published by the EC in spring ("I") and autumn ("II") of each year. First, the European Economic Forecast (EEF) contains esti-

[1] Fernald (2015) confirms this finding over a larger time frame and argues that PO returned to a lower path after the exceptionally high TFP growth during the 2000s ended.

mates of the PO level, the estimated contributions to PO growth (capital, trend labor, and trend TFP), and the estimated contributions to trend labor growth (the actual working-age population, the trend labor force participation rate, the NAWRU, and trend hours worked per head). All variables are published along with four- to five-years-ahead forecasts. Second, the Annual Macro-economic Database (AMECO) contains macroeconomic time series (such as the level of the working-age population between 15 and 64 years) along with forecasts for one year ahead. Our sample contains 27 data vintages ranging from autumn 2005 to autumn 2018. It covers all EU27 countries.[2] The vintages contain annual data starting in 1965 or in some cases later (e.g. the time series for Germany start in 1991 due to the reunification and data for Central and Eastern European countries start at different points in the 1990s).

The use of the EC data is appealing for the following three reasons: First, it allows us not only to track PO revisions across different vintages but also to decompose these revisions into revisions of estimates of the capital stock, trend labor (which we can further decompose into detailed labor market components), and trend TFP. Second, the data allow us to analyze revisions during the Great Recession for all EU member countries. Third, the data are comparable across countries since the EC uses a production function approach to estimate PO that differs only slightly in terms of parameterization across the member countries.

The EC assumes that PO is generated by a standard Cobb-Douglas production function

$$\overline{Y}_{i,t} = \overline{A}_{i,t}\, \overline{L}_{i,t}^{\alpha}\, K_{i,t}^{1-\alpha} \tag{1}$$

with a common labor share $\alpha = 0.65$ for all countries i and years t. Bars above variables denote the trend of the variable. PO is composed of three components: Trend TFP, $\overline{A}$, is estimated using a state-space model that decomposes TFP into a trend and a cycle and relates the latter to the degree of capacity utilization. Capital, K, is the unfiltered capital stock which is calculated from consumption of fixed capital. Trend labor, $\overline{L}$, corresponds to the trend of total hours worked and is calculated as the product of trend employment

[2] The EU27 countries are Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

(which is the product of the actual working-age population, N, the trend labor force participation rate, $\overline{PR}$, and 1 minus the NAWRU, $\overline{UR}$), and the trend of average hours worked per head, $\overline{H}$:

$$\overline{L}_{i,t} = N_{i,t}\,\overline{PR}_{i,t}\,(1 - \overline{UR}_{i,t})\,\overline{H}_{i,t}\,. \tag{2}$$

The EC applies a Hodrick-Prescott (HP) filter to the the labor force participation rate and the average hours worked in order to extract the trend components. The NAWRU is obtained from a state-space model that decomposes the unemployment rate into a trend and a cyclical component making use of the Phillips curve relationship.

2.2 Normalization of Potential Output Data

Changes in the unit of measurement (e.g. due to the adoption of the euro) and/or base years require that we normalize PO to make it comparable across vintages and countries. Figure 1 shows the raw PO level estimates for Italy from all 27 available vintages. Pictures for other countries contain similar breaks between the vintages.

We normalize PO by the deviation of PO for the year $t_0 = 2000$ in vintage v from PO for t_0 in the first available vintage v_{min} for country i:

$$\overline{Y}^{v}_{i,t} = \widetilde{Y}^{v}_{i,t} \cdot \widetilde{Y}^{v_{min}(i)}_{i,t_0} / \widetilde{Y}^{v}_{i,t_0}\,. \tag{3}$$

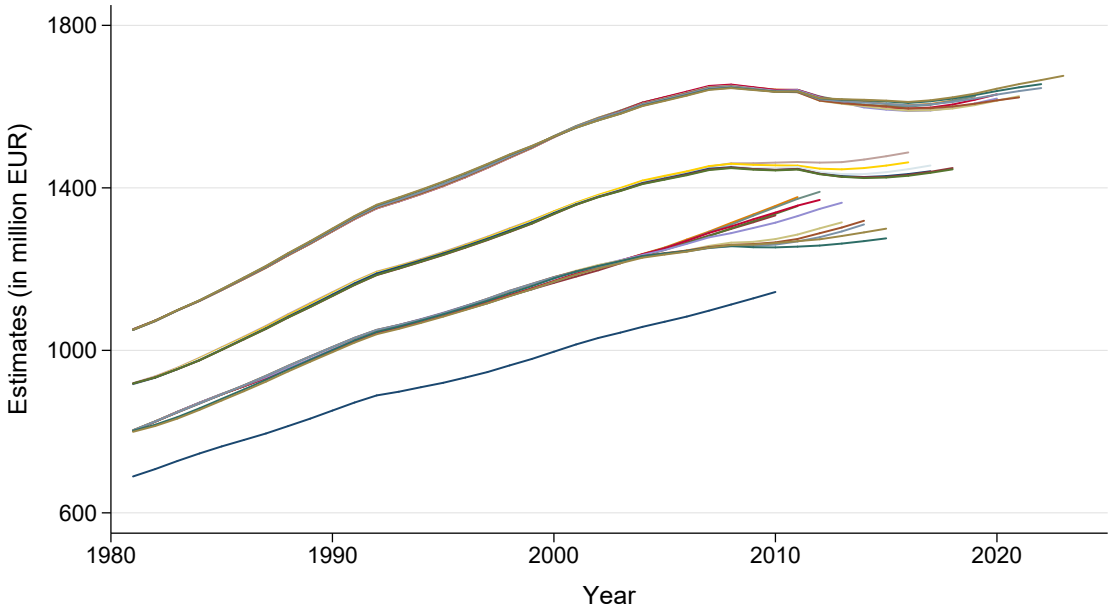
We obtain the raw level of PO, $\widetilde{Y}$, directly from the EEF vintages. The first available vintage v_{min} is 2005:II except for Bulgaria and Romania for which estimates are not reported before 2007:I. We choose $t_0 = 2000$ since it is the earliest common year for which we can normalize PO for all countries and almost all vintages.[3] This implicitly assumes that the level of PO for the year 2000 is no longer revised after 2005 but rather changes only due to changes in the base year or units of measurement.

2.3 Construction of Levels of Potential Output Components

Unfortunately, information about the estimated level of the components of PO is not available in vintages from before 2014:I. Therefore, we need to construct "synthetic"

[3] In the vintages 2014:I–II, time series of Bulgaria and Romania do not start before 2003. We therefore do not use these two vintages for the two countries.

Figure 1: Raw data vintages of PO estimates for Italy



Notes: The plot shows estimates of PO for Italy from different EC vintages (subject to base year changes). Each line represents a time series from on particular vintage.

levels of components. For the capital stock, trend labor, trend average hours worked per head, and the actual working-age population, we do this by resorting to information provided about the contributions of those variables to PO growth. For $X = \{K, \overline{L}, \overline{H}, N\}$, we compute the level as follows

$$X^v_{i,t+1} = (1 + \dot{x}^v_{i,t+1})\, X^v_{i,t} \tag{4}$$

where $t > t_0$, X^v_{i,t_0} is fixed, and $\dot{x}$ denotes the annual growth rate of the component X as implied by the growth contribution provided by the EC.[4] We choose $t_0 = 2000$ for all countries i and vintages v and set X^v_{i,t_0} to 100. We do not choose an earlier year t_0, because we have time series of growth rates which do not start before. By setting all series to the same value in the year 2000, we implicitly normalize the synthetic variables.

