Hysteresis elasticities: Estimates for high and middle-income economies*

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Abstract

Macroeconomics has long assumed that demand shocks do not affect the potential output. This study uses a Bayesian bivariate Kalman filter to estimate the hysteresis elasticities for potential GDP and the NAIRU for 73 economies. It also estimates these elasticities using a simple New-Keynesian model for 28 economies. The main finding suggests that these hysteresis elasticities are high in most economies studied. The latter implies that demand and monetary policy shocks could have long-run effects on potential GDP and the NAIRU, which firmly rejects the natural rate hypothesis. In addition, the study explores cross-country differences and finds evidence supporting the insiders-outsiders explanation of unemployment hysteresis. Similarly, it finds evidence supporting the endogenous TFP theory as a relevant source of GDP hysteresis.

Keywords - Hysteresis, business cycle, Bayesian Methods, Kalman filter, Potential GDP, NAIRU

JEL Code - E32, E37, E47, E58, C11

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1 Introduction

A natural rate that hops around from one triennium to another under the influence of unspecified forces, including past unemployment rates, is not 'natural' at all. 'Epiphenomenal' would be a better adjective; look it up!
Solow (1986)

Friedman (1968) posited that monetary policy could not permanently affect the unemployment rate. Thus, the role of monetary policy should be to stabilize inflation and smooth the economic cycle. His view comes from two joint hypotheses, which gave rise to the *Natural Rate Hypothesis*. The first hypothesis is that monetary policy cannot affect the natural unemployment rate (independence hypothesis). The second hypothesis is that attempts to lower the unemployment rate below the natural unemployment rate permanently will increase inflation (the accelerationist hypothesis).

In contrast, O. J. Blanchard & Summers (1986) argued that European unemployment rates behaved at odds with Friedman's natural rate hypothesis. Specifically, they suggested that if wages are largely set by bargaining between insiders and firms, shocks that affect actual unemployment tend also to affect equilibrium unemployment. This latter hypothesis is known as the hysteresis hypothesis.

O. Blanchard (2018) provides the next toy model to clarify these hypotheses. Potential GDP $\bar{y}_t$ (in logs) is governed by the following process:

$$\bar{y}_t = a\bar{y}_{t-1} + b(y_{t-1} - \bar{y}_{t-1}) \text{ where } a \leq 1 \tag{1}$$

A similar process describes the NAIRU $\bar{u}_t$:

$$\bar{u}_t = a_u\bar{u}_{t-1} + (1 - a_u)\bar{u}^{ss} + b_u\hat{u}_{t-1} \text{ where } a_u \leq 1. \tag{2}$$

The independence hypothesis (monetary policy does not affect potential output and the NAIRU) holds when $b = 0$, $b_u = 0$, $a < 1$, and $a_u < 1$. In contrast, the hysteresis hypothesis suggests that both potential output and the NAIRU are permanently affected by short-run shocks (see O. J. Blanchard & Summers (1986)), which implies that $b > 0$, $b_u > 0$, $a = 1$, and $a_u = 1$. O. Blanchard (2018) argues that these two hypotheses are rather extreme and that, in reality, $b > 0$ and $b_u > 0$ and also $a < 1$, and $a_u < 1$. The independence hypothesis holds when b, b_u, a, and a_u are small. The hysteresis hypothesis holds when b, b_u, a, and a_u are high.

On its part, inflation π_t obeys the following process:

$$\pi_t = c(y_t - \bar{y}_t) + E\pi_t \text{ where } E\pi_t = k \text{ for } -x \leq \pi_t \leq x \text{ , } E\pi_t = \pi_{t-1} \text{ otherwise} \tag{3}$$

Inflation is a function of the output gap and expected inflation. In normal times, $-x \leq \pi_t \leq x$ inflation expectations are anchored around k. Otherwise, inflation expectations are unanchored and become a unit-root process. From this toy model, O. Blanchard (2018) suggests that research should focus on the values a, b, c, and x. He argues that the failure of some of these sub-hypotheses of the natural rate hypothesis led to a more attractive inflation-output (unemployment) trade-off.

This paper attempts to answer whether the natural rate or hysteresis hypothesis holds. To do so, a simple bivariate Kalman filter is proposed and estimated using Bayesian methods. This method simultaneously estimates a_u, b, b_u, the potential output, and the NAIRU and it is applied for 73 economies[1]. In addition, several robustness checks regarding the *a priori* distributions and the model structure are estimated. One of the robustness checks includes estimating a semi-structural new-Keynesian model for 28 economies.

The use of Bayesian methods with a multivariate Kalman filter is suitable for this question. On the one hand, it helps to estimate unobservable variables such as the NAIRU and potential GDP. On the other hand, informative *a priori* distributions can be used to estimate the parameters in relatively small samples, which is the case in this study. However, the use of Bayesian methods is not a free lunch. It is known that the *a priori* distributions used can affect the *a posteriori* distributions. For this reason, the paper discusses the *a priori* distributions used at length. *A priori* distributions can be defined using expert judgment but can also be informed by prior literature. In this case, the paper shows that the natural rate hypothesis, as defined by O. Blanchard (2018), provides a straightforward way to determine the *a priori* distribution of the parameters of interest. Moreover, the study also constructs a literature-informed *a priori* distributions by performing a meta-analysis of existing estimates. Finally, it is known that the Bayesian approach tends to reject the null-hypothesis testing approach; however, in some discussions, it is fruitful to decide whether some hypothesis holds or not. For this reason, the paper follows Kruschke (2021) and provides a way to define this region of practical equivalence (ROPE) in relatively more complex settings than those considered by Kruschke (2021).

The paper is closely related to two strands of the literature. The first strand deals with the estimation of the NAIRU hysteresis elasticity (see Jaeger & Parkinson (1994), Logeay & Tober (2006), Logeay & Tober (2006), Jump & Stockhammer (2018), Jump & Stockhammer (2019), and Ball &

[1] The paper assumes that $a = 1$, which is a common assumption as GDP follows a unit-root process.

Onken (2022)). The second strand deals with the estimation of potential GDP (see DeLong & Summers (2012), Łukasz Rawdanowicz et al. (2014), Alichi et al. (2019), and Jordà et al. (2020)). The closest in methodological terms is Jump & Stockhammer (2019), who estimated the NAIRU hysteresis elasticity by using Bayesian multivariate Kalman filter. This paper expands their framework to simultaneously estimate the NAIRU hysteresis elasticity and the potential GDP hysteresis elasticity. In other words, the paper integrates both strands of literature. In this sense, the only study that tried to integrate both strands of the literature is Alichi et al. (2019) by allowing for potential GDP hysteresis effects that stem from labor market hysteresis.

The study contributes to the knowledge of hysteresis in various ways. First, it estimates these hysteresis elasticities for more than 70 economies. To the author's knowledge, previous studies mainly dealt with European economies and the United States. These findings are a relevant contribution to the literature as, for many economies, the hysteresis elasticities are unknown. Of course, these estimates are likely to be biased since the model used is quite simple. Nevertheless, the findings challenge a commonly accepted view and, at the very least, should put the idea that potential output or the NAIRU are not affected by the economic cycle in doubt. These findings align with Ball & Onken (2022) and Jordà et al. (2020). If our results hold, the policy implications are relevant. During economic crises, monetary and fiscal policy should act to avoid relevant long-term GDP losses and increases in the NAIRU.

A second contribution of the study is that it examines the cross-country variation of the hysteresis elasticities. By doing so, the paper sheds some light on how institutional developments and the economic structure can affect economic performance. For instance, economies with higher average GDP growth rates (relative to their regional peers) tend to have higher levels of potential GDP persistence a and higher potential GDP hysteresis elasticities b. This finding aligns with the theoretical implication that when TFP is endogenous to the business cycle, persistence is an increasing function of long-term growth rates (see Fatás (2000)). It is also found that labor market power measures such as union density and the labor share on GDP are positively correlated with NAIRU hysteresis elasticity. Interestingly, there is no correlation between labor market rigidities proxies and the NAIRU hysteresis elasticity. Therefore, the estimates tend to favor the insiders-outsiders explanation of hysteresis (see O. Blanchard & Katz (1997) and O. J. Blanchard & Summers (1986)) over other hypothesis like the labour market rigidities explanaition (see Nickell (1997)).

The paper is organized into six sections. The first section is this introduction. In the next section, the data and some stylized facts are presented. The third section presents the methodology of the study. It begins by outlining the characteristics of the bivariate model. Then, it discusses the *a priori* distributions of the key parameters at length. Finally, it proposes some robustness checks, introduces the reader to the ROPE approach, and shows how it can be used to assess the likelihood of the *natural rate hypothesis*. The fourth section presents the study's results and is divided into three subsections. The first subsection shows the baseline estimates. The second subsection shows the ROPE approach's results to the *natural rate hypothesis*. Finally, in the third subsection, the paper explores cross-country heterogeneity in the estimates. Section 5 compares the main results to previous literature. Finally, section 6 concludes the document.

2 Data and motivating evidence

2.1 Data sources and sample

Data comes from the IMF's World Economic Outlook (October 2021 version). This database has data on unemployment rates and GDP for more than 190 countries. Intuitively identifying b and b_u requires long swings in the output gap and the unemployment gap, which are observable during economic crises; thus, a long time series helps identify these parameters. That is why the sample is restricted to economies having complete information on unemployment rates from 1990 onwards. Brazil was included as it is relevant for world output, and its data was available from 1991 onwards. While it is possible to lengthen the sample by splicing data from various sources, the IMF's database procures that data is comparable through time within the country, which might not be possible by using different sources.

The countries included are Albania, Algeria, Argentina, Australia, Austria, Barbados, Belgium, Belize, Brazil, Bulgaria, Cabo Verde, Canada, Chile, China, Colombia, Costa Rica, Cyprus, Denmark, Ecuador, Egypt, El Salvador, Fiji, Finland, France, Germany, Greece, Honduras, Hong Kong SAR, Hungary, Iceland, India, Indonesia, Ireland, Islamic Republic of Iran, Israel, Italy, Jamaica, Japan, Jordan, Korea, Kuwait, Luxembourg, Malaysia, Mauritius, Mexico, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Romania, Singapore, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Santo Tome and Principe, Taiwan Province of China, The Bahamas, Tunisia, Turkey, United Kingdom, United States, Uruguay, and Vietnam.

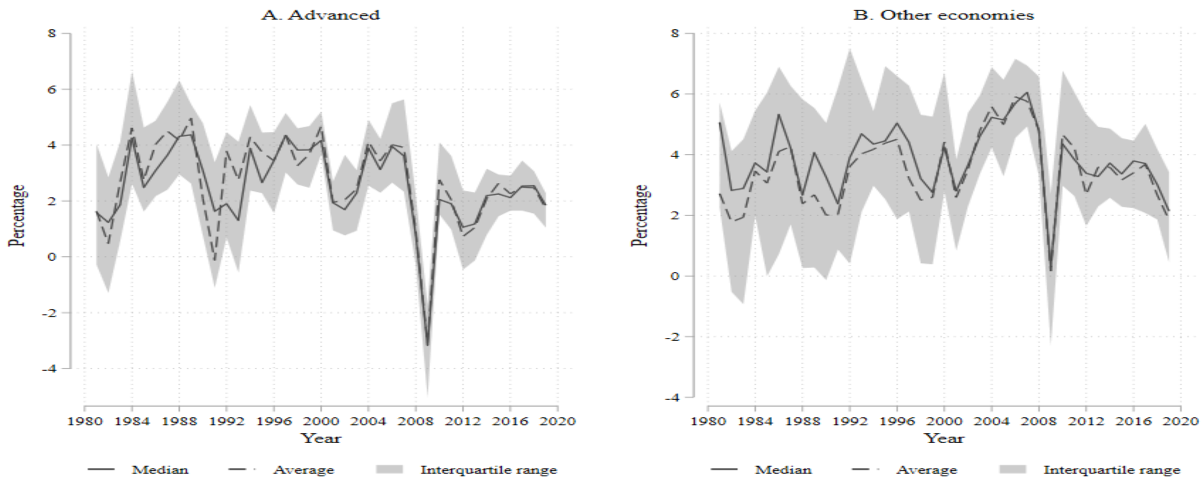
The sample covered about 79% of world GDP in 2015. It also covered 46% of Africa's GDP, 75% of Asia's GDP, 79% of Europe's GDP, 89% of Latin American GDP, 100% of North America's GDP, and 97.6% of Oceania's GDP in 2015. In terms of income (World Bank classification), the sample is representative of high-income economies (96% of GDP is included) and middle-income economies (67% of GDP is included). The sample is not representative of low-income economies.

Data from other sources was also used. Data from the Penn World Tables on TFP, capital stock, employment, population, labor share of GDP, trade openness, and investment share of GDP was used. Inflation data comes from the Ha et al. (2021) dataset. Real interest rate data comes from the World bank. The United Nations' World Population Prospects data regarding the total and working-age populations (15 to 64 years old) was used. Finally, Botero et al. (2004) data on market labor regulations was also used.

2.2 Motivating evidence

Some stylized facts are introduced in this subsection. First, the GDP growth rates have faced structural changes and have decreased, especially after the GFC. Figure 1 shows the median, average, and the interquartile range of GDP growth for advanced economies and the remaining economies. In the case of advanced economies, there is an important downwards shift after the GFC. For instance, while the (simple) average GDP growth was about 3.3% before 2008, the average GDP growth was about 1.7% from 2009 to 2019. In the remaining economies, the opposite thing happened. Before 2000, the average GDP growth was about 3.3%, whereas, after 2000, the average GDP growth was about 3.8%, though the GFC also negatively affected the growth rate after 2009. It also seems that there is a higher level of coordination after 2000, as the interquartile range shrank, especially in non-advanced economies.