We obtain the levels of the remaining components as follows. First, we calculate trend TFP as a residual from equation (1) using the normalized level of PO and the synthetic levels of the capital stock and trend labor. Second, we use the synthetic levels of trend

[4]For instance, we multiply the growth contribution of trend labor by one divided by the labor share to get the annual growth rates.

labor, the actual working-age population, and the trend average hours worked per head together with estimates of the NAWRU (which we obtain directly from the EEF) to calculate the trend labor force participation rate as a residual according to equation (2).

Our choice to compute the trend labor force participation rate as a residual is not arbitrary. Since vintage 2013:I, the EC has used the working-age population between 15 and 74 years. Until 2012:II, the age bracket had been 15 to 64 years. Without adjustment this would imply a systematic upward revision of the working-age population and a downward revision of the the trend labor force participation rate. We avoid this methodological revision by using the working-age population between 15 and 64 years for all vintages. For vintages before 2013:I, we obtain the growth rates directly from the EEF. From 2013:I onwards, we resort to the growth rates implied by the level series provided by AMECO.

3 Empirical Results

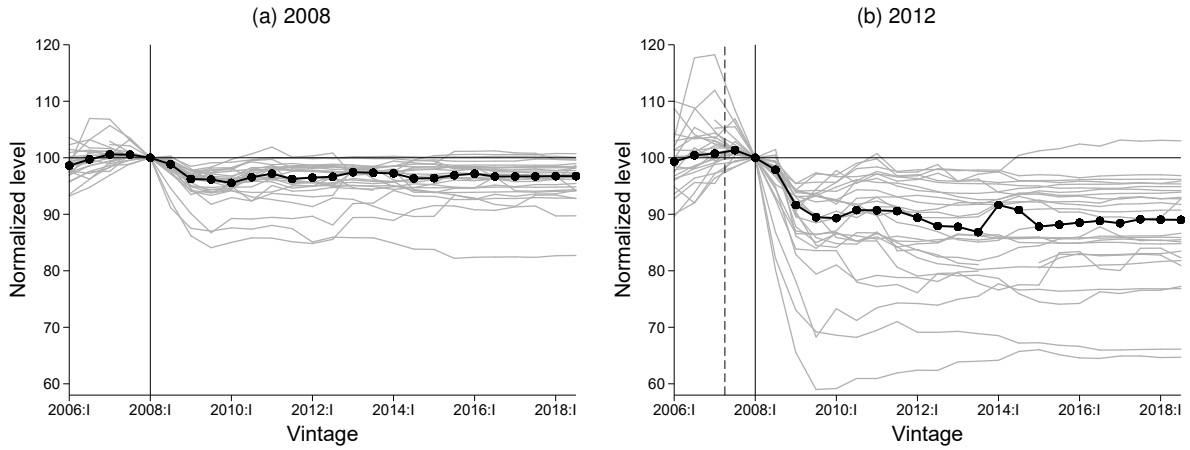
3.1 Revisions of Potential Output Levels

We begin our analysis by tracking how the EC revises its PO estimates for specific years following the Great Recession. To make estimates comparable across countries, we normalize them such that the PO estimate in year t and vintage 2008:I is 100 for each country. The choice of the vintage 2008:I as the first recession vintage is driven by the data. 14 EU economies are in a recession in the second qaurter of 2008 and six additional economies slip into a recession in 2008Q3. Hence, we will refer to 2008 as the first recession year for all countries.[5] Figure 2 shows the median revisions of PO estimates for the years 2008 and 2012.

Three characteristics stand out: First, the median revisions are substantial and increase the longer the forecast horizon is. The PO estimate for 2008 is, on average, revised by more than -3 % in the long run. For 2012, the median PO estimate for 2018:II is revised by nearly -12 %. For many countries, especially the Baltic states, the PO revisions are much larger. For 2012, the PO estimates for the Baltic states in 2018:II are less

[5] We use the simple method of Harding and Pagan (2002) to identify recessions based on quarterly real GDP. The algorithm searches for business cycle peaks and troughs requiring a cycle length of five quarters and a length of each business cycle phase of at least two quarters. Table A.1 in the appendix summarizes the identified recessions.

Figure 2: Revisions of PO estimates after the Great Recession



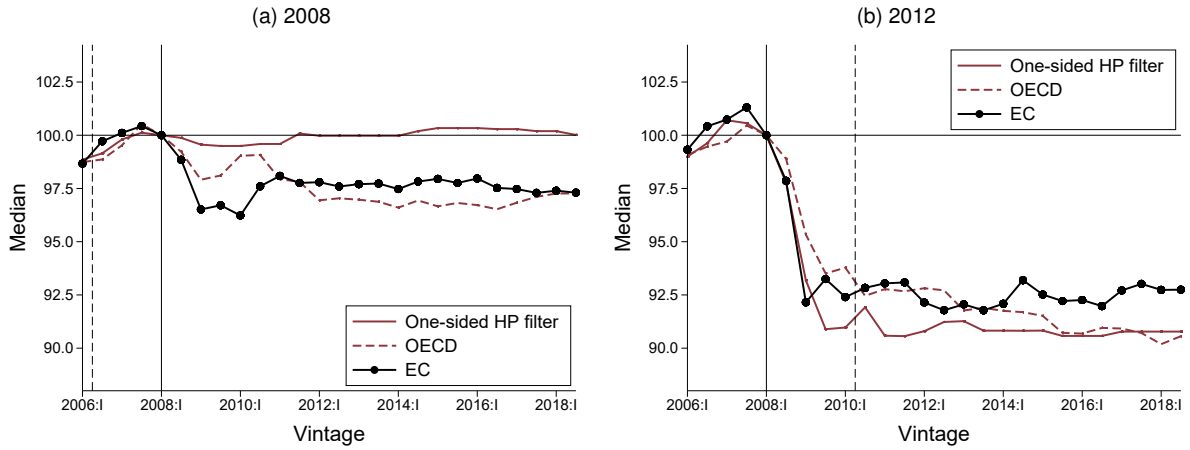
Notes: The plots show the median revisions of the EC's PO estimates for 2008 and 2012 across different vintages. Grey lines represent single country revisions. Levels are normalized such that they are 100 in 2008:I for every country and year. Values to the left of the dashed line are extrapolated as in Dovern and Zuber (2019). For 2014:I and 2014:II, estimates are missing for Bulgaria and Romania.

than 80 % of their pre-crisis levels. Second, most of the median revisions of PO are made within one year (equivalent to two vintages). PO estimates remain persistently below the pre-crisis estimates. Fluctuations afterwards are country-specific and small.[6] Third, revisions are very heterogeneous in magnitude across countries but positive revisions are scarce. The standard deviation of PO estimates measured in the most recent vintage triples from three for 2008 to more than nine for 2012. For 2008, PO is almost unrevised for Germany and slightly positive revised for Malta. Estonia experienced the largest PO revision for 2008 (almost −19 % measured in the most recent vintage). In 2012, Malta remains the only country for which PO estimates are above the pre-crisis level. With values of less than −30 %, the PO revisions in Estonia and Latvia are largest in 2018:II.