Figure 1: GDP growth rate

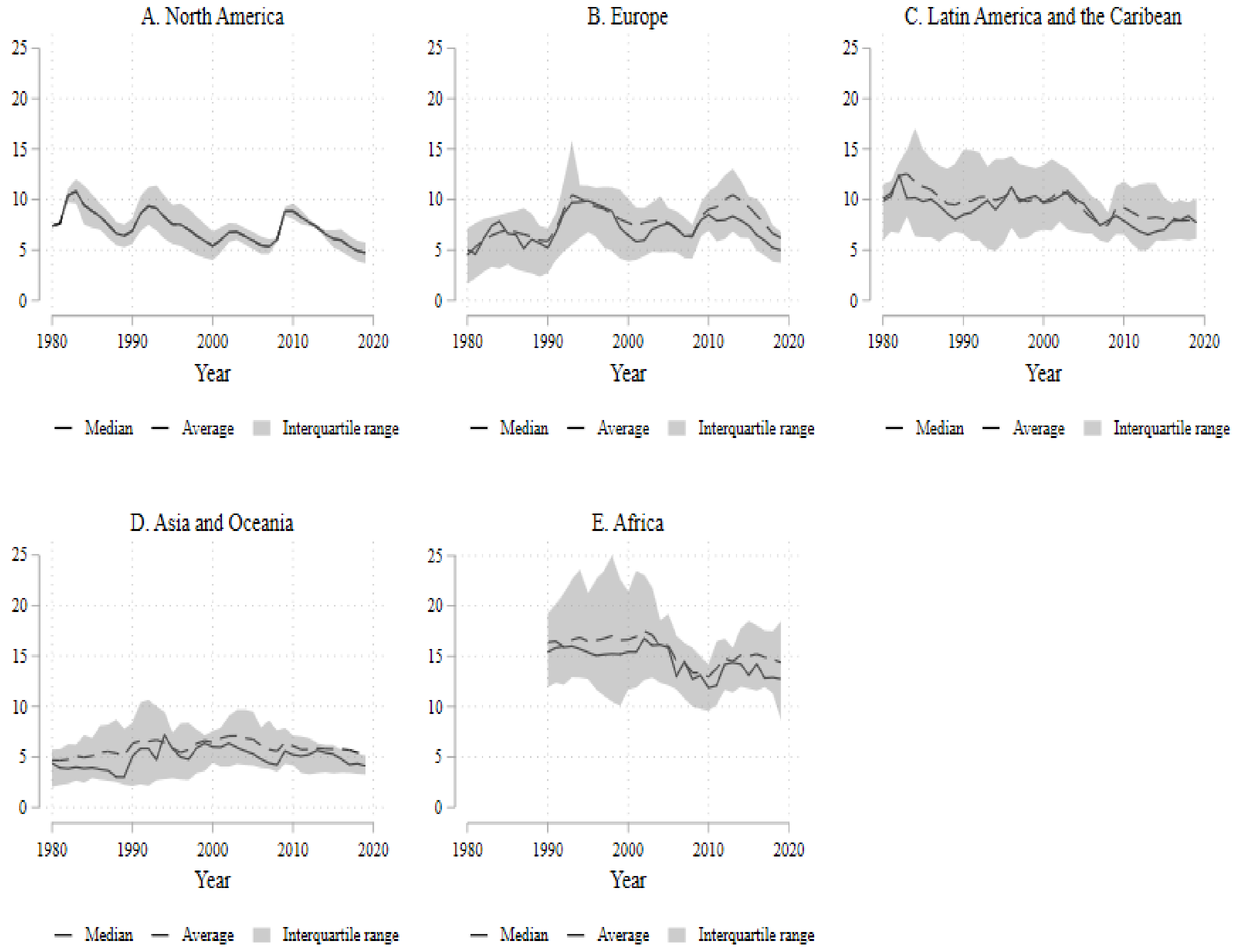


Source: Author's calculations using WEO data
Note: See the list of countries in appendix D.

Second, the unemployment rate behavior is heterogeneous through regions and time. On the one hand, North American economies exhibited a decreasing trend from 1980 to 2019, with some bumps during the dot com crisis and the GFC. On the other hand, in Europe, the unemployment rates increased notably from 1990 to 1993 after which they steadily decreased, but they never reached the levels seen in the 80s. The GFC also increased the unemployment rates significantly, and then they decreased steadily until 2019 when some economies recovered to the pre-GFC levels.

South American unemployment rates are the most erratic. For one thing, during the '80s, there was an increase due to the debt crisis. Then during the '90s, there was a stonger one that reached its peak during the 1997-2000 Latin American crisis. This one decreased steadily until 2014 when commodity prices crashed. In contrast, Asia and Oceania have the most stable unemployment rates and the lowest ones. Finally, African unemployment rates are among the highest and have fallen significantly since 2000.

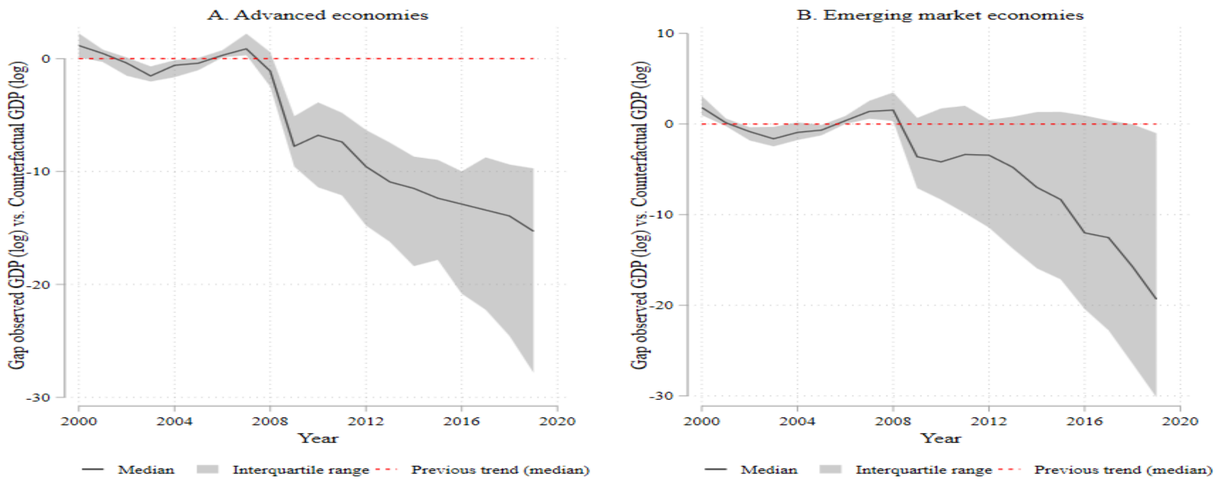
Figure 2: Unemployment rates



Source: Author's calculations using WEO data
Note: See the list of countries in appendix D.

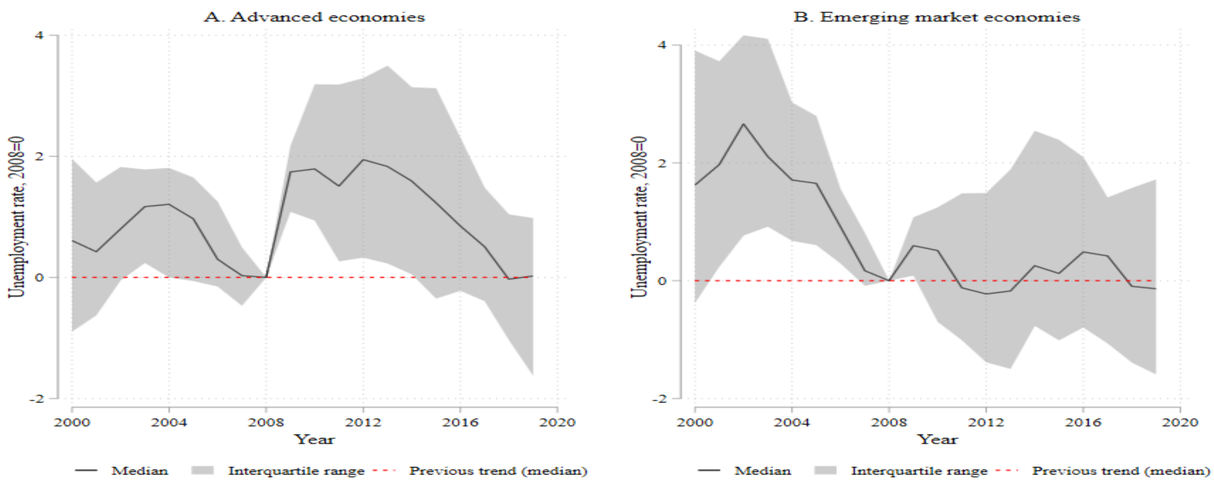
Third, GDP tends to have permanent losses after an economic crisis. In our sample period, the major economic crisis was the GFC. Figure 3 plots the median and the interquartile range of the gap between the observed GDP and the previous trend. As can be seen, in advanced economies, GDP losses are substantial, and most economies have never returned to their previous trend. The same applies to emerging market economies though some were not highly affected by this crisis.

Figure 3: GDP after the GFC



Source: Author's calculations using WEO data
Note: See the list of countries in appendix D.

Figure 4: Unemployment rates after the GFC



Source: Author's calculations using WEO data
Note: See the list of countries in appendix D.

Fourth, unemployment rates tend to surge during economic crises, but they return to pre-crisis levels after five years. In figure 4, the median and interquartile unemployment rate range is plotted relatve to its level in 2008 for advanced and remaining economies. Developed economies' unemployment rate surged after the GFC, and six years later, about half of the advanced economies recovered their previous levels while the remaining half are still above 2008 levels. However, in emerging market economies, unemployment rates did not rise systematically, but the GFC seems to have stopped their previous downward trend.

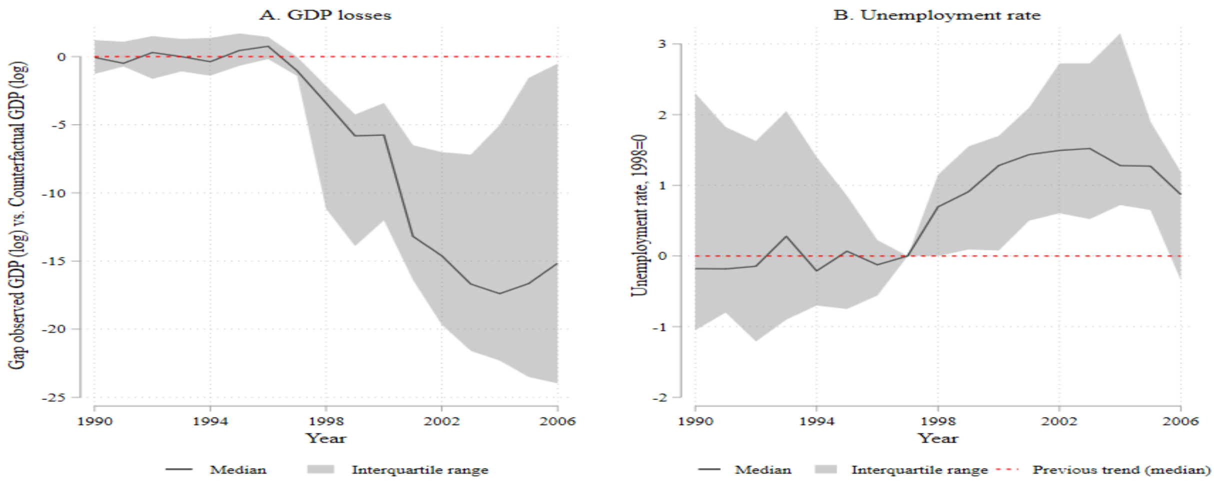
Persistent and substantial GDP losses after an economic crisis are not just a GFC feature. In figures 5 and 6, the GDP losses after the 1997 Asian crisis and the 1998 south American financial crisis are plotted. These persistent losses in GPD were also found in both crises as was the surge in unemployment rates and its posterior convergence to pre-crisis levels.

The main difference between crises is the size and type of the shocks. For example, the GFC seems to have created a permanent and growing gap between advanced economies' observed GDP and the previous trend. The gap seems to be caused by the combination of a crash in GDP and a fall in the growth rate. On the other hand, the Asian and South American crisis seems to result from a fall in GDP but similar growth rates.

Unemployment rates follow a similar pattern when there are crises, and the main difference is the size of the shock. While in South America, the median unemployment rate rose four percentage points above the pre-crisis level, in the Asian crisis, the 75% percentile unemployment rate rose less than three percentage points. The advanced economies' median unemployment rate rose about two percentage points during the GFC.

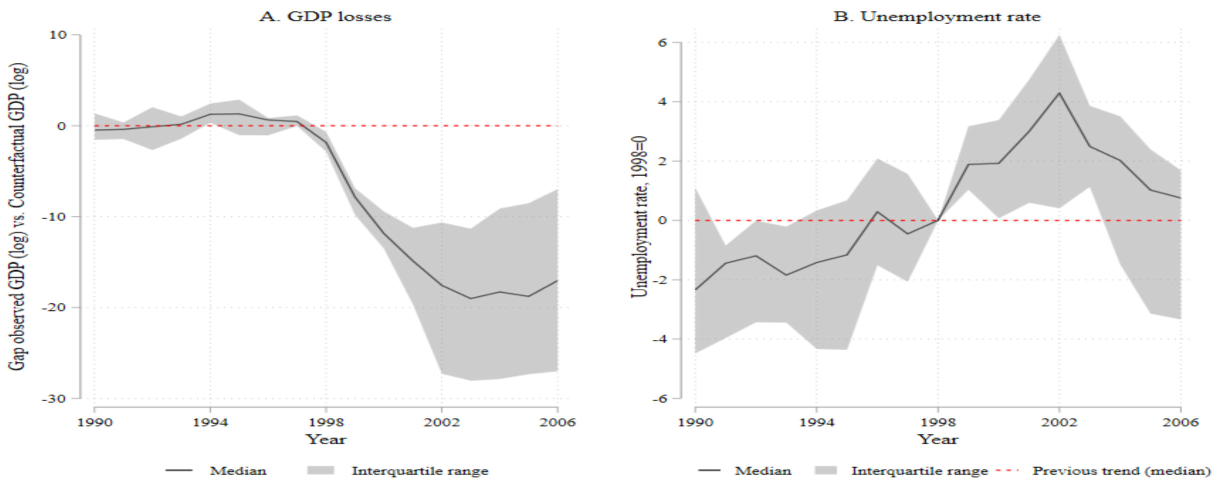
Finally, all these patterns suggest that crises have permanent effects on GDP and temporary though persistent effects on unemployment. Thus, if the potential output was not affected by the economic crisis, the gaps shown in figure 3 should be similar to the output gap, and this would suggest a high disinflation. Nevertheless, core inflation levels after the GFC were similar to the average core inflation levels from 2001 to 2007 (see Figure 7). In advanced economies, inflation remained relatively stable until 2013, and a similar pattern appears in the remaining economies. The lack of disinflation suggests that the output gap is probably smaller than what is implied by Figure 3. Thus potential output should have been negatively affected by the GFC.