To evaluate the size of revisions, we need to consider alternative PO estimates. First, we use estimates from a purely statistical application. We obtain these estimates by applying the one-sided HP filter (with $\lambda = 100$) to annual time series of real GDP (and additional GDP forecasts) in each vintage. The use of the one-sided HP filter is appealing since it is only backward looking in contrast to the two-sided HP filter. Thus, only data revisions for previous years but not future realizations can change the trend today. Second, we use PO estimates from the OECD Economic Outlook. These estimates are especially interesting because the OECD uses a production function approach to estimate PO as

[6]The median revision for 2012 temporarily jumps in 2014:I and 2014:II due to the missing estimates for Bulgaria and Romania.

Figure 3: Comparison of PO revisions from the EC, OECD, and the HP filter



Notes: The plots show the median revisions of PO estimates obtained from the one-sided HP filter for 2008 and 2012 across different vintages. For comparison, we show the median PO revisions of the OECD and EC. Medians are normalized such that they are 100 in 2008:I for every year. Estimates of the OECD and the HP filter which are to the left of the dashed line are extrapolated as in Dovern and Zuber (2019). We omit the extrapolation line of EC estimates in (b) to keep things simple (see Figure 2). The medians are based on 17 countries (Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, Spain, Sweden, and the United Kingdom) since they are covered by both institutions.

well. We normalize both sets of PO estimates in the same way as we normalize the EC's PO estimates. Unfortunately, the OECD only provides PO estimates for a subsample of European countries. To make estimates for the comparison of the different estimates comparable, we concentrate on those 17 countries which are covered by both the EC and the OECD.[7]

Two points are noteworthy in Figure 3. First, the EC revises the PO estimates much more quickly than the OECD. This is especially evident for 2012. While the EC PO estimate for 2012 is hardly revised after vintage 2009:I (revisions range from −6.75 % to −8.25 %), the OECD PO estimate in the same year is continuously revised downwards (from around −5 % in 2009:I to nearly −10 % in 2018:II). Second, the EC median revisions are similar or more moderate compared to the OECD revisions in the long run. For 2008, the revision is roughly −3 % until 2018:II for the estimates of the EC and OECD. Since the one-sided HP filter is purely backward looking, we do not see any revision for 2008. For 2012, both alternative estimates are about two percentage points lower than the EC median in 2018:II. We conclude that the EC PO estimates are the least revised estimates

[7]The EU countries covered by both institutions are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, Spain, Sweden, and the United Kingdom.

in the set of available alternatives. The gradual revisions of the OECD indicate that the OECD attributes a larger part of the PO estimate to cyclical factors than the EC does.

3.2 Revisions of Potential Output Components

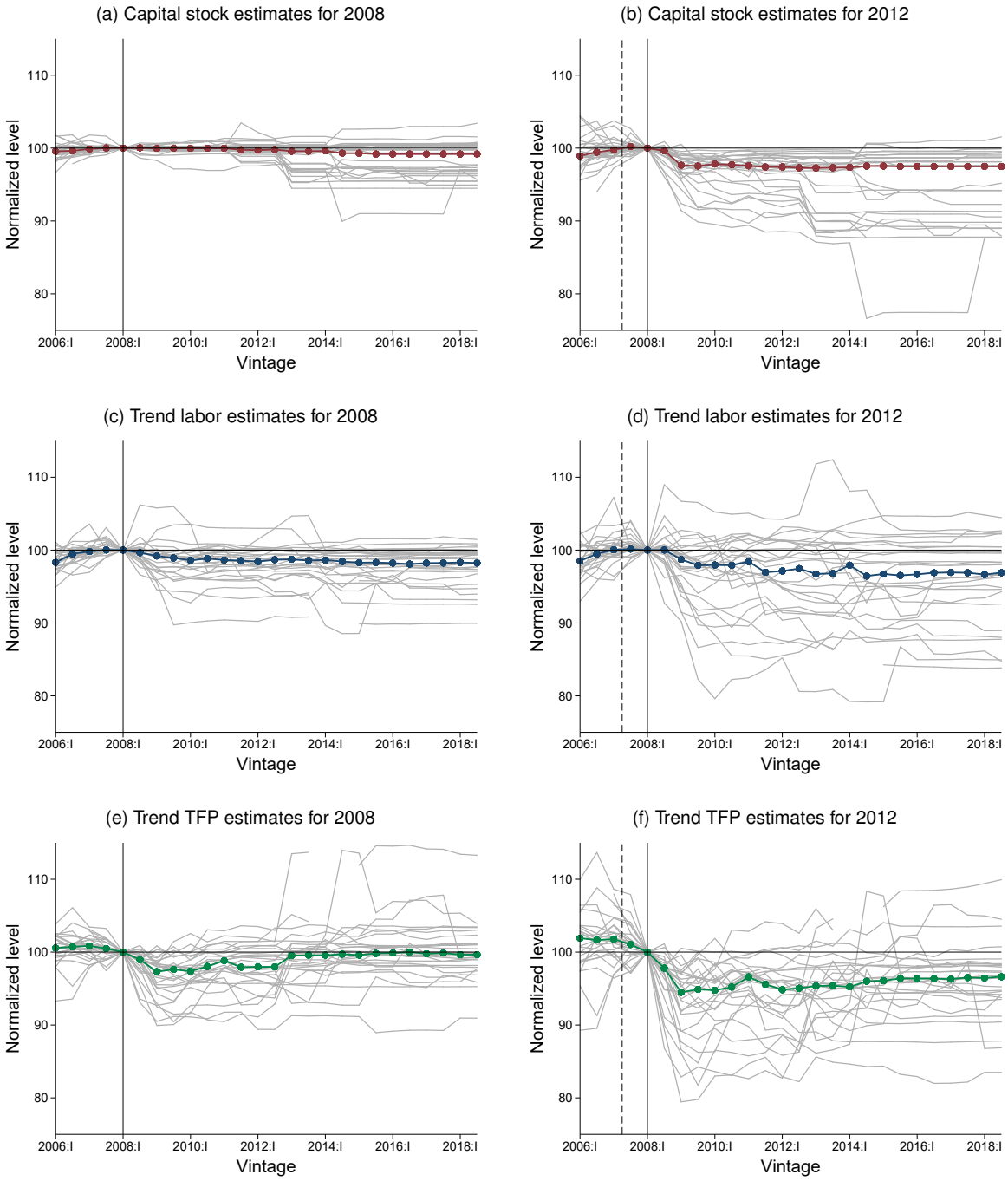
The data allow us to break down PO revisions into revisions of the capital stock, trend labor, and/or trend TFP. Figure 4 shows the median revisions of the three PO components after the Great Recession. As for PO before, we apply a normalization such that the values in vintage 2008:I for the shown years are equal to 100.