Figure 5: GDP and unemployment rates after the Asian crisis (1997) - Asian economies



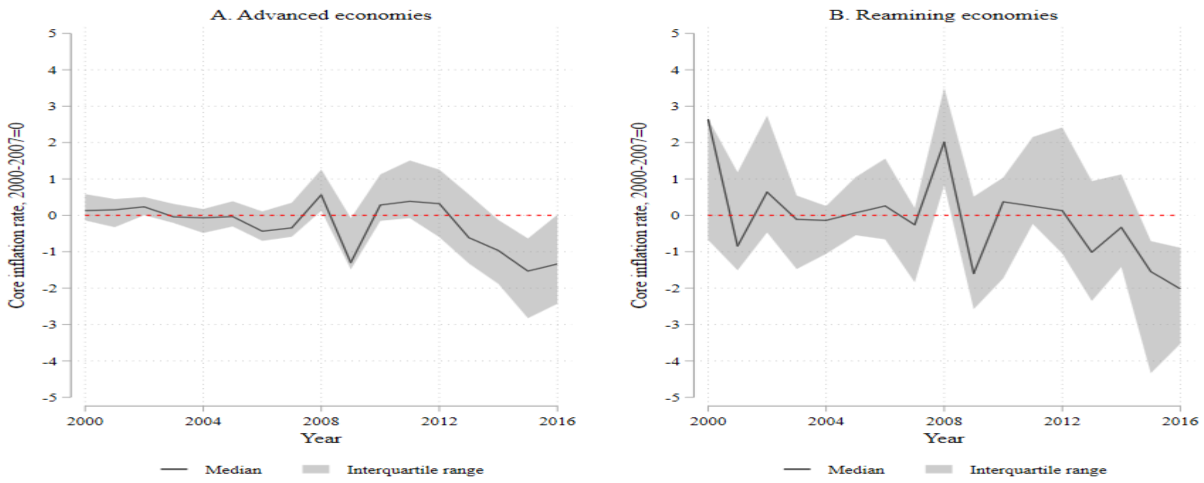
Source: Author's calculations using WEO data.
Note: See the list of countries in appendix D.

Figure 6: GDP and unemployment rates after the Latin America financial crisis (1998) - South American economies



Source: Author's calculations using WEO data.
Note: See the list of countries in appendix D.

Figure 7: Core inflation after the GFC



Source: Author's calculations using WEO data.
Note: See the list of countries in appendix D.

Overall, the previously mentioned facts suggest evidence against the natural rate hypothesis. Crises seem to have long and persistent scarring effects on GDP, but the effects on inflation are negligible. Therefore, the potential output should have fallen during the crisis as well. Thus, potential GDP has high levels of a and positive and relevant b values. A similar conclusion applies to the NAIRU, though it seems that a_u is smaller than a.

3 Methodology

3.1 The baseline model

This section presents the models used to estimate the potential GDP hysteresis elasticities and the NAIRU hysteresis elasticities. The following bivariate Kalman filter is estimated through Bayesian methods in this paper and is the baseline model.

$$y_t = \bar{y}_t + \hat{y}_t \tag{4}$$

$$\bar{y}_t = \bar{y}_{t-1} + \gamma_t + b\hat{y}_{t-1} + \varepsilon_t^{\bar{y}} \tag{5}$$

$$\gamma_t = \delta\gamma_{t-1} + (1-\delta)\gamma_t^{ss} + \varepsilon_t^{\gamma} \tag{6}$$

$$\gamma_t^{ss} = \gamma_{t-1}^{ss} + \varepsilon_t^{\gamma^{ss}} \tag{7}$$

$$\hat{y}_t = \phi \hat{y}_{t-1} + \varepsilon_t^{\hat{y}} \tag{8}$$

$$u_t = \bar{u}_t + \hat{u}_t \tag{9}$$

$$\bar{u}_t = a_u \bar{u}_{t-1} + (1 - \rho_u)\bar{u}_t^{ss} + b_u \hat{u}_{t-1} + \varepsilon_t^{\bar{u}} \tag{10}$$

$$\bar{u}_t^{ss} = \bar{u}_{t-1}^{ss} + \varepsilon_t^{\bar{u}^{ss}} \tag{11}$$

$$\hat{u}_t = \tau_1 \hat{u}_{t-1} - \tau_2 \hat{y}_t + \varepsilon_t^{\hat{u}} \tag{12}$$

where y_t is GDP (in logs), $\hat{y}_t$ is the output gap, and $\bar{y}_t$ is potential output. Potential output is an autoregressive process with a drift γ_t (potential GDP growth), and it can be affected by the output gap if $b > 0$. γ_t is a stationary process over a time-varying long-run growth rate γ_t^{ss}.

With this structure, the model should capture some stylized facts. First, the fact that γ_t^{ss} is a unit-root process should help the estimation of potential GDP as figure 1 shows that the growth rates are not stable. Second, if economic crises can dampen the potential output, then by estimating b, the extent of these effects can be assessed. Note that this structure is suggested by Blanchard's (2018) toy model, but these effects from the output gap to the potential could also be found in DeLong & Summers (2012), Jordà et al. (2011), and Cerra et al. (2020). For instance, DeLong & Summers (2012) define the hysteresis elasticity as the percent reduction in the flow of future potential output per percentage-point-year of the present-period output gap. If equation 3 is expressed in $t + 1$, b has the same interpretation.

The unemployment rate u_t is decomposed into the NAIRU $\bar{u}_t$ and the unemployment gap $\hat{u}_t$. The unemployment gap is an autoregressive variable affected by the output gap (Okun's law). The NAIRU is an autoregressive process, and it gravitates toward the natural unemployment rate $\bar{u}_t^{ss}$, which is time-varying. The unemployment gap affects the NAIRU. A time-varying natural unemployment rate should capture some trends shown in Figure 2. For instance, demography and technological changes could permanently affect the natural unemployment rate, and therefore, shocks to the natural unemployment rate $\varepsilon_t^{\bar{u}^{ss}}$ should capture these features. As shown in figures 4, 5, and 6, unemployment rates surge significantly during economic crises and take some time to return to their previous levels, so it seems possible that temporary shocks to the unemployment gap could also affect the NAIRU. Estimating b_u can help assess the relevance of these effects.

The system of equations here proposed is estimated using a Bayesian Kalman filter. The estimation was performed for 73 economies, separetely. In the following subsections the *a priori* distributions are discussed at lenght. Then, the regions of practical equivalence are also discussed. Finally, some robustness checks are explained.

3.2 *A priori* distributions

Today's posterior is tomorrow's prior.

Lindley (1970)

It is known that the *a priori* distribution influences the *a posteriori* distribution. For this reason, this subsection discusses at length the shapes of the *a priori* distributions for b and b_u, which are the key and relatively novel parameters of this study. Then it deals with alternative *a priori* distribution for these parameters. Finally, it briefly discusses the *a priori* distributions for a_u, ϕ, τ_1, and τ_2.

The *a priori* distributions can be selected from various sources, such as a metanalysis of the previous literature and/or expert judgment. In the case of literature-informed priors, a meta-analysis of existing treatment effects can be used as a prior. Notice that the result of the meta-analysis gives a highly informative prior.

From expert judgement, the most up to date opinion by a leading economists is from O. Blanchard (2018, p.118) who stated:

> "Thus, the general advice must be that central banks should keep the natural rate hypothesis (extended to mean positive but low values of b and a) as their baseline, but keep an open mind and put some weight on the alternatives. For example, given the evidence on labor force participation and on the stickiness of inflation expectations presented earlier, I believe that there is a strong case, although not an overwhelming case, to allow US output to exceed potential for some time, so as to reintegrate some of the workers who left the labor force during the last ten years." (Underlined by the author)

From O. Blanchard (2018), two key aspects follow. First, b and b_u are most likely to be *positive* and *small*. For an economist trained in the mainstream school of thought, the *a priori* distributions of these parameters should be tight and around zero. From all this, the *a priori* distribution should have a higher probability mass around zero while using a distribution with a range of exclusively positive values. For an economist trained in the mainstream, making a case for negative values is extremely difficult. Also, the empirical case is hard to make, as previous literature has yet to find negative values.

From previous literature, there are three studies worth mentioning: DeLong & Summers (2012), Łukasz Rawdanowicz et al. (2014), Jordà et al. (2020), and Ball & Onken (2022). First, DeLong & Summers (2012) gathered micro and macro-economic evidence for the United States and suggested some values for b. They found evidence suggesting that (η in their parlance) could be as small as 0.065 and as high as 0.34[2]. After dissecting all the information gathered, DeLong & Summers (2012) posit that $0 \leq b \leq 0.25$ in the United States.

The study of Łukasz Rawdanowicz et al. (2014) also provides some back-of-the-envelope calculations for b in OECD economies (see table 1 of Łukasz Rawdanowicz et al. (2014)). In their study, they report that b could be as small as 0.08 and as high as 1.2. The average of their reported potential GDP hysteresis elasticities (b) calibrations is 0.5 with a standard error of 0.05. Interestingly, they did not report negative hysteresis elasticities (b), even though their proposed methodology yielded negative values in some economies. If these negative hysteresis elasticities are included, the average potential GDP hysteresis elasticity is 0.27 with a standard error of 0.09. Finally, Jordà et al. (2020) estimated b for 18 developed economies. In a sample from 1870 to 2015, they found that b is about 0.25 with a standard error 0.02 while in a more recent sample (1950-2015) they found that b is equal to 0.67 with a standard error of 0.16.

Other sources that can inform the choice of *a priori* distributions are quantitative exercises done by the econometrician. In this sense, Ball & Onken (2022) provide a way to estimate the hysteresis elasticity of the NAIRU using an error-correction model and the OECD's real-time estimates of the NAIRU. Thus, this study applies an error-correction model using OECD's real-time estimates of potential GDP to estimate the potential GDP hysteresis elasticity. The same is done for IMF's WEO potential output estimates.[3]

The following forestplot shows the potential GDP hysteresis elasticities estimates from prior studies. Interestingly, most studies have found positive and statistically different from zero effects. More importantly, the size of the effect is economically relevant and far from the natural rate hypothesis.

On average, prior literature suggests that this parameter is about 0.35. The highest estimate is about 0.67, with relatively high uncertainty. The smallest guess is from DeLong & Summers (2012), who suggest that, on average, it could be about 0.22. The test of equality of prior literature estimates ($\theta_i = \theta_j$) is rejected, which is unsurprising as they consider different countries and use different methodologies to estimate the quantitiy.

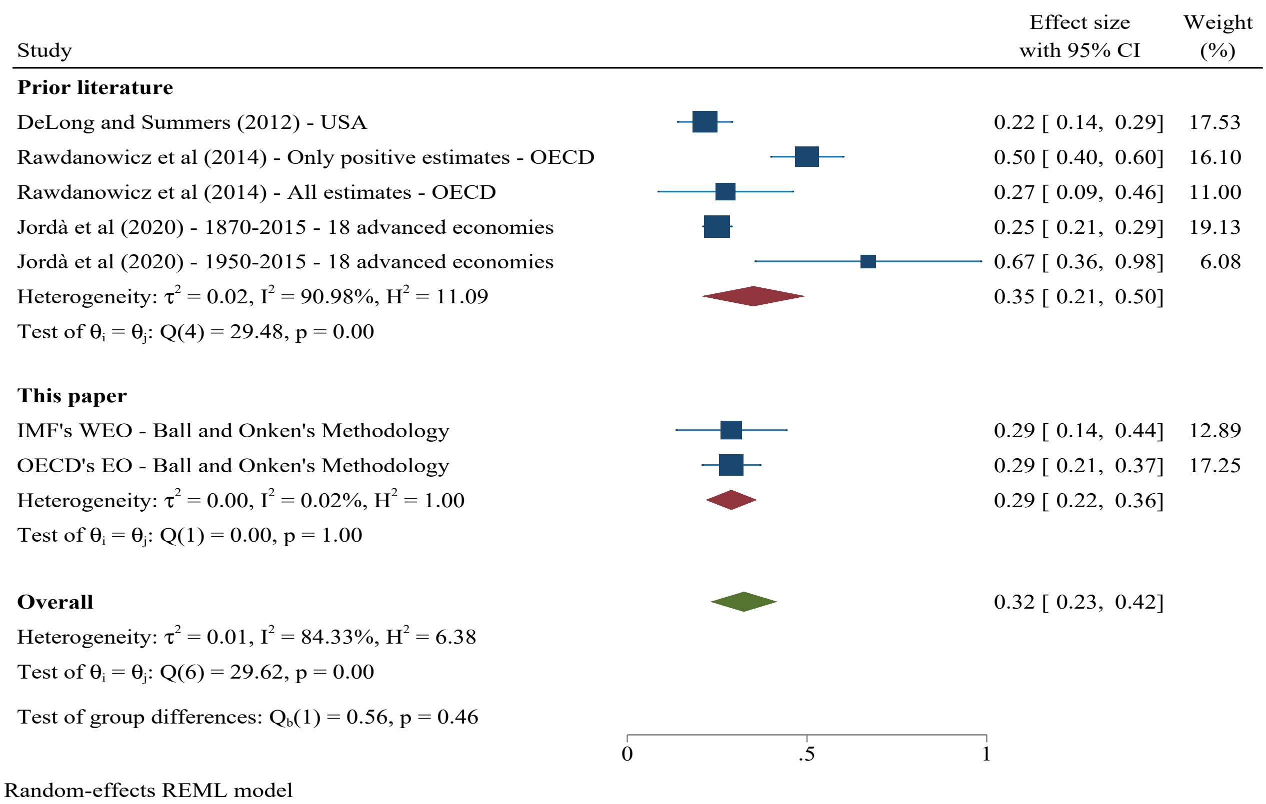
[2]It must be noted that all the potential numbers for η given by DeLong & Summers (2012) have no uncertainty associated, as they are well-informed back-of-the-envelope calculations. The average of all the potential value of η is 0.216 with a standard error of 0.038

[3]See appendix A for details.