The median component estimates stay persistently below the pre-crisis value in five of the six cases. For 2008, median revisions of trend labor are largest (-1.8 %) followed by small revisions of the capital stock (-0.8 %), with no visible revisions of trend TFP. For 2012, the median revisions are more balanced between the components, ranging from -2.5 % (capital stock) to -3.4 % (trend TFP) for the most recent vintage. The median revisions show further that the revision of trend labor is gradual especially for the year 2012. The EC seems to continuously receive new information on the labor market and updates its trend labor estimates accordingly to lower values. In contrast, the revision of the capital stock is a one-off revision within one year after the recession started. Between 2008:II and 2009:I, the estimate of the capital stock for 2012 is revised by -2 % which is already more than three quarters of the long-run capital stock revision. The capital stock is estimated and projected using forecasts of the investment ratio. Sudden revisions of the investment ratio translate immediately into revisions of the capital stock since the EC does not filter the latter. Therefore, we do not observe gradual adjustments to the capital stock revisions.[8] For 2012, the median investment ratio is, for instance, revised by -1.7 percentage points between 2008:II and 2009:I.

To measure how much, on average, the revisions of a component contribute to the overall PO revisions, we calculate the deviation of the level of variable X in vintage v_k from the level in vintage $v_0 = 2008$:I for the years $t = \{2008, 2012\}$. Specifically, we calculate for $X = \{\overline{Y}, K, \overline{L}, \overline{A}\}$ the log difference $\Delta x_{i,t}^{v_0 \to v_k} = \log(X_{i,t}^{v_k}) - \log(X_{i,t}^{v_0})$. By

[8] If the capital stock was estimated by an HP filter, the weights for the end-of-sample years would change continuously with each data vintage that contains revised or new forecasts.

Figure 4: Revisions of estimates of PO components after the Great Recession



Notes: The plots show the median revisions of the EC's component estimates for 2008 and 2012 across different vintages. Grey lines represent single country revisions. Levels are normalized such that they are 100 in 2008:I for every country and year. Values to the left of the dashed line are extrapolated as in Dovern and Zuber (2019). For 2014:I and 2014:II, estimates of trend labor and trend TFP are missing for Bulgaria and Romania.

Table 1: Revisions of estimates after the Great Recession

		Change vs. vintage 2008:I (in %)					
		2006:I	2007:I	2009:I	2010:I	2013:I	2018:II
2008	PO	−1.61	0.53	−4.81	−5.03	−3.92	−4.05
	Capital stock	−0.44	−0.13	−0.10	−0.07	−1.39	−1.57
	Trend labor	−1.54	−0.14	−1.17	−1.88	−1.76	−2.37
	Trend TFP	0.37	0.80	−3.54	−3.08	−0.77	−0.11
2012	PO	$-1.11^{\dagger}$	$1.93^{\dagger}$	−12.09	−13.61	−14.67	−13.95
	Capital stock	$-0.67^{\dagger}$	$-0.14^{\dagger}$	−2.68	−3.29	−5.30	−5.39
	Trend labor	$-1.46^{\dagger}$	$0.24^{\dagger}$	−2.18	−3.85	−4.37	−4.37
	Trend TFP	$1.02^{\dagger}$	$1.83^{\dagger}$	−7.23	−6.47	−5.00	−4.19

Notes: The table reports full sample mean revisions of PO and the three PO components. † indicates that the computation of the result involves our extrapolation of estimates as in Dovern and Zuber (2019).

doing so, we can decompose PO revisions into revisions of the three components:

$$\Delta\overline{y}_{i,t}^{v_0\to v_k} = \Delta\overline{a}_{i,t}^{v_0\to v_k} + \alpha\Delta\overline{\ell}_{i,t}^{v_0\to v_k} + (1-\alpha)\Delta k_{i,t}^{v_0\to v_k}\,. \tag{5}$$

Table 1 shows the mean revisions of PO and the contributions of PO components for the years 2008 and 2012 across different vintages. We find that trend TFP revisions dominate in the short run while in the long run revisions of trend labor and the capital stock are more prominent. In vintages which are shortly after the first recession vintage 2008:I, revisions of trend TFP account for 74 % (59 %) of the overall PO revision for 2008 (2012). Compared to the most recent vintage, revisions of trend labor (59 %) account for the most of the overall PO revision for 2008 and revisions of the capital stock (39 %) account for the most for 2012. The strong reaction of trend TFP in the short run suggests that trend TFP revisions may lead revisions in the capital stock and/or trend labor. Experts initially attribute the PO revisions to negative technology shocks but revise this view by putting more emphasis on labor market changes and a reduced capital stock.

Although the EC changed the calculation of the components over the vintages, these changes do not systematically drive our results. In our sample, we identify four major changes in the methodology.[9] First, since 2010:II, the EC has used a Kalman filter to estimate trend TFP. Before, the EC had used an HP filter approach which was more revision

[9]Unfortunately, the EC does not provide one single document which lists all the methodological changes in our sample. We used the EC's technical papers by Denis et al. (2006), D'Auria et al. (2010), and Havik et al. (2014) to identify important methodological changes.

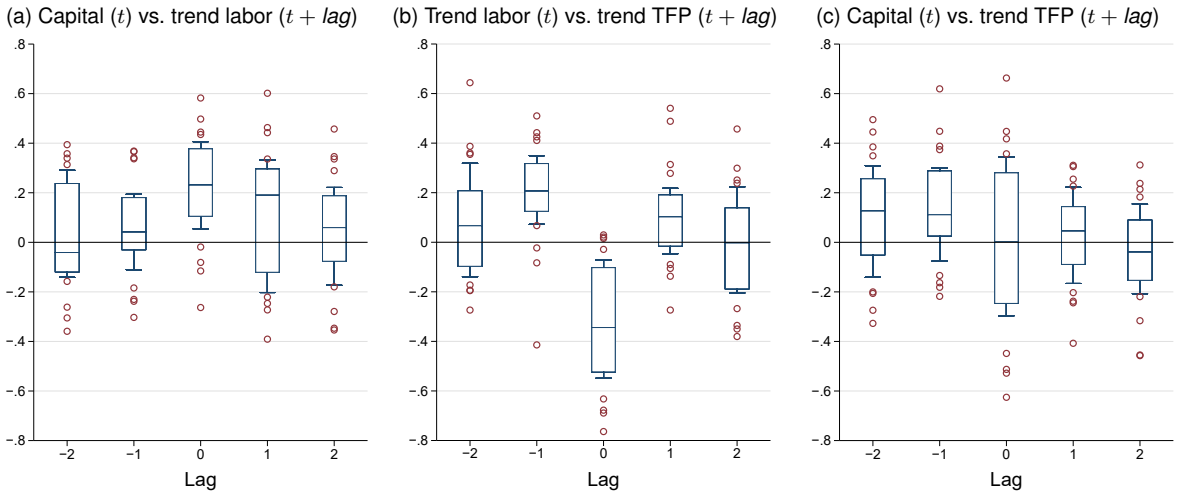
prone and returned less realistic estimates in the short and medium run. Second, the EC switched in 2013:I from measuring the capital stock by the perpetual inventory method to using the capital stock series by AMECO which builds on data on the consumption of fixed capital. Especially for newer member states with a limited history of data points, this leads to large changes. Third, since 2014:I, the EC has used a non-centered NAWRU for three quarters of the countries and has changed how it extends the NAWRU forecasts. Fourth, also since 2014:I, the European System of National and Regional Accounts (ESA) 2010 replaced the previous accounting standard ESA 95. Carefully inspecting Figure 4, we find that the medians in the vintages before the methodological changes are roughly the same as the medians in the vintages shortly after the methodological change. A closer look at the single revisions of each country at the three time points reveals that estimates of trend labor or trend TFP are not systematically revised upwards or downwards in 2010:II or 2014:I. For capital, we observe downward revisions for some countries from 2012:II to 2013:I (and to a lesser extent from 2013:II to 2014:I) but they do not affect the median.[10]

We investigate the relative timing of the revisions by looking at the correlations between revisions to the PO components. We calculate a revision time series for each PO component $X = \{K, \overline{L}, \overline{A}\}$ and country i according to $\Delta x_{i,t}(v_k) = \log(X_{i,t}^{v_k}) - \log(X_{i,t}^{v_{k-1}})$ where year t is the maximum year available in both vintages.

Figure 5 shows the distributions of pairwise correlations between those time series across countries. Three correlations stand out: First, revisions of trend labor and the capital stock contemporaneously tend to move in the same direction. The median correlation is 23 %. In a boom, higher labor demand leads to a downward revision of the NAWRU and therefore to an upward revision of trend labor. At the same time, the investment ratio is revised upwards leading to a positive revision of capital. Second, the median of the contemporaneous correlation between trend labor and trend TFP is −34 %. The revisions of the two components contemporaneously move in opposite directions. Only for three countries the correlations between those revision series are slightly positive. Experts initially seem to attribute changes in PO to technology shocks. Later, they revise this view by putting more weight on labor market changes. Third, trend TFP revisions lead,

[10]We cannot exclude the possibility that the upward revisions of trend TFP for 2008 from 2012:II to 2013:I come from the change in the capital stock measurement. For the following years up to 2012, these revisions, however, do not affect the median.

Figure 5: Pairwise correlations of revisions of PO components



Notes: The plots show the pairwise correlation between the PO components for different lags. Boxes show the interquartile range, the interior line the median, and whiskers the 17th and 83rd percentiles for the EU27 countries.

on average, revisions of trend labor by one vintage. The median correlation is around 21 % between trend labor revisions and lagged trend TFP revisions and only three out of 27 countries exhibit a negative correlation. Thus, it seems that technology shocks initially contribute in large parts to the PO revision while later this view is revised. Qualitatively, the relation between trend labor and trend TFP holds between the capital stock and trend TFP, too.

Non-contemporaneous correlations indicate how experts adjust revisions in the future. These relationships are particularly interesting since one could infer the direction of future revisions. We explore these non-contemporaneous relationships more formally by conducting Granger causality tests as formalized by Dumitrescu and Hurlin (2012) for panel data. If the test rejects the null hypothesis, we reject that a revision series A does not Granger-cause another revision series B for each country. Hence, revision series A Granger-causes revision series B for at least one country or more. We choose a lag length of one based on the Akaike criterion. Table 2 reports the p-values of the Dumitrescu-Hurlin test.

In line with our previous result, we reject the hypothesis that trend TFP revisions do not Granger-cause trend labor revisions at the 10 % level. The relationship between trend TFP revisions and subsequent revisions of the capital stock is similar although the test result is less clear (with a p-value of 0.105). In addition, we reject the hypothesis

Table 2: P-values from Granger causality tests

Granger causality from / to	Capital stock	Trend labor	Trend TFP
Capital stock	–	0.810	0.105
Trend labor	0.019	–	0.069
Trend TFP	0.170	0.501	–

Notes: The table reports p-values of the standardized test statistic of Dumitrescu and Hurlin (2012). The lag length is one. The choice is based on the Akaike criterion. We exclude the revision series for Bulgaria and Romania since the revision series start later and the Dumitrescu-Hurlin test requires a balanced panel.

that revisions of the capital stock do not Granger-cause revisions of trend labor at the 5 % level. This is plausible since trend labor is revised gradually while the capital stock tends to be changed in one-off revisions.

3.3 Cross-country Differences

Revisions of component estimates are very heterogeneous across countries and positive revisions are not as rare as they are for PO estimates as Figure 4 shows. For 2008, approximately one third of the countries experience a positive revision of the capital stock and trend TFP if one compares the most recent vintage to the estimates from 2008:I. Until 2018:II, we observe large negative revisions for 2008 in trend labor (Romania: −10.6 %), the capital stock (Slovakia: −5.7 %), and trend TFP (Estonia: −9.5 %). The revisions for these countries are even larger for 2012. From 2008:I to 2018:II, the EC revises both Estonia's trend TFP estimate for 2012 and Romania's trend labor estimate for 2012 by around −18 %. For the same year, the estimate of the capital stock for Slovakia in 2018:II is −13 % below the pre-crisis estimate.

In Dovern and Zuber (2019) we show that country characteristics systematically drive the revision of PO estimates after recessions. Hence, country characteristics can probably explain differences in revisions of component estimates, too. For example, one could conjecture that the EU's freedom of movement is one driver behind downward revisions of trend labor in countries which were hit particularly hard by the recession. This out-migration from severely hit countries to less affected countries has been an important concern in the EU and has been extensively covered by the media (e.g. Paul Krugman in the New York Times, 2011). To test in general if revisions of PO and its components are systematically different from certain groups of EU countries, we split the EU27 countries