This paper also used IMF's and OECD's potential GDP estimates to estimate the potential GDP hysteresis elasticity. On average, the estimated hysteresis elasticity using Ball & Onken (2022) approach is 0.29. The main difference is the uncertainty of the estimates, with IMF's being more uncertain.Some factors could explain the differences in uncertainty. First, the length of the time series used is longer in OECD's economic outlook. Second, OECD's estimates for each country studied are methodologically aligned (Production function approach, see Chalaux & Guillemette (2019)), while IMF's estimates methodology is not homogenous across countries.

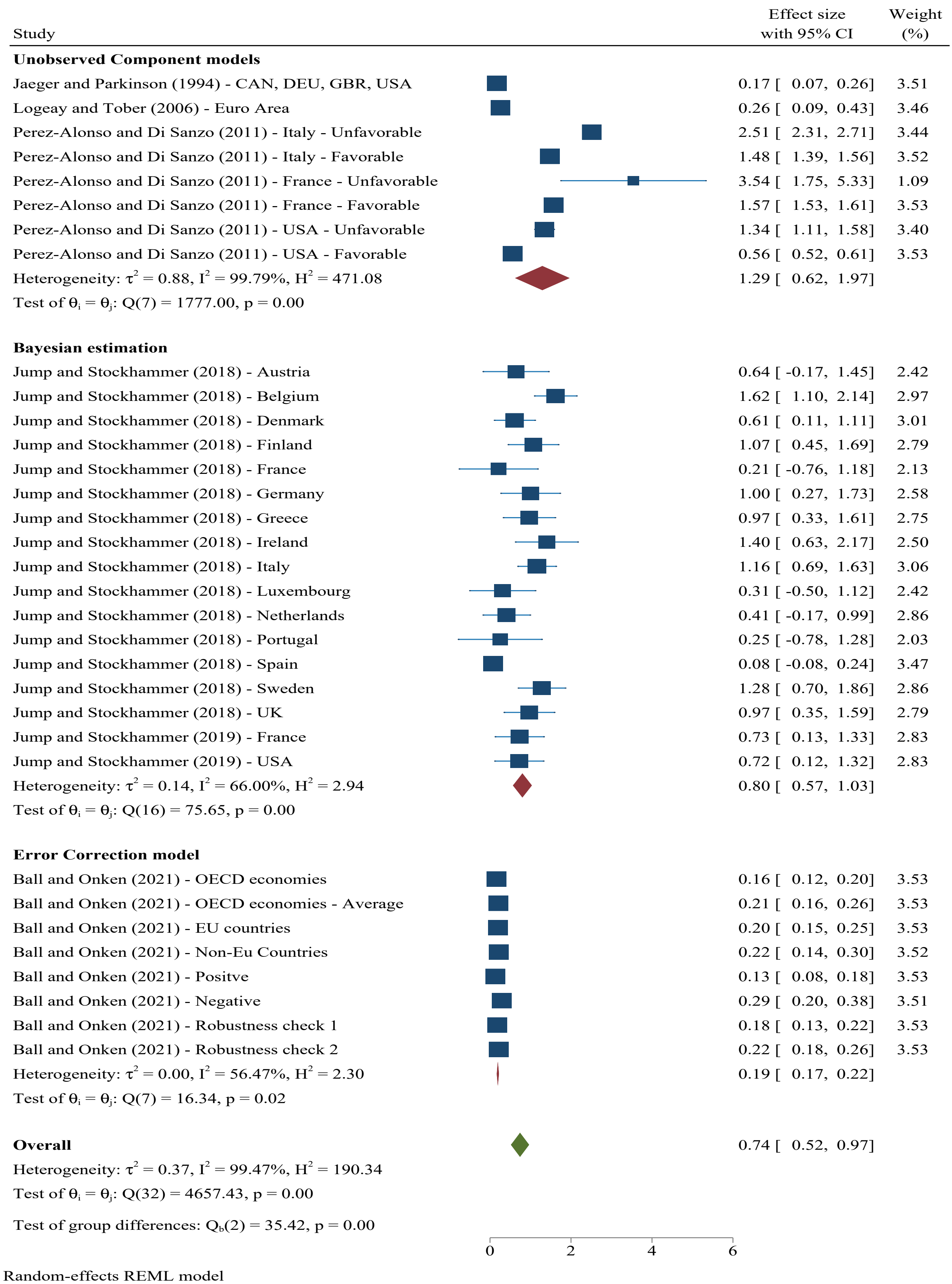
By combining all the information contained in the literature, the potential GDP hysteresis elasticity is about 0.35, with a 95% CI from 0.21 to 0.5. Information from estimates of this potential GDP hysteresis elasticity from OECD and IMF's potential output estimates yield a similar result (0.29 [0.22-0.36]) and the test of group differences (Prior literature vs. This paper estimates) is not rejected, suggesting similarities across estimates. Finally, information from all sources suggests that the potential GDP hysteresis elasticity is about 0.32, with a 95% CI from 0.23 to 0.42. The literature-informed prior for the potential GDP hysteresis elasticity can be derived from this last estimate: $N(0.32, 0.045)$.

Figure 8: Meta-analysis of Potential GDP hysteresis elasticities estimates - Forestplot



Source: Author's calculations using WEO data

Figure 9: Meta-analysis of NAIRU hysteresis elasticities estimates - Forestplot



Source: Author's calculations using WEO data

Regarding the NAIRU hysteresis elasticity b_u, figure 9 summarizes prior estimates using a forest-plot. A substantial amount of heterogeneity is found, with estimates as high as 3.5 and estimates as small as 0.08. However, it should be noted that no study reported a negative point estimate. The quality of the studies is significantly better than those used for potential GDP hysteresis elasticities, as there are no back-of-the-envelope calculations. For instance, Jaeger & Parkinson (1994), Pérez-Alonso & Sanzo (2010), and Logeay & Tober (2006) used unobserved component models to estimate simultaneously the NAIRU hysteresis elasticity as well as the NAIRU itself. Jump & Stockhammer (2018) and Jump & Stockhammer (2019) used a Kalman filter with Bayesian methods, being the closest to the framework used in this study. Finally, Ball & Onken (2022) used a frequentist approach and used the NAIRU estimates from the OECD estimates. The literature-informed prior for the potential GDP hysteresis elasticity can be derived from this last estimate: $N(0.72, 0.06)$.

Now, as shown, there is a stark contrast with the expert judgment, which suggests that b and b_u are positive and small, and the results from meta-analysis, which is hard to reconcile with one prior distribution. If prior distributions should summarize the best information available for the econometrician, the results from the meta-analysis should be used instead of expert judgment.

However, this study uses, as a baseline, an a priori distribution close to the expert judgment in mainstream macroeconomics, that is, an a priori distribution with a high mass of probability around zero and in the positive range. The rationale for this is that the natural rate hypothesis is the default for most economists. For this reason, the use of an a priori distribution different from what most economists assume might lead to an over-rejection of the natural rate hypothesis. However, the findings could be criticized for assuming their result as it is known that the prior distribution, especially a highly informative one, can affect the posterior inference. Thus, we used a relatively uninformative a priori distribution to not bias the result. However, an estimation using literature-informed prior is also used as a robustness check. In other words, it is preferable to be highly conservative and use a priori distributions with a higher probability of around zero because if the estimation finds rejections of the natural rate hypothesis, these rejections are likely to be driven by the data rather than by the econometrician judgment.

Another key parameter is the NAIRU persistence a_u and an *a priori* distribution for a_u should be defined. It should lie in the 0 - 1 interval since it is an autoregressive term. This study follows Jump & Stockhammer (2018) who used a uniform distribution, putting the same weight on all possible values. It should be noted that for some economists (Ball & Onken (2022), Rusticelli et al. (2015) and Galí (2015)) this parameter is assumed to be equal to 1, which suggest that some already believe in the existence of shocks that affect the unemployment rate permanently. Stanley (2004) presented a meta-analysis suggesting that $a_u = 1$. Thus, in a robustness check, instead of estimating a_u, it is fixed to be equal to 1, to take into account this prior knowledge.

The following table summarize the *a priori* distributions used in the baseline model.

Table 1: Baseline *a priori* distributions

Parameter	*A priori* distribution	Source	Rationale
a_u	$Uniform(0,1)$	Jump & Stockhammer (2018)	Autoregressive parameter
b	$Gamma(0.3, 0.3)$	None	Close to zero and only positive values
b_u	$Gamma(0.3, 0.3)$	Jump & Stockhammer (2018)	Close to zero and only positive values
ϕ	$Normal(0.6, 0.05)[0.4 - 0.8]$	Blagrave et al. (2015)	Half-life close to 1 year but a bit higher
α	$Normal(0.6, 0.025)[0.4 - 0.8]$	Blagrave et al. (2015)	Half-life close to 1 year but a bit higher
β	$Normal(0.25, 0.05)[0.1 - 0.6]$	Blagrave et al. (2015)	Half-life close to 1 year but a bit higher

Source: Author's elaboration. In square brackets are imposed restrictions.

3.3 Regions of practical equivalence

Moreover, the key question should not be, Can I reject zero?
Instead it should be, Can I reject all small (or all large) values
for this parameter?
De-Long & Lang (1992)

In frequentist statistics, it is usual to test whether an estimate differs from zero. From a Bayesian perspective, the null hypothesis cannot be a single point, rather, the posterior distribution should be compared to a region of practical equivalence (ROPE) (see Kruschke (2021)). Kruschke (2021) provides some rules of thumb to define the ROPE in linear and logistic regressions. However, there is no rule of thumb for determining the ROPE in the study context. Moreover, the object of interest in this study are not parameters by themselves but two impulse-response functions: the effect of a shock to the unemployment gap on the NAIRU and the impact of a shock to the output gap on potential GDP. From an econometrician perspective, a way to define the ROPE interval is to pick a value k for the following statement: "a 1-unit unemployment gap shock have a relevant effect on the NAIRU if the effect in the fifth year is higher or equal to k"[4]. Thus, the following decision rule is proposed:

- If the 90% HDI is outside the 0 - k interval, the natural rate hypothesis is rejected.
- If the 90% HDI is contained in the 0 - k interval, the natural rate hypothesis is accepted.
- Otherwise, the researcher should remain undecisive.

[4]This should also apply for potential GDP.

It should be noted that the election of k is completely arbitrary and given the importance of the question, it should be highly debated[5]. For this reason, instead of defining one k, the author decided to use various k, from 0.1 to 0.5.

The use of the fifth year can also be debated. Regarding this, the author suggests that in the presence of *partial hysteresis* ($0 < a_u < 1$ and $b_u > 0$), the effect will dissappear in the long run, regardless of the values a_u and b_u, so in the opinion of the author a five-year period is sufficiently long to capture highly persistent effects while also being able to accept that there are cases in which the effect disappears quickly.

There are other ways to define the ROPE. For instance, one of the main implications of the potential existence of hysteresis effects is that fiscal deficits can become self-financing (see DeLong & Summers (2012)). DeLong & Summers (2012) provided a simple model to show under which conditions a transitory expansionary fiscal policy is self-financing. Solving for the potential GDP hysteresis elasticity, the following expression is found[6].

$$b \geq \frac{(r-g)(1-\mu\tau)}{\mu\tau} \tag{13}$$

where b is the hysteresis elasticity, r is the real government borrowing rate, g is the long-run potential GDP growth, μ is the fiscal multiplier, and τ is the marginal tax-and-transfer rate. DeLong & Summers (2012) argue that under plausible values of r, g, μ, and τ, if b is greater than 0.05, then a transitory expansionary fiscal policy is self-financing. Thus, the area from 0 to 0.05 could be the ROPE. Notice that defining this ROPE for each economy studied requires information about μ and τ and is beyond the scope of the study.

3.4 Robustness checks

This subsection proposes two kinds of robustness checks. Some are related to the model structure, while others are related to the *a priori* distributions. Regarding the first type of robustness checks, the following changes to the baseline model were performed.

[5] The choice of k in this question is more likely to reflect the econometrician ideology, rather than an objective reason. For the author, a $k > 0.4$ is extremely high, as it suggest that if an economy suffers an economic crisis that rises the unemployment rate in 2 points, if in the fifth year the NAIRU is a about 0.8 points higher than prior to the crisis, this should not motivate a central bank to act against that situation, which seems at odds with social reality.

[6] See page 239.

- The first alternative model is to fix the NAIRU persistence $a_u = 1$, which implies that the NAIRU is assumed to be a unit-root process. This modeling choice is seen in previous studies like Rusticelli et al. (2015) and Jaeger & Parkinson (1994), among others.
- The second alternative model is similar. Still, these variables are modeled as fixed parameters instead of modeling the long-run GDP growth rate γ_t^{ss} and the natural unemployment rate as $\bar{u}_t^{ss}$ as unit root processes, these variables are modeled as fixed parameters[7]. This modification is closer to the usual modeling choice of a constant steady state seen in the literature.
- A third robustness check is proposed. The results may be biased because the simple model ignores critical variables such as inflation and interest rates. For this reason, a simple New-Keynesian model was estimated for eighteen economies. The model includes an IS curve, a Phillips curve, an Okun's law curve, and a Taylor rule. Appendix E shows the model's structure and key information on the estimation and data.

Regarding the second type of robustness checks, two robustness checks were performed.

- A first robustness is to use literature-informed *a priori* distributions for b and b_u, like the ones defined in section 3.2.
- In the baseline model, the standard deviations of the shocks were calibrated. A robustness check is to estimate these standard deviations.

To assess robustness, the following rule of thumb was used. The estimate is robust to some modification if the posterior mean of the baseline model is inside the 90% HDI of the alternative model. The paper also assesses the robustness of testing the natural rate hypothesis using the ROPE defined in section 3.3. The robustness checks provide five estimates of the NAIRU and Potential GDP hysteresis elasticities for some economies. In 18 economies, there are six estimates for these hysteresis elasticities.

Appendix B shows the equations for the first two robustness checks. Table C1 shows the *a priori* distributions and the calibrations used in the baseline model, and the robustness checks. Table D1 shows *a priori* distributions used in the new-Keynesian model.

[7]The long-run growth rate is equal to the GDP growth rate sample average and the natural rate of unemployment is equal to the sample average of the unemploymen rate. This also implies that the standard deviations of $\varepsilon_t^{\gamma^{ss}}$ and $\varepsilon_t^{\bar{u}^{ss}}$ are shrinked to zero.

4 Results

This section is divided into three subsections. Subsection 4.1 discusses the baseline estimates and compares the baseline estimates to alternative specifications. This subsection also deals with the convergence of the *a posteriori* distributions. Subsection 4.2 assesses the *natural rate hypothesis* using the ROPE approach explained in subsection 3.3; this assessment is performed for the baseline model results and the other five robustness checks proposed in subsection 3.4. Finally, subsection 4.3 analyzes the cross-country heterogeneity in the estimatesa_u, b, and b_u.