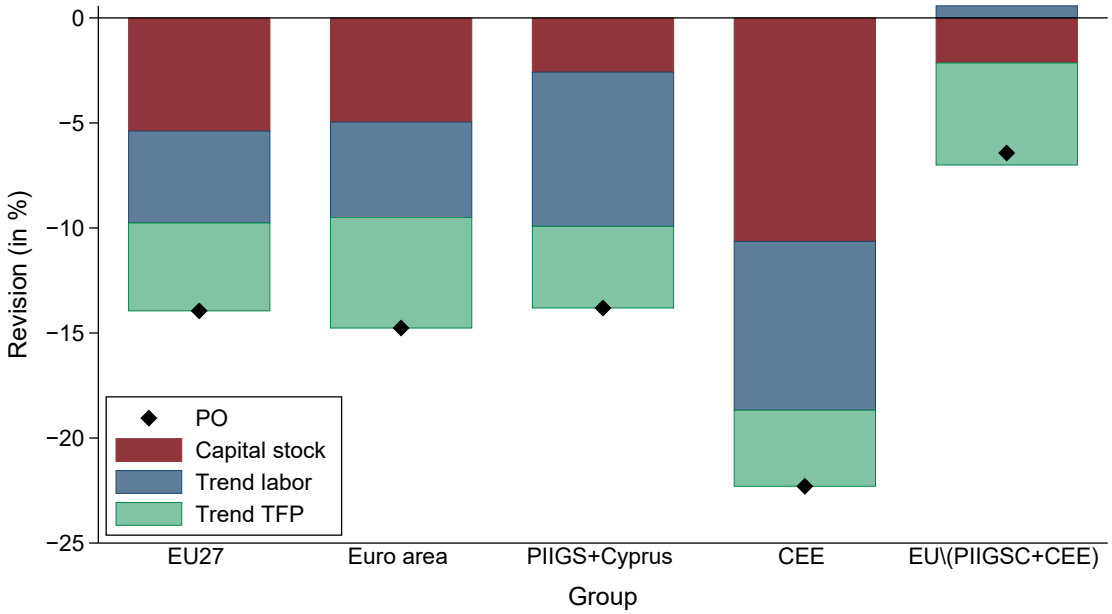
into three groups: (a) the six countries Portugal, Ireland, Italy, Greece, Spain, and Cyprus (PIIGS+Cyprus) which suffered the most from the Great Recession, (b) the Central and Eastern European (CEE) countries[11], and (c) the remaining eleven countries which have been hit less by the Great Recession. In addition, we calculate the mean revisions for the 19 euro area countries to test whether being part of the monetary union made a difference. For instance, members of the euro area could suffer more from hysteresis effects in the long run since they possess less stabilization tools.

We find that revisions of PO and the PO components are significantly different for PIIGS+Cyprus and the CEE countries while we find no difference between euro area members and the remaining countries. Figure 6 shows the mean revisions for the different subgroups for 2012. For PIIGS+Cyprus, trend labor revisions contribute to more than a half (53 %) of the overall PO revisions. As we will show in Section 3.4, labor migration partly explains these revisions. For the CEE countries, the main component behind PO revisions is the capital stock (which contributes 48 %). In the beginning of the 2000s these ten countries had very high investment ratios which were revised substantially downwards after 2008, which, in turn, led to the large revisions of the capital stock. The average of the pre-recession estimate of the investment ratio for 2012 was 33 % for the CEE countries while it dropped to 22 % in the latest available vintage. For comparison, the EU average dropped by only six percentage points in the same period. For countries neither being PIIGS+Cyprus nor CEE countries, trend TFP revisions account for roughly three quarters of the overall PO revision. This agrees with the notion that TFP is the major driver of growth in highly developed countries.

Revisions of component estimates for CEE countries are much larger than for other countries. We compare estimates for the years $t = \{2006, ..., 2012\}$ from the spring vintage of the same year t with estimates for year t from the most recent vintage. For $X = \{\overline{Y}, K, \overline{L}, \overline{A}\}$, we calculate these revisions by $\Delta x_{i,t}^{v_{\mathrm{I}}(t) \to v_{max}} = \log(X_{i,t}^{v_{max}}) - \log(X_{i,t}^{v_{\mathrm{I}}(t)})$ where $v_{\mathrm{I}}(t)$ refers to the spring vintage in year t and $v_{max} = 2018$:II. Figure 7 shows the results. First, we see large downward revisions of PO for the years 2006–08. The revisions reflect the experts' changed assessment of the economic conditions after the start of the Great

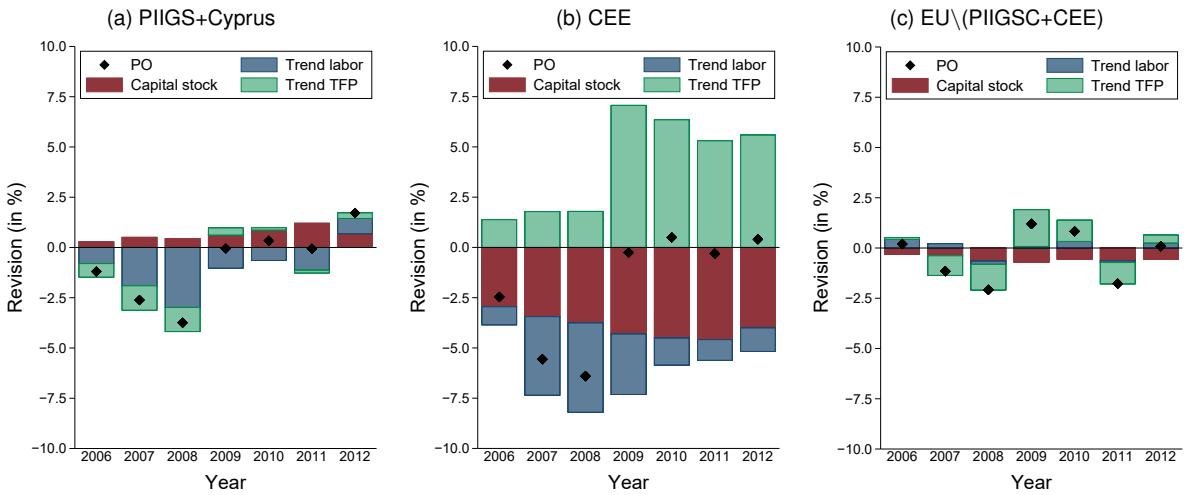
[11]The ten CEE countries are Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.

Figure 6: Country group revisions for 2012



Notes: The plot shows the mean contribution of component revisions to the overall PO revision between 2008:I and 2018:II for different country groups for 2012.

Figure 7: Revisions across groups and years



Notes: The plots show the mean contribution of component revisions to the overall PO revision between 2008:I and 2018:II for different country groups for 2006–2012.

Recession. The relevance of component revisions differs by countries for these years.[12] Second, PO revisions after 2008 fluctuate only little within a band of ±1.5 % around zero. Experts have already revised the PO estimates to incorporate the worsened economic outlook after the Great Recession. The relatively small band width suggests that the sovereign debt crisis in 2011–12 did not have noticeable long-term effects on the estimates of the years before. Third, component revisions for CEE countries are more than ten times larger than the actual PO revision for the years after 2008. For the other countries, component revisions are in general smaller than the overall PO revision. Year by year, experts initially seem to overestimate the contribution of the capital stock to PO for CEE countries. Later, this culminates in large downward revisions of the capital stock and large upward revisions of trend TFP. The pattern reveals a serious overestimation of the capital stock for CEE countries in real time.[13]

3.4 Closer Look at the Labor Market

A nice feature of the EC data is that we can break down the contribution of trend labor to PO into four subcomponents: trend average hours worked per head, working-age population, trend labor force participation rate, and the NAWRU. We measure how much the revisions of each of those subcomponents contribute to the revisions of the trend labor aggregate by calculating their percentage deviation in vintage v_k from the estimates in vintage $v_0 = 2008$:I for the years $t = \{2008, 2012\}$. Formally, we calculate for $X = \{\overline{L}, \overline{H}, N, \overline{PR}, (1 - \overline{UR})\}$ the log difference $\Delta x_{i,t}^{v_0 \to v_k} = \log(X_{i,t}^{v_k}) - \log(X_{i,t}^{v_0})$ and decompose the overall revision of trend labor into

$$\Delta \overline{\ell}_{i,t}^{v_0 \to v_k} = \Delta \overline{h}_{i,t}^{v_0 \to v_k} + \Delta n_{i,t}^{v_0 \to v_k} + \Delta \overline{pr}_{i,t}^{v_0 \to v_k} + \Delta (1 - \overline{ur}_{i,t})^{v_0 \to v_k} . \tag{6}$$

Table 3 shows that the EC revises the estimates of trend labor substantially in the first five years. For 2008, trend labor is, on average, revised by roughly three quarters of its total revision between 2008:I and 2013:I. For 2012, the total revision of trend labor

[12] In fact, Figure 7 shows that the revision of different components is particularly relevant for each country group and for all years between 2006 and 2012. It is therefore a generalization of our finding from Figure 6.

[13] The estimates of trend labor for CEE countries are affected to a lesser extent as well.

Table 3: Detailed component revisions

	2008			2012		
	2008:I–2018:II	2008:I–2013:I	2013:I–2018:II	2008:I–2018:II	2008:I–2013:I	2013:I–2018:II
Trend labor	−2.37	−1.76	−0.61	−4.37	−4.37	0.00
1 − NAWRU	−1.33	−1.05	−0.28	−2.45	−3.03	0.58
Population	−0.69	−0.11	−0.58	−0.98	−0.47	−0.51
Trend LFPR	0.11	−0.06	0.17	0.11	−0.03	0.14
Trend hours	−0.46	−0.54	0.08	−1.06	−0.83	−0.23

Notes: The table reports full sample mean revisions of the trend labor aggregate and its four subcomponents.

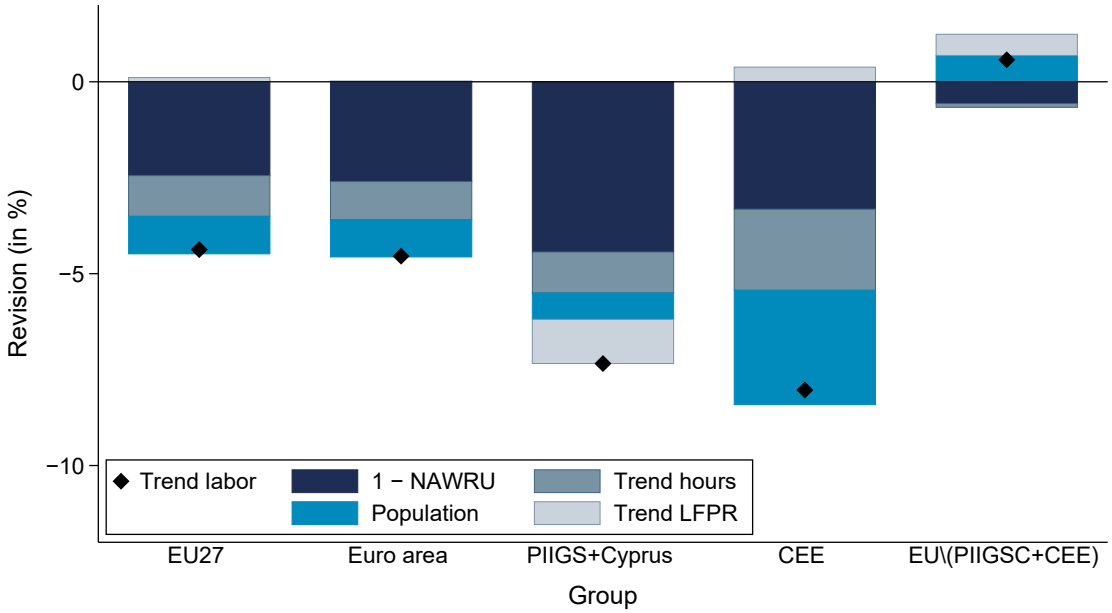
happens, on average, until 2013:I. The fast revisions of the NAWRU and trend hours contribute especially to the large revisions during the first five years.

Revisions of the NAWRU estimates make up the largest share of the overall revisions of the trend labor estimates. They explain 56 % of the revisions of the trend labor aggregate for 2008 and 2012 between 2008:I and 2018:II. The average NAWRU estimate for 2012 increased by 3.4 percentage points from 5.6 % in 2008:I to 9.0 % in 2018:II. Revisions were much larger in countries which were severely hit by the Great Recession. PIIGS+Cyprus experienced an average increase of the NAWRU by 6.1 percentage points resulting in an average NAWRU estimate of 12.7 % in 2018:II.

Not only were revisions of the NAWRU larger for PIIGS+Cyprus but also the NAWRU revisions contributed significantly more to the trend labor revisions for these countries as Figure 8 shows. NAWRU revisions for PIIGS+Cyprus make up 60 % of the revisions of the trend labor aggregate whereas they contribute only 41 % to the trend labor revisions for the CEE countries. For the remaining countries, the small negative revision of the NAWRU is offset by upward revisions of trend hours and the trend labor force participation rate.

Revisions of the working-age population level are almost equally important as the NAWRU revisions for CEE countries. The revision of the working-age population contributes 37 % to the trend labor revision and the share is significantly larger than for all other groups. Labor migration from CEE countries to the rest of Europe may explain the large downward revision of the working-age population level for CEE countries by −3 % and the upward revision of the working-age population level for the EU excluding PIIGS+Cyprus and CEE countries by 0.7 %. Labor mobility seems to serve as an adjustment mechanism that reduces the output gap of individual countries. Through

Figure 8: Decomposed trend labor revisions across groups for 2012



Notes: The plots show the mean contribution of component revisions to the revisions of the trend labor aggregate for different country groups for 2012.

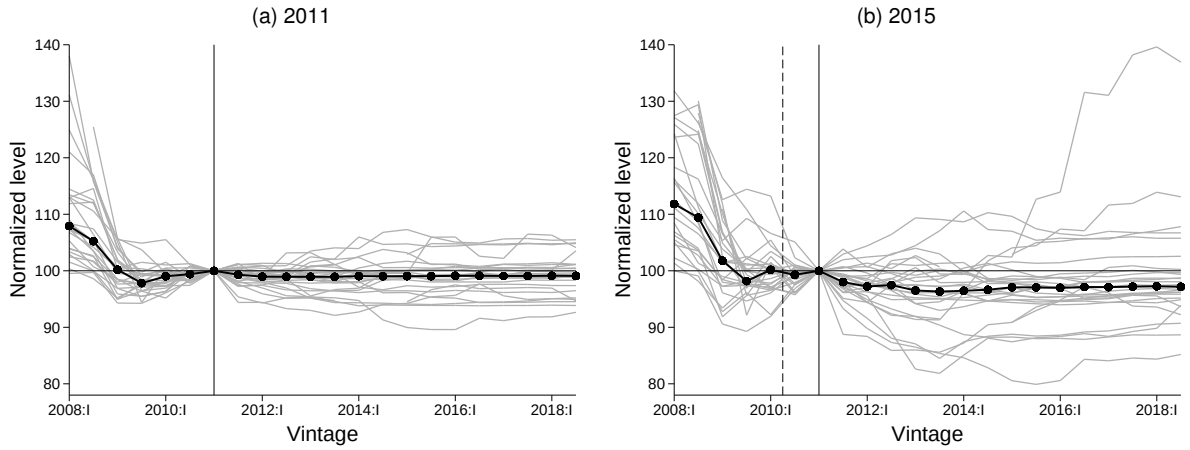
emigration, the unemployment rate decreases towards the NAWRU. In the immigrant-receiving country, the tightness of the labor market decreases and the unemployment rate increases towards the NAWRU.