4.1 Estimates

This subsection discusses the baseline estimates and also compares the baseline estimates to alternative specifications. Before discussing the estimates, it is important to discuss the estimation process.

4.1.1 The estimation

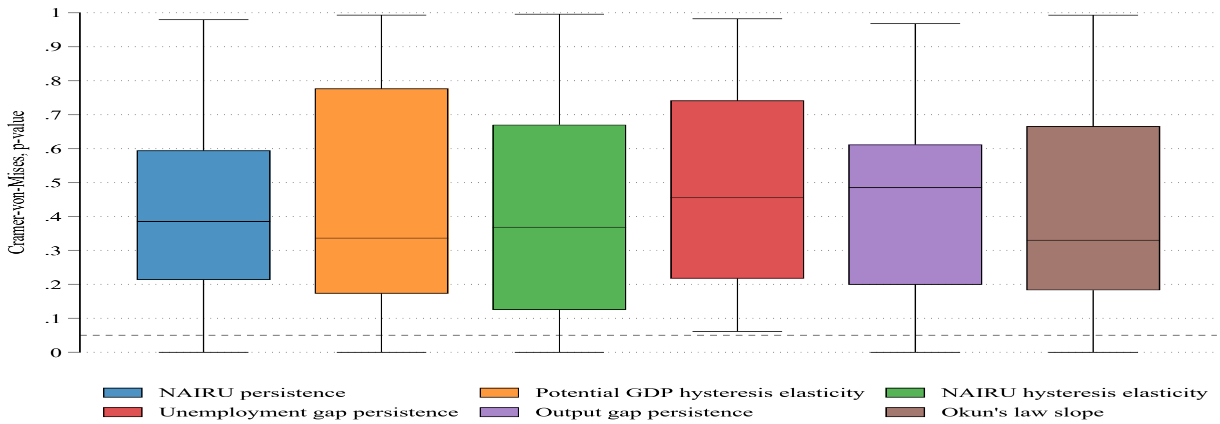
This study follows the Bayesian approach to estimate the model (see An & Schorfheide (2007)). The *a posteriori* distribution associated with the vector of observables is computed numerically using a Monte Carlo Markov Chain sampling approach. Specifically, the Metropolis–Hastings algorithm was used to obtain a random draw of size 100.000 (with a burn-in of 50%) from the *a posteriori* distribution of the parameters. The choice of 100.000 draws might seem small, but the scope of the study to estimate the models for more than 70 economies imposes some restrictions. To assess convergence of the *a posteriori* distribution, the diagnostic test proposed by Heidelberger & Welch (1981) and Heidelberger & Welch (1983) was used[8].

Regarding the baseline model estimate, the convergence can be deemed as satisfactory. Figure 10 shows the box-plots of the p-values of the Heidelberg and Welch diagnostic test for the six parameters that were estimated using the *a priori* distributions shown in table 1. In all six parameters, most of the p-values are above 0.05, meaning that a 5% of statistical significance, it is not possible to reject that the distributions come from a stationary distribution. Spain was only one economy with 5 out of 6 of its parameters with a p-value below 0.05 which suggests serious convergence problems. In addition, there are eight economies with only one of the estimated parameters with a p-value below

[8]The test consists of comparing the distribution of early batches of the Markov chain to that of batches at the end the of the chain. If the null that the distributions are not different is not rejected, the conclusion is that the posterior distribution of the estimated parameter is stationary.

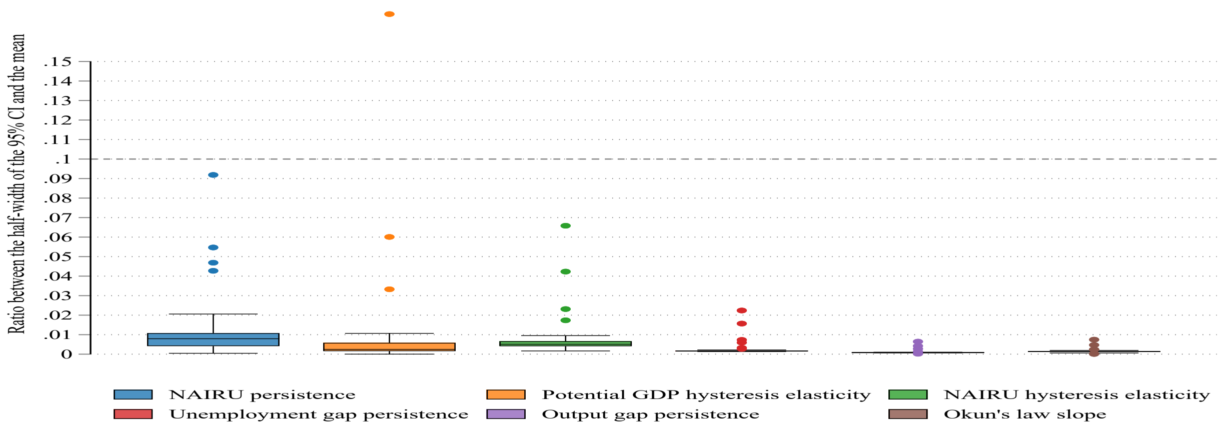
0.05. From all this, there are 64 economies in which all parameters seem to have converged to a stationary distribution.

Figure 10: Heidelberg and Welch test - First step p-value



Source: Author's calculations using WEO data

Figure 11: Heidelberg and Welch test - Second step Halfwidth ratio



Source: Author's calculations using WEO data

The Heidelberg and Welch diagnostic test also assesses the precision of the estimates. Figure 11 shows the ratio between the half-width of the 95% CI and the mean, and it can be seen than in most cases this ratio is below 0.1 suggesting that most estimates are precise enough to render credible inferences of the parameter's mean.

In regards to the other estimates from the robustness checks, the situation is similar. Table 2 show the results of the Heidelberg and Welch test by type of model. As it was already shown in previous paragraphs, in 64 out 73 economies all the parameters converged, in 8 economies out 73 all but one parameter converged, and in 1 economy 5 out of 6 parameters did not converge. The statistics are better for the model with constant long-run steady state. For that model, in 68 economies out 73 all parameters converged; in only 4 economies all parameters but one converged; and in only 1 economy all paramters but two converged. The model in which the NAIRU is assumed as a unit-root process is the best performing, as all parameters converged to a stationary distribution. The New-Keynesian model performed well, in 26 economies out of 28 all the 12 parameters converged, and in 2 economies all paramaters but one converged. In regards to the literature informed model, it also performed well, in 67 out 73 economies all parameters converged, and in the remaining 6 only one out six parameters did not converge. The worst performing model is the one in which the standard deviations of the shocks was estimated, in only 31 out 73 economies all the parameters converged, which suggests the results of this model should be considered with caution.

Table 2: Results of the Heidelberg and Welch test by type of model

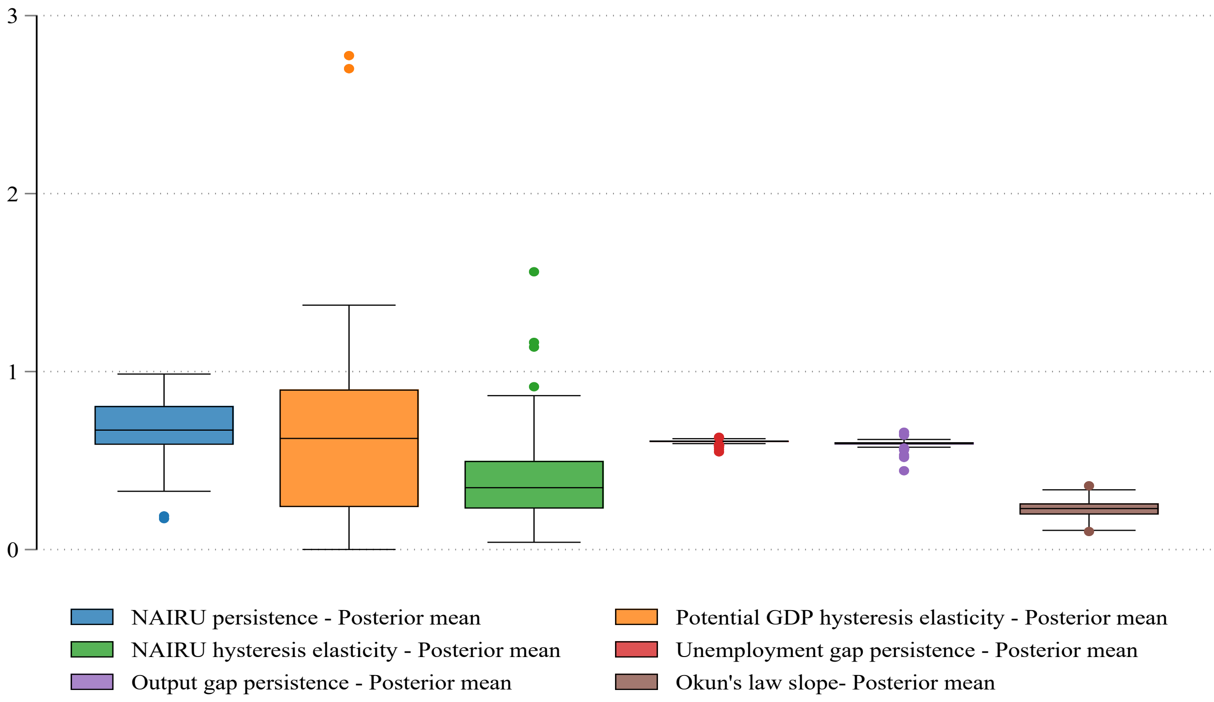
Model	Number of parameters that did not converge								Countries	Parameters
	0	1	2	3	4	5	6	More than 6		
Baseline model	64	8	0	0	0	1	0	NA	73	6
Constant LR model	68	4	1	0	0	0	0	NA	73	6
Unit-root model	73	0	0	0	0	0	NA	NA	73	5
NK model	26	2	0	0	0	0	0	0	28	12
Literature informed Priors	67	6	0	0	0	0	0	NA	73	6
Estimated Shocks std.	31	17	7	6	5	4	0	3	73	13

Source: Author's elaboration using WEO data and Òscar Jordà et al. (2017) data.

4.1.2 Baseline estimates and its robustness

Figure 12 shows the distribution of the parameters' posterior means.

Figure 12: Parameter's posterior mean - Boxplot - Baseline model



Source: Author's calculations using WEO data

The first parameter is the NAIRU persistence (a_u) and it can be seen that the distribution of parameters suggests a higher persistence than the implied by an uniform distribution from zero to 1. The interquartile range of the parameters posterior mean is from 0.58 to 0.81, with a median estimate of 0.67. This median estimate implies a half-life close to two-years, suggesting the level of persistence is not as high. However, 63 out 73 economies include 0.9 in the 90% credible intervarls, which suggests that a half-life of 6.5 year cannot be rejected.

The second parameter is the potential GDP hysteresis elasticity (b). The posterior means are diferent to the *a priori* distribution used. The 10-90 range of the parameters' posterior mean is from 0.005 to 1.21, which is close to the interval found by Łukasz Rawdanowicz et al. (2014) from zero to 1.2. It can also be seen that the interquartile range is from 0.23 to 0.89, sugessting a substantial level of hysteresis in at least three quarters of the sample studied.

The third parameter is the NAIRU hysteresis elasticity (b_u). The posterior means are diferent to the *a priori* distribution used. The 10-90 range of the parameters' posterior mean is from 0.12 to 0.91, while the interquartile range starts at 0.23 and ends in 0.5. Compared to other studies that found relevant hysteresis effects of 0.16 (see Ball & Onken (2022)) the estimates here found are substantially higher suggesting a higher deal of hysteresis. However, there are also studies that found hysteresis elasticities higher than the unity (see Pérez-Alonso & Sanzo (2010)) that are not so common in the sample studied.

The unemployment gap and the output gap persistences are shown in the fourth and fifth box plot of figure 12. It is important to note that the *a priori* distributions used were relatively tight reflecting qualitative choice of the level of persistence of the demand shocks. Finally, there is more variation on the Okun's law slope parameter as it was allowed by using a *loose a priori* distribution.

In subsection 3.4 five robustness checks were proposed. The first robustness check is whether the estimates are robust to assuming that the NAIRU is a unit-root process. Figure E1 shows the estimates for the baseline model and the alternative one. In essence it is found that the estimates are robust to this model specification. In regards to the potential GDP hysteresis elasticity only two out of 73 estimates are statiscally different. In regards to the NAIRU hysteresis elasticity, the estimates are also robust with only four estimates out of 73 being statistically different.

Figure E2 shows the estimates for the baseline model and the alternative one where the long-run steady state is constant. It is found that some estimates are robust and others are not. The potential GDP hysteresis elasticity is not robust to this change in the model specification and tend to increase importantly. This is perhaps due to the fact that the alternative model is not able to detect long-run effects growth rate shocks and confounds them with demand shocks, and therefore, it increases the level of hysteresis. The NAIRU hysteresis elasticity is robust to this modification as only three economies have statistically different estimates accross models. Finally, the result is similar for the NAIRU persistence as in only six economies the estimates differ significantly.

Figure E3 shows the estimates for the baseline model and the New-Keynesian model. It is found that most estimates are robust to this change. The potential GDP hysteresis elasticity differs in eight economies out of 28, while the proportion is large, it is not easy to extract a pattern, as in four countries the potential GDP hysteresis elasticity is higher in the New-Keynesian model, while in other four countries the opposite happens. The other parameters (a_u and b_u are robust as none of the parameters differ statistically accross models.

All in all, model specification does not seem to change the conclusions of the study.

However, it is known that Bayesian methods are sensitive to the *a priori* distribution used, and the estimates might not be robust to changes on it. Figure E4 shows the estimates for the baseline model and the model that used literature-informed *a priori* distributions. It is found that the estimates are not robust to this change. In essence it is found that the potential GDP hysteresis elasticity differs in most ecoomies, and while the correlation is positive (see panel a of Figure E4) there is an interesting shift in the results. In some economies, where the baseline potential GDP hysteresis elasticity is smaller than 0.4, the potential GDP hysteresis elasticity is higher in the model that used literature-informed *a priori* distributions. The opposite happens when the baseline estimate is above 0.4. Something similar happens with the NAIRU hysteresis elasticity but in general the estimates tend to be significantly higher.

Finally, figure E5 shows the estimates for the baseline model and the model that used estimated standard deviations of the shocks. It is found that the estimates are somewhat robust to this change. In essence it is found that the potential GDP hysteresis elasticity differs in some economies but it is not easy to find a pattern in the differences. Regarding the NAIRU hysteresis elasticities the alternative model suggests a bias in the baseline model. The estimates that are statistically diferent tend to be smaller in the alternative model than in the baseline model. Something similar happens with the NAIRU persistence.

As it can be seen the model is not robust to changes in the *a priori* distribution used. However, as it will be seen in the following subsection, the lack of robustness suggest that the level of hysteresis tends to be lower in the baseline model. Thus, the qualitative results are the same.

4.2 Should we reject the natural rate hypothesis? Results from the ROPE framework

This subsection discusses the *natural rate hypothesis*. As it was shown in subsection 3.3, in Bayesian statistics the null hypothesis cannot be a single point, rather it should be a ROPE (see Kruschke (2021)). Given that it is not easy to pin-point at which point the natural rate hypothesis holds, the author decided to use varios cutoff points.

Table 3 shows the results of the decision process about the *natural rate hypothesis* using different cutoff points. In regards to the baseline model, it is found that potential GDP exhibits a relatively level of hysteresis which suggests than in 43 out 73 economies the *natural rate hypothesis* should be rejected, even using the highest[9] cut-off point. The results also suggests that in the baseline model only in 16 out 73 economies the null hypothesis should be accepted using the highest cutoff point. Regarding the NAIRU, there is also a relevant level of hysteresis, if $k = 0.3$ the *natural rate hypothesis* for the NAIRU is accepted in 8 out 73 economies, while it is rejected in 19 economies, while the

[9]And perhaps socially unaceptable.

reamining 46 economies remain undecisive. These results by its own suggest that the *natural rate hypothesis* does not hold in the majority of economies studied.

Table 3: Results of the ROPE decision aproach

Model	Potential GDP					NAIRU				
	k					k				
	0.1	0.2	0.3	0.4	0.5	0.1	0.2	0.3	0.4	0.5
Baseline Model										
Accepts the NRH	11	15	16	16	16	1	3	8	11	14
Undecisive	15	14	13	14	14	40	46	46	47	50
Rejects the NRH	47	44	44	43	43	32	24	19	15	9
Constant Long-run Model										
Accepts the NRH	5	5	5	5	5	2	3	7	11	13
Undecisive	3	4	4	4	5	39	44	47	45	52
Rejects the NRH	65	64	64	64	63	32	26	19	17	8
Unit root NAIRU Model										
Accepts the NRH	11	15	16	16	16	0	1	2	4	8
Undecisive	14	11	12	12	13	32	39	43	47	49
Rejects the NRH	48	47	45	45	44	41	33	28	22	16
New Keynesian Model										
Accepts the NRH	2	3	4	4	4	0	2	2	2	5
Undecisive	5	4	5	6	7	16	18	21	22	21
Rejects the NRH	21	21	19	18	17	12	8	5	4	2
Literature informed priors										
Accepts the NRH	6	7	9	9	10	1	2	2	3	6
Undecisive	4	5	5	7	6	13	41	48	54	56
Rejects the NRH	63	61	59	57	57	59	30	23	16	11
Shocks estimated std.										
Accepts the NRH	0	0	0	0	0	1	8	13	21	27
Undecisive	26	29	34	37	39	60	61	57	50	45
Rejects the NRH	47	44	39	36	34	12	4	3	2	1

Source: Author's elaboration using WEO data and Òscar Jordà et al. (2017) data.

It could be argued that the baseline model betted against the *natural rate hypothesis* and that the specification is not as conventional as usual. Thus, a more conventional model which assumes constant steady states might be able to overturn the results. The opposite is found in regards to potential GDP as actually only in 5 economies it can be said the that *natural rate hypothesis* holds and the undecisiveness level is also low, suggesting strong rejections in 64 out of the 73 economies studied. In regards to the NAIRU, the results are similar to the baseline model. The rationale for this result is that actually by assuming a constant long-run steady state, all those long-run shocks that were captured by $\varepsilon_t^{\gamma^{ss}}$ are not *correctly* identified and are mixed up with demand shocks and shock to the medium-run growth rate. Thus, structural changes in γ_t^{ss} that coincided with economic crisis are assumed to be caused by demand shocks, rather than by long-run shocks. Thus, there is an increase in b as it was shown previously in figure E2.

It could also be argued that the baseline model bets in favour of the *natural rate hypothesis* and that the specification is not as conventional as usual. It has become an stylized fact to assume that the NAIRU follows a unit-root process (see O. Blanchard & Katz (1997), O. J. Blanchard & Summers (1986), Rusticelli et al. (2015), Galí (2015) and Jaeger & Parkinson (1994)). While the argument against the unit-root process can be made[10] it is true that prior literature has found a higher level of persistence than the implied by a uniform *a priori* distribution. A way to deal with that critique is to assume that it is a unit-root process as others have made. The changes of the results of the *natural rate hypothesis* are as expected. There is now a higher level of rejection, with only 2 economies accepting this hypothesis when $k = 0.3$, instead of 8 as in the baseline model. This is expected as assuming that it is a unit-root process does not allow for bell-shaped impulse-response functions that eventualy die out.

The results from the New-Keynesian model are interesting. The inclusion of inflation dynamics and monetary policy rules does not seem to influence the conclusion importantly. Using the highest cutoff point of 0.5 only in 4 out of 28 economies (14.2% of the sample) the null hypothesis should be mantained in regards to GDP. There is also a low level of indecisiveness regarding GDP hysteresis. In terms of the NAIRU, the *natural rate hypothesis* holds only in 5 out 28 economies (17.2% of the sample) with a high level of indecisiveness.

The results in literature informed priors suggest that *natural rate hypothesis* holds in few economies. The result is not surprising as the modes of the *a priori* distributions are far from zero which can led to some over-rejections of the *natural rate hypothesis*. However, in qualitative terms the results are the same: the *natural rate hypothesis* should be rejected, regardless of the *a priori* distributions used.

For completeness the results for the model in which the standard deviations of the shocks are shown. The results are interesting. In the one hand, the results suggests that there is no economy in which there is no hysteresis on potential GDP, regardless of the cutoff point k. In stark contrast, it sugests a relevant level of indecisiveness on the NAIRU hysteresis and tends to suggests that the natural rate hypothesis holds. However, even in this scenario, in less than half of the sample studied the *natural rate hypothesis* holds.

[10]Unit-root process are unbounded process which is not consistent with the unemployment rate that is bound in the interval from zero to one.

The results shown in this section show that the *natural rate hypothesis* does not hold in most countries, regardless of the modelling assumptions or the *a priori* distributions used. Thus, the results imply an important update in our priors.

4.3 Exploring cross-country heterogeneity

This subsections explores the sources of cross-country heterogeneity on the key parameters estimated a, b, and b_u. To do so, it is useful to review prior literature on the sources of hysteresis.

The literature on hysteresis starts by looking at the unemployment rate rather than GDP. There are three main approaches that explain hysteresis in the unemployment rate: the insider-outsider explaination (see O. Blanchard & Katz (1997), Drautzburg et al. (2021), Stansbury & Summers (2020)), the de-skilling explanaition (see d Abiad et al. (2009), O. Blanchard et al. (2015)) and the labor-market rigidities (see Nickell (1997) and Nugent (2012)).

The insiders-outsiders explanaition suggests that there are two distinct groups in the labor market: insiders and outsiders. Insiders are those who are already employed and have job security and benefits, such as regular pay raises, promotions, and pensions. Outsiders, on the other hand, are those who are unemployed or seeking employment, and therefore have no job security or benefits. O. Blanchard & Katz (1997) suggests insiders have the power to negotiate better wages and benefits for themselves, which creates a barrier to entry for outsiders, making it more difficult for them to find work. This can lead to a situation where insiders are protected, but outsiders struggle to find stable employment, creating a divide between the two groups. The insiders-outsiders theory can help explain certain labor market phenomena, such as why wages can be sticky (resistant to change), even in the face of changing economic conditions, and why unemployment can persist, even when there are available jobs.

Therefore, for the insiders-outsiders explanaition it is clear that labour market power measures such as the level of unionization can be key to explain the level of hysteresis in a given economy. As it can be seen in figures F1 and F4 , both the NAIRU persistence (a_u) and the NAIRU hysteresis elasticity are positively and significantly correlated with the union density at 1995[11]. Also there seems to be a positive correlation with the labour share on GDP which is an outcome variable that should be correlated with labor market power (see Drautzburg et al. (2021)). Thus, the findings seem to be aligned with the outsider-insider theory.

[11]Union density statistics are not so common, thus, the author used Botero et al. (2004) data on union density for 1995.

The de-skilling explanaition considers that when workers are unemployed for a long time, they may lose some of the skills and experience that they had when they were employed. This can make it harder for them to find work when the job market improves, even if there are more job openings available. This is because employers may be hesitant to hire workers who have been out of work for a long time, seeing them as less productive or less skilled than those who have been employed more recently (see Lockwood (1991)). This can lead to a situation where a high level of unemployment becomes entrenched, creating a cycle of long-term unemployment and skill losses.

For these reasons, a correlation between hysteresis (measured by a_u and b_u) and the incidence of long-term unemployment might be expected. At first glance the correlation should be positive, the higher the level of hysteresis, the more long-term unemployment. However, this assumes that hysteresis is more pervasive during crisis than during booms. If the contrary were to happen, that is that decreases on the unemployment rate have more persistent effects than increases on the unemployment rate, then a negative correlation could arise, as higher positive effects imply lower long-term unemployemt incidence. There is evidence pointing out that possibility (see Okun (1973), Girardi et al. (2020) Ball & Onken (2022)). Figure F2 a negative correlation between the NAIRU hysteresis elasticity and the long-term unemployment incidence[12]. A similar correlation is also found with the NAIRU persistence, although it is less clear (see figure F5).

Labour market rigidities can contribute to unemployment hysteresis, as they can make it more difficult for the labor market to adjust to changing economic conditions. Labour market rigidities refer to institutional or structural features of the labor market that can impede the functioning of the market (see Nickell (1997) and Nugent (2012)). For example, minimum wage laws, employment protection regulations, and collective bargaining agreements can all create rigidities that make it harder for firms to adjust to changes in economic conditions. Thus, it should be expected than in economies where labour market rigidities are more pervasive, there should be higher levels of hysteresis (measured by a_u and b_u) in the presence of stringent labour market rigidities (higher incidence of the minimum wage, higher unemployment benefits, among others). Figures F3 and F6 do not show that positive correlation and suggests no correlation among the labor market rigidities index proposed by Nugent (2012) as well as the unemployment benefits. In the case of the minimum wage to median wage ratio, there seems to be a positive correlation but is inflated by the presence of Colombia, once that economy is excluded of the analyses, the positive correlation vanishes.

[12]Measured as the share of unemployed people with an unemployment duration of 12 or more months.

All in all, the estimates tend to be more aligned with the view that unemployment hysteresis exists due to the insiders outsiders explanaition and does not seem to align with the view that unemployment hysteresis exists due to labour market rigidities.

It is now turn to look at GDP hysteresis. The focus on GDP hysteresis is more recent than the unemployment hysteresis literature. However, the theoretical insights come from endogenous growth models (see Cerra et al. (2020) for a literature review on the insights of GDP hysteresis). A production function approch can help idenfity the source of GDP hysteresis: productivity, capital and employment.

Regarding productivity, the endogenous TFP literature has suggested that economic crisis can generate protracted slowdowns in TFP growth. One of the most popular explanaitions is that R&D investments tend to be procyclical, and thus innovations is hindered after economic crisis (see Anzoategui et al. (2019), Jordà et al. (2020), Fernald et al. (2017) and Òscar Jordà et al. (2017)). Figure F7 shows a positive correlation between the potential GDP hysteresis elasticity and the procyclicality of TFP growth and GDP growth. This suggests that the potential GDP hysteresis elasticity is capturing hysteresis in TFP.

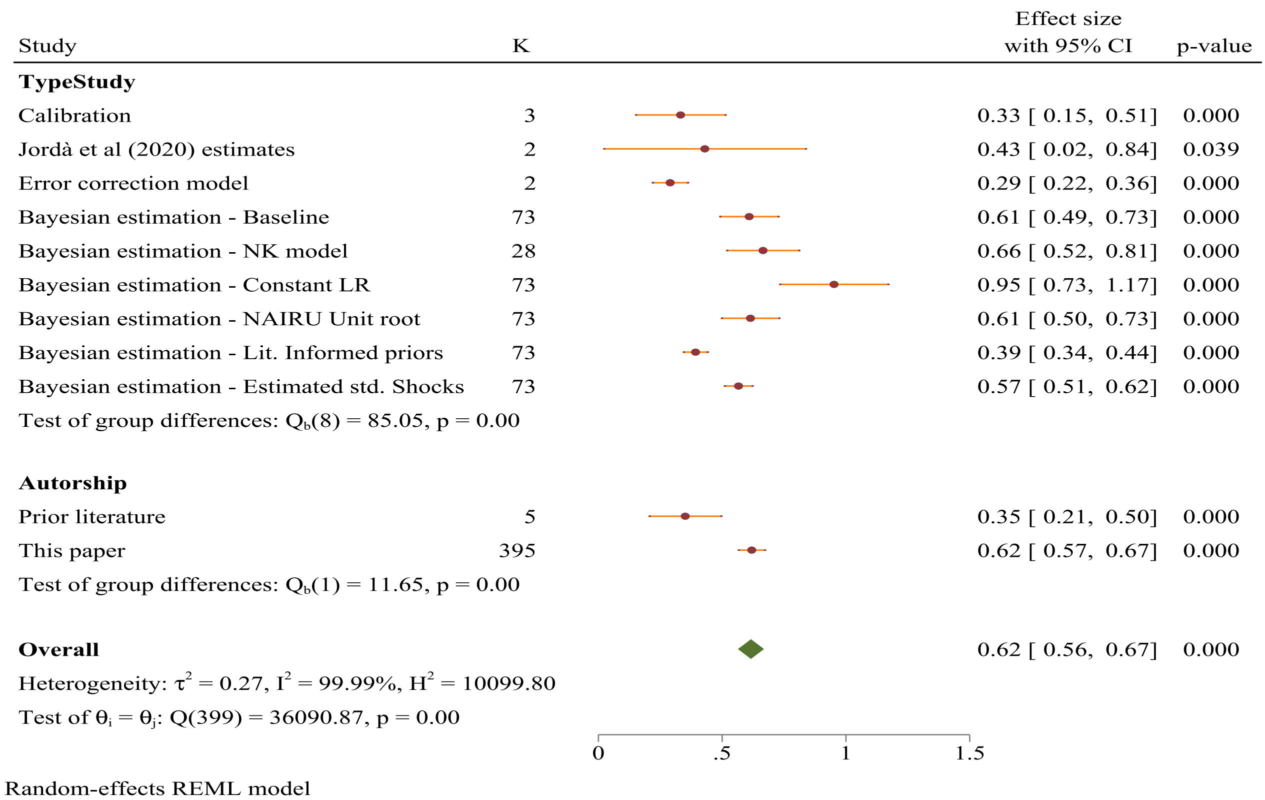
The linkages between capital accumulation and hysteresis arise from the fact that the accumulation of capital can affect the long-term path of the economy. If capital accumulation is slow or insufficient, the economy may not be able to fully recover from recessions or other economic shocks, leading to a persistent state of low economic activity and high unemployment. This is because the lack of investment in productive assets can lead to a decline in the productive capacity of the economy, which can make it harder to generate new jobs and economic growth. Figure F7 shows a positive correlation between the potential GDP hysteresis elasticity and the procyclicality of capital stock growth and GDP growth. This suggests that the potential GDP hysteresis elasticity is capturing hysteresis in capital stock.