3.5 The Great Recession versus the Sovereign Debt Crisis

The sovereign debt crisis of 2011 led to double-dip recessions in several European countries. Did PO revisions during the sovereign debt crisis evolve similarly to PO revisions during the Great Recession? We provide answers to this question by comparing the PO revisions after 2011 for 2011 (the first year of the sovereign debt crisis) to the PO revisions after 2008 for 2008 (the start of the Great Recession) and the revisions for the four-year-ahead PO estimates.

In the aftermath of the Great Recession, countries like Greece, Portugal, and Spain, among others, ran high structural deficits which rapidly increased national debt levels. Anxious that the high debt levels would not be sustainable, lenders started to ask for ever-higher interest rates in 2010. In autumn 2011, the long-term interest rates for Greece, Portugal, and Spain rose to above ten percent and were more than three times higher than

Figure 9: Revisions of PO estimates after the sovereign debt crisis



Notes: The plots show the median revisions of EC PO estimates for 2011 and 2015 across different vintages. Grey lines represent single country revisions. Levels are normalized such that they are 100 in 2011:I for every country and year. Values to the left of the dashed line are extrapolated as in Dovern and Zuber (2019).

the long-term interest rate of Germany. The high interest rates increased the pressure on those countries to run restrictive fiscal policies. Greece and Ireland requested bailouts from the EU and the IMF in 2010, Portugal followed in 2011, and Spain and Cyprus received financial support in 2012. Shortly thereafter, Mario Draghi announced in July 2012 that the ECB was willing to do "whatever it takes" to calm down markets and decrease pressure on the interest rates of the affected countries. The financial support and the unprecedented guarantee of the ECB probably minimized negative long-term effects.

Figure 9 shows that the PO revisions after the sovereign debt crisis differ significantly in size compared to the PO revisions after the Great Recession shown in Figure 2. We compare estimates for 2011 with estimates for 2008 and estimates for 2015 with estimates for 2012. The median revision of PO estimates for 2011 is -1 % if one compares the estimate in 2011:I with the final release in 2018:II. In contrast, the median revision of the PO estimates for 2008 was more than -3 % in the long run. The same is valid for the four-year-ahead PO estimate: the median for 2015 is revised by roughly -3 % which is only one quarter of the median PO revision for 2012 which we observed after 2008. Individual country estimates are again very heterogeneous. On the one hand, the estimate for Greece for 2015 is revised by nearly -15 % and the corresponding estimates for Finland and Slovenia by around -10 %. On the other hand, the estimate for Ireland is revised upwards by nearly 40 % and the estimate for Malta by 13 %. The large revision for

Ireland emerged from the relocation of a few multinational corporations which induced a one-off permanent increase of the level of investment and net exports.[14] In general, however, experts seem to have fully incorporated lower trend growth by 2011 and did not expect a further decline in trend growth due to the sovereign debt crisis, either.

4 Conclusion

We document that EC estimates of PO were revised substantially in response to the Great Recession. The new estimates imply that EU countries are currently on a lower growth path than before the Great Recession. These revisions are very persistent and were mainly made within one year after the start of the Great Recession.

Our results extend the work by Dovern and Zuber (2019) by also analyzing the revisions of the components of PO. Revisions of the PO components contribute, on average, equally to the overall PO revision. Briefly after the Great Recession, revisions of trend TFP dominate due to an initial "overshooting" which is partly reversed in subsequent years. In contrast, it takes time before trend labor estimates are fully revised. The revisions of capital stock estimates is a one-off revision shortly after the start of the Great Recession. We document important differences in the share of component revisions for CEE countries, PIIGS+Cyprus, and the remaining countries. For the first group, a strong reduction of capital stock estimates is the main source of overall PO revisions. For PIIGS+Cyprus, the major factor behind overall PO revisions are changes in trend labor estimates. Technology shocks primarily seem to lower PO estimates for the remaining countries. A closer look at the labor market shows that NAWRU revisions dominate the revisions of trend labor estimates. In addition, we provide evidence that migration from Central and Eastern Europe to the remaining countries makes up another large share of the aggregate trend labor revisions.

Our results demonstrate that different policy actions might be needed to push countries back to their previous growth trends. While stimulating investment could help to regain the "lost" PO level in CEE countries, PIIGS+Cyprus should focus on labor market

[14] Low Irish corporate taxes attracted large multinational enterprises (e.g. Apple) which relocated to Ireland together with their intellectual property. Revenues from this intellectual property led to a one-off growth of GDP by 34.4 % for 2015 and similarly increased PO. The OECD (2016) estimates that the GDP growth for 2015 would be just around 4.5 % if one excluded the one-off effect of relocation of multinational corporations. Angerer et al. (2016) provide further details.

policies. In a wider context, our results identify the mechanisms by which recessions, or negative shocks in general, affect an economy's potential. Thereby, our findings can serve as a basis to delevop macroeconomic models which explicitly model how different types of permanent *and* transitory shocks affect PO in the long run.

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Appendix A List of Identified Recessions

Table A.1: Recession starts between 2007Q2 and 2009Q1

#	Country	Start	Length	Depth
1	Austria	2008Q2	5	−5.29
2	Belgium	2008Q3	4	−3.81
3	Bulgaria	2009Q1	4	−6.43
4	Cyprus	2008Q4	4	−2.50
5	Czech Republic	2008Q4	3	−5.88
6	Denmark	2008Q1	6	−7.07
7	Estonia	2008Q1	7	−20.89
8	Finland	2008Q1	6	−10.01
9	France	2008Q2	5	−3.92
10	Germany	2008Q2	4	−6.94
11	Greece	2007Q3	26	−27.44
12	Hungary	2008Q3	7	−7.73
13	Ireland	2007Q2	11	−10.90
14	Italy	2008Q2	5	−7.88
15	Latvia	2007Q4	12	−22.70
16	Lithuania	2008Q3	6	−16.78
17	Luxembourg	2008Q1	6	−7.88
18	Malta	2008Q4	2	−5.11
19	Netherlands	2008Q3	4	−4.36
20	Portugal	2008Q2	4	−4.33
21	Romania	2008Q4	2	−8.50
22	Slovenia	2008Q3	4	−9.52
23	Spain	2008Q3	6	−4.62
24	Sweden	2008Q1	5	−7.43
25	United Kingdom	2008Q2	5	−6.26

Notes: "Start" corresponds to the year and quarter in which the recession begins. "Length" refers to the duration of a recession in quarters. "Depth" refers to the maximum depth of a recession (in % of the pre-recession peak level of output). Note that the algorithm does not identify a recession for Poland and Slovakia in the time period of the Great Recession.