Finally, there is no positive and statistically significant correlation between the employment growth procyclicality and the potential GDP hysteresis. This result is not surprising as Jordà et al. (2020) has found that the main sources of hysteresis from monetary policy shocks are TFP and capital, not employment.

5 Discussion

This subsection compares the estimated key parameters with previous estimates using a meta-analysis. Figure 13 shows the average potential GDP hysteresis elasticity by type of study/methodology as well as by the authorship. By type of study/methodology it can be found that the average estimate is relativaly stable in four model specifications (baseline, New-Keynesian model, NAIRU modeled as a Unit-root and the model where the standard deviations of the shocks were estimated), with relatively similar estimates, on average. The specification that used literature-informed *a priori* distributions has, on average, the lowest hysteresis elasticities. The rationale for this phenomena is that even though the specification assummes a mode higher than zero, the *a priori* distribution used is less sparse than the $Gamma(0.3, 0.3)$ distribution used in the other models.

Figure 13: Meta-analysis of Potential GDP hysteresis elasticities estimates - Forestplot



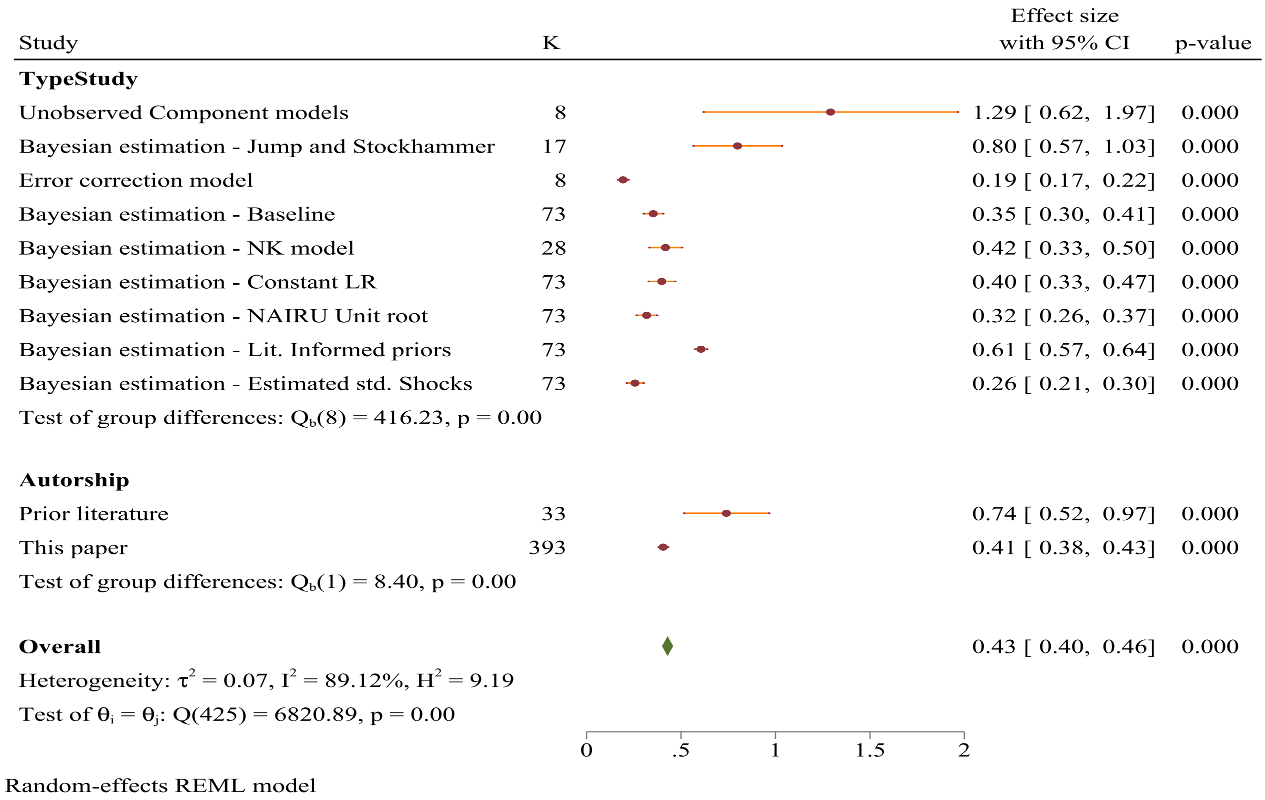
Source: Author's calculations using WEO data

The panel that compares the authorship shows clearly the contribution of this study. Prior to the study there were five estimates of the hysteresis elasticity, while the study provides 395 new estimates. The main insight of this study is that the level of hysteresis elasticity is significantly higher than previously thought. By combining all the information available it is feasible to derive relatively tight *a priori* distributions for future studied ($N(0.62, 0.03)$). However, it should be noted that, as it was shown in the previous section, there is substantial cross-country heterogeneity and therefore, a country-specific estimate might be better than an overall-estimate. These country-specific estimates are found in table G1.

Figure 14 shows the average potential GDP hysteresis elasticity by type of study/methodology as well as by the authorship. By type of study/methodology it can be found that the average estimate is relativaly stable in four model specifications (baseline, New-Keynesian model, the model with constant steady states and the model where the NAIRU is modeled as a Unit-root), with relatively similar estimates, on average. The contribution of this study tends to lie in between the estimates found by Ball & Onken (2022) (error correction model) and the estimates found by Jump & Stockhammer (2018), Jump & Stockhammer (2019), and Jaeger & Parkinson (1994) and Pérez-Alonso & Sanzo (2010) (unobserved components model). The specification that used literature-informed *a priori* distributions has, on average, the highest hysteresis elasticities among those estimates provided by this study. The rationale for this phenomena is that the specification assummes a mode higher than zero and also a relatively tight *a priori* distribution.

The panel that compares the authorship shows clearly the contribution of this study. Prior to the study there were 33 estimates of the hysteresis elasticity, while the study provides 393 new estimates. The main insight of this study is that the level of hysteresis elasticity is significantly higher than what the *natural rate hypothesis* suggests but is not as high as some studies have suggested. By combining all the information available it is feasible to derive relatively tight *a priori* distributions for future studies ($N(0.43, 0.015)$). However, it should be noted that, as it was shown in the previous section, there is substantial cross-country heterogeneity and therefore, a country-specific estimate might be better than an overall-estimate. These country-specific estimates are found in table G1.

Figure 14: Meta-analysis of NAIRU hysteresis elasticities estimates - Forestplot



Source: Author's calculations using WEO data

6 Conclusions

O. Blanchard (2018) asked in his study: "should we reject the natural rate hypothesis?" This study answers "Yes! Decisively."

In this paper, more evidence against the *natural rate hypothesis* is provided, particularly against the independence sub-hypothesis. To do this, a simple multivariate Kalman filter was proposed to extract both the potential output and the NAIRU while also estimating a_u, b_u and b through Bayesian methods. The results suggest that there is a relatively high level of hysteresis. On the one hand, a_u is relativaly high and the estimates do not reject a view of highly persistent NAIRU (63 countries have 0.9 within their 90% credible interval.). The NAIRU hysteresis elasticity was found to be about 0.43 on average, which is a level higher than than found by (Ball & Onken (2022) of 0.16, but lower than the estimates found by Jump & Stockhammer (2018), Jump & Stockhammer (2019), Jaeger & Parkinson (1994), and Pérez-Alonso & Sanzo (2010). Finally, the potential GDP hysteresis elasticity was about 0.62 on average, which a number higher than prior-literature average of 0.35 [95% CI 0.21-0.5].

Moreover, there was substantial cross-country heterogeneity, and the sources of this heterogeneity was explored. High-growth economies turn out to have higher potential output persistence and higher potential output hysteresis elasticities. Fatás (2000) anticipated this result by showing that this is a feature of models with endogenous TFP. European economies also exhibit higher levels of NAIRU hysteresis elasticity. Higher labor market rigidities also turned out to be correlated with higher NAIRU hysteresis elasticities, a result anticipated theoretically by the insider-outsider theory of hysteresis (see O. J. Blanchard & Summers (1986)).

These findings have paramount relevance to macroeconomic policies. Long-run monetary neutrality might not hold (in line with Jordà et al. (2020)), and self-financing fiscal expansions during a crisis could be possible (see DeLong & Summers (2012)). Also, the findings suggest a more appealing trade-off between output (unemployment) and inflation than usually believed (see O. Blanchard (2018)). These three implications make the case for more aggressive policies during a crisis as well as making a case for running a high-pressure economy (see Okun (1973) and Yellen (2016)). The model is quite simple, and the results might not hold with more detailed or micro-founded models. However, its results imply, at the very least, that our prior beliefs about the natural rate hypothesis are doubtful/questionable, particularly the idea that monetary policy does not permanently affect output or the NAIRU.

Future research should focus on various avenues. First, an expansion of the model could deal with the accelarationist hypothesis by allowing regime switches or non-linear phillips curve that could inform the accelerationist hypothesis. Rolling estimation could also inform the accelerationist hypothesis as well . In the light of the COVID-19 crisis, it seems that the x value in which inflation becomes unanchored is quite low, which could also explain why episodes of booms leading to increaes in potential output seem uncommon. Secondly, hysteresis seems to be an asymmetric phenomenon and non-linear Kalman filters could deal with these asymmetries. Thirdly, a clearer description of the mechanisms behind hysteresis is needed and the use of theoretical and applied models could help in this matter.

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A Estimation of the potential GDP hysteresis elasticity using OECD's and IMF's potential output estimates

Ball & Onken (2022) suggests that both the unemployment rate (u) and the NAIRU (u^*) wander up and down in ways that suggest they are nonstationary. They also suggests that, at least since Friedman (1968), u gravitates around the NAIRU (u^*). In other words, the unemployment gap ($u - u^*$) is stationary. Therefore, u and u^* are cointegrated and the long-run cointegrating relation is $u = u^*$. Thus an error-correction model can be used to capture the dynamics of u and $u*$. Notice that a similar and even more credible argument can be done for the relationship between the output (y) and potential output (y^*)[13]. For these reasons Ball & Onken (2022) propose the following error-correction model to model the dynamics of u and u^*.

$$\Delta u_t^* = \beta_1 \Delta u_{t-1}^* + \beta_2 \Delta u_{t-1} + \beta_3 (u_{t-1} - u*_{t-1}) + \epsilon_t \tag{A1}$$

$$\Delta u_t = \gamma_0 \Delta u_t^* + \gamma_1 \Delta u_{t-1}^* + \gamma_2 \Delta u_{t-1} + \gamma_3 (u_{t-1} - u_{t-1}^*) + \upsilon_t \tag{A2}$$

In the case of this study, u and u^* can be replaced with y and y^*, respectively, and the same definition of the degree of hysteresis proposed by Ball & Onken (2022) can be used to estimate the hysteresis elasticity of potential GDP. The definition is as follows:

$$h = \text{Long-run effect on potential GDP/Cumulative sum of the output gap} \tag{A3}$$

The confidence intervals of h were derived using the same procedure proposed by Ball & Onken (2022).

Importantly, to increase the statistical power panel data was used. The sources for y^* can be the IMF's World Economic Outlook or the OECD's Economic outlook. In the same fashion of Ball & Onken (2022) the last yearly update of these documents is used to represent the year as it is assumed that the estimate of y^* contains more information than earlier versions. The following table summarizes the economies used in the estimation and the sample used.

[13] There is a consensus about the unit-root of GDP and potential GDP whereas there is no consensus about the unit-root of the unemployment rate or the NAIRU.

Table A1: Countries and number of years considered

IMF's WEO		OECD's EO	
Australia	18	Australia	24
Austria	18	Austria	24
Belgium	18	Belgium	24
Canada	18	Canada	24
Cyprus	12	Denmark	24
Denmark	12	Finland	24
Estonia	9	France	24
Finland	18	Germany	24
France	18	Greece	24
Germany	18	Iceland	20
Greece	12	Ireland	24
Ireland	18	Italy	24
Italy	18	Japan	24
Japan	18	Netherlands	24
Korea	9	New Zealand	23
Luxembourg	9	Norway	24
Malta	12	Portugal	24
Netherlands	18	Spain	24
New Zealand	18	Sweden	24
Norway	18	Switzerland	24
Portugal	18	United Kingdom	24
Slovak Republic	12	United States	24
Slovenia	12		
Spain	18		
Sweden	18		
United Kingdom	18		
United States	18		

B Other models equations

B.1 Unit root model

$$y_t = \bar{y}_t + \hat{y}_t \tag{A4}$$

$$\bar{y}_t = \bar{y}_{t-1} + \gamma_t + b\hat{y}_{t-1} + \varepsilon_t^{\bar{y}} \tag{A5}$$

$$\gamma_t = \delta\gamma_{t-1} + (1-\delta)\gamma_t^{ss} + \varepsilon_t^{\gamma} \tag{A6}$$

$$\gamma_t^{ss} = \gamma_{t-1}^{ss} + \varepsilon_t^{\gamma^{ss}} \tag{A7}$$

$$\hat{y}_t = \phi\hat{y}_{t-1} + \varepsilon_t^{\hat{y}} \tag{A8}$$

$$u_t = \bar{u}_t + \hat{u}_t \tag{A9}$$

$$\bar{u}_t = \bar{u}_{t-1} + b_u\hat{u}_{t-1} + \varepsilon_t^{\bar{u}} \tag{A10}$$

$$\hat{u}_t = \tau_1\hat{u}_{t-1} - \tau_2\hat{y}_t + \varepsilon_t^{\hat{u}} \tag{A11}$$

B.2 Constant steady state model

$$y_t = \bar{y}_t + \hat{y}_t \tag{A12}$$

$$\bar{y}_t = \bar{y}_{t-1} + \gamma_t + b\hat{y}_{t-1} + \varepsilon_t^{\bar{y}} \tag{A13}$$

$$\gamma_t = \delta\gamma_{t-1} + (1-\delta)\gamma^{ss} + \varepsilon_t^{\gamma} \tag{A14}$$

$$\hat{y}_t = \phi\hat{y}_{t-1} + \varepsilon_t^{\hat{y}} \tag{A15}$$

$$u_t = \bar{u}_t + \hat{u}_t \tag{A16}$$

$$\bar{u}_t = a_u\bar{u}_{t-1} + (1-\rho_u)\bar{u}^{ss} + b_u\hat{u}_{t-1} + \varepsilon_t^{\bar{u}} \tag{A17}$$

$$\hat{u}_t = \tau_1\hat{u}_{t-1} - \tau_2\hat{y}_t + \varepsilon_t^{\hat{u}} \tag{A18}$$

C Other models calibrations and a priori distributions

Table C1: Summary of models' specifications, *a priori* distributions and calibrations

	Model functional forms			*A priori* distribution specification	
	Baseline Model	Unit root model	Constant Long-run	Literature-informed	Standard errors
Parameters					
a_u	$U(0,1)[0.001, 0.999]$	1	$U(0,1)[0.001, 0.999]$	$U(0,1)[0.001, 0.999]$	$U(0,1)[0.001, 0.999]$
b	$\Gamma(0.3, 0.3)[0 - \infty)$	$\Gamma(0.3, 0.3)[0 - \infty)$	$\Gamma(0.3, 0.3)[0 - \infty)$	$N(0.32, 0.045)$	$\Gamma(0.3, 0.3)[0 - \infty)$
b_u	$\Gamma(0.3, 0.3)[0 - \infty)$	$\Gamma(0.3, 0.3)[0 - \infty)$	$\Gamma(0.3, 0.3)[0 - \infty)$	$N(0.72, 0.06)$	$\Gamma(0.3, 0.3)[0 - \infty)$
ϕ	$N(0.6, 0.05)[0.4 - 0.8]$	$N(0.6, 0.05)[0.4 - 0.8]$	$N(0.6, 0.05)[0.4 - 0.8]$	$N(0.6, 0.05)[0.4 - 0.8]$	$N(0.6, 0.05)[0.4 - 0.8]$
α	$N(0.6, 0.025)[0.4 - 0.8]$	$N(0.6, 0.025)[0.4 - 0.8]$	$N(0.6, 0.025)[0.4 - 0.8]$	$N(0.6, 0.025)[0.4 - 0.8]$	$N(0.6, 0.025)[0.4 - 0.8]$
β	$N(0.25, 0.05)[0.1 - 0.6]$	$N(0.25, 0.05)[0.1 - 0.6]$	$N(0.25, 0.05)[0.1 - 0.6]$	$N(0.25, 0.05)[0.1 - 0.6]$	$N(0.25, 0.05)[0.1 - 0.6]$
Shocks s.d					
$\sigma_{\varepsilon^{\hat{y}}}$	1	1	1	1	N(1,0.25) [0.1 - 1.9]
$\sigma_{\varepsilon^{\bar{y}}}$	0.33*0.5	0.33*0.5	0.33*(5/9)	0.33*0.5	N(0.35,0.075) [0.1 - 0.6]
$\sigma_{\varepsilon^{\gamma}}$	0.33*0.4	0.33*0.4	0.33*(4/9)	0.33*0.4	N(0.15,0.05) [0.05 - 0.25
$\sigma_{\varepsilon^{\gamma^{ss}}}$	0.33*0.1	0.33*0.1	0	0.33*0.1	N(0.05,0.025) [0.01 - 0.09]
$\sigma_{\varepsilon^{\hat{u}}}$	1	1	1	1	N(1,0.25) [0.1 - 1.9]
$\sigma_{\varepsilon^{\bar{u}}}$	0.33*0.7	0.33	0.33	0.33*0.7	N(0.35,0.075) [0.1 - 0.6
$\sigma_{\varepsilon^{\bar{u}^{ss}}}$	0.33*0.3	0	0	0.33*0.3	N(0.15,0.05) [0.05 - 0.25]
Steady state					
γ_t^{ss}	Unit-root	Unit-root	Constant, sample average	Unit-root	Unit-root
$\bar{u}_t^{ss}$	Unit-root	NA	Constant, sample average	Unit-root	Unit-root

Source: Author's own elaboration.

Note: Regarding the parameters a_u is the NAIRU persistence, b is the potential GDP hysteresis elasticity, b_u is the NAIRU hysteresis elasticity, ϕ is the unemployment gap persistence, α is the output gap persistence, β is the Okun's law slope, and δ is potential GDP growth persistence. Regarding the shocks, the standard deviations are listed as follows: output gap shock, potential GDP shock, potential GDP growth shock, long-run GDP growth shock, unemployment gap shock, NAIRU shock, natural rate shock. The steady state indicates if the model has a constant steady state or if the steady state is time-varying. Finally, the numbers in parentheses indicate the mean and the standard deviation of the *a priori* distributions while the numbers in square brackets are the minimum and the maximum.

D A new-Keynesian semi-structural model with hysteresis

The model here proposed follows closely Blagrave et al. (2015), the main difference is the inclusion of an effect from the output gap to potential GDP. GDP (in logs) y_t is decomposed in two terms the output gap $\hat{y}_t$ and the potential output $\bar{y}_t$.

$$y_t = \hat{y}_t + \bar{y}_t \tag{D1}$$

The output gap $\hat{y}_t$ follows an autoregressive process and the error term is meant to capture $\varepsilon_t^{\hat{y}_t}$ all shocks in the right-hand side of the equation that can be thought as demand shocks.

$$\hat{y}_t = \phi \hat{y_{t-1}} - \alpha(r_t - \bar{r}_t) + \varepsilon_t^{\hat{y}_t} \tag{D2}$$

Potential GDP is a unit root process with a drift γ_t, which is the potential output GDP growth rate.

$$\bar{y}_t = \bar{y_{t-1}} + \gamma_t + \eta \hat{y}_{t-1} + \varepsilon_t^{\bar{y}_t} \tag{D3}$$

γ_t is a stationary process over a time-varying long-run growth rate γ_t^{ss} as shown in the next two equations.

$$\gamma_t = \delta\gamma_{t-1} + (1-\delta)\gamma_t^{ss} + \varepsilon_t^{\gamma} \tag{D4}$$

$$\gamma_t^{ss} = \gamma_{t-1}^{ss} + \varepsilon_t^{\gamma^{ss}} \tag{D5}$$

It should be noted that the potential output could be affected by output gap due to the hysteresis elasticity η which is our parameter of interest.

This specification is closely related to Jordà et al. (2020) who suggest TFP (Z_t) follows the next process: $Z_t = Z_{t-1} + \mu + \eta\hat{y}_{t-1}$, where μ is the long run TFP growth, (it can be subject to trend shocks $\varepsilon_t^{\gamma_t}$). In their model TFP growth is equal to potential GDP growth, so this reduced form is valid. It is also related to DeLong & Summers (2012) who defined hysteresis elasticity as the percent reduction in the flow of future potential output per percentage-point-year of the present-period output gap.

The model also includes a Phillips curve:

$$\pi_t = \lambda\pi_{t+1|t} + (1-\lambda)\pi_{t-1} + \beta\hat{y}_t + \varepsilon_t^{\pi} \tag{D6}$$

where π_t is headline inflation, $\pi_{t+1|t}$ is the rational expectation of inflation and ϕ is the slope of the Phillips curve.

It also includes an Okun's Law

$$u_t = \hat{u}_t + \bar{u}_t \tag{D7}$$

$$\hat{u}_t = \tau_1 \hat{u}_{t-1} - \tau_2 \hat{y}_t + \varepsilon_t^{\hat{u}} \tag{D8}$$

$$\bar{u}_t = \rho_u \bar{u}_{t-1} + (1-\rho_u)\bar{u}_t^{ss} + \eta_u \hat{u}_{t-1} + \varepsilon_t^{\bar{u}} \tag{D9}$$

$$\bar{u}_t^{ss} = \bar{u}_{t-1}^{ss} + \varepsilon_t^{\bar{u}^{ss}} \tag{D10}$$

where $\hat{u}$ is cyclical unemployment and $\bar{u}$ is the NAIRU and follows an autoregressive process around a time varying $\bar{u}_t^{ss}$. It should be noted that if $\rho_u = 1$ and $\eta_u > 0$ the cycle has permanent effects on the NAIRU. If $\rho_u < 1$ and $\eta_u > 0$ the cycle has temporary effects on the NAIRU, which is known as partial hysteresis Alichi et al. (2019). During a crisis (booms), the NAIRU will increase (decrease) (see O. Blanchard & Katz (1997)).

Finally, monetary policy follows a Taylor rule:

$$i_t = \rho_1 i_{t-1} + (1-\rho_1)[\bar{r_t} + \pi_{t+1|t} + \rho_2 \hat{y} + \rho_3(\pi_t - \bar{\pi}_t)] + \varepsilon_t^i \tag{D11}$$

where $\bar{r_t}$ is the natural interest rate and follows a unit-root process[14]. Inflation targets follow a unit-root process as well. Our data sample contains periods where inflation was high (1970-1995) and other periods where inflation was low (post GFC crisis). For this reason, the inflation target is represented as the trend component from a Hodrick-Prescott filter as it captures these breaks on inflation data.

D.1 Data

Intuitively, the identification of η and η_u requires long swings in the output gap which mostly occurs in economic crises, thus, long time series are required for the identification of these parameters. For these

[14]The choice of a unit-root process is due to long span of the data. It is important to note that Holston et al. (2017) and Gómez-Pineda (2019) have shown that the natural interest rate has decreased. The former showed this pattern in advanced economies while the latter in latin-american economies. A unit-root process could capture that trend. Finally, in the model the output gap affects the potential output, but it could, instead of affecting the potential output, affect the potential GDP growth rate, which is an important feature as Holston et al. (2017), and Laubach & Williams (2003) have argued that the natural rate has decreased due to producitivity slowdowns closely tied to the potential GDP growth rate. This avenue is worth exploring as it would imply that crisis could dampen the natural interest rate as well.

reasons, a variety of sources were used to have long time-series on real GDP, inflation, unemployment rates and short-term interest rates.

The Òscar Jordà et al. (2017) dataset was used with special focus on the post/war period (1950-2020) for the next economies: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

D.2 *A priori* distributions

All parameters were estimated using Bayesian methods. Its priors are found in the next table and are similar to Blagrave et al. (2015).

Table D1: Parameters' prior distribution

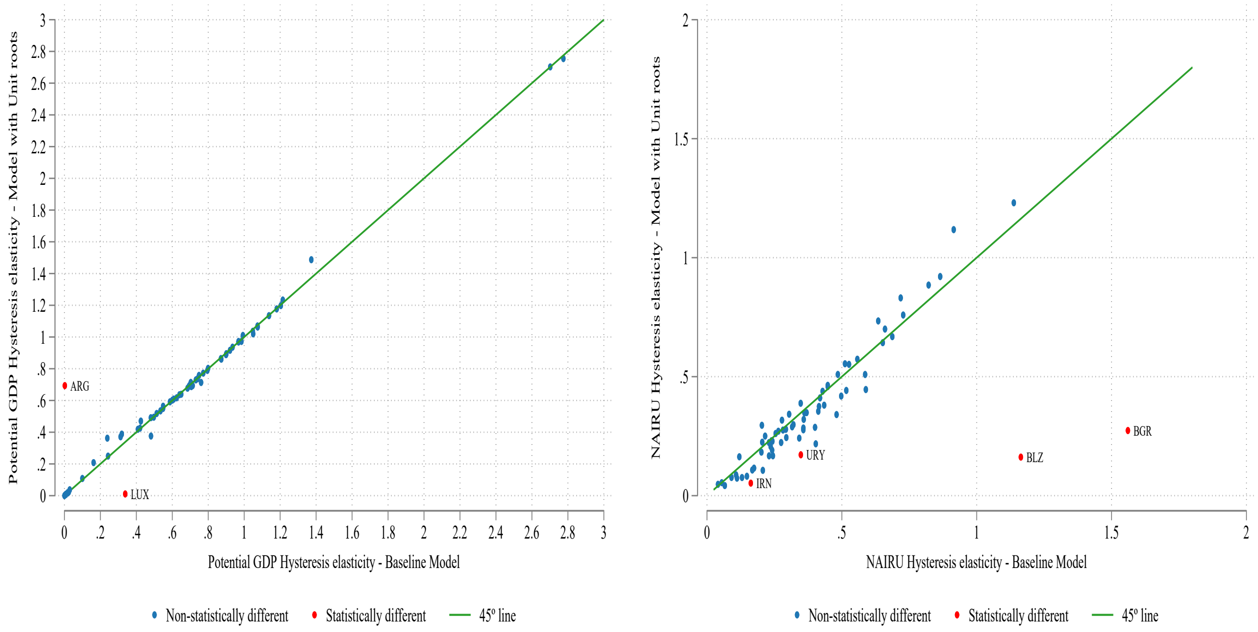
Parameter	Prior distribution	Bounds
λ	Uniform(0,1)	[0.001,0.999]
β	Normal(0.15,0.01)	[0.05,0.3]
ϕ	Normal(0.6,0.1)	[0.1,0.99]
α	Normal(0.2,0.05)	[0.03,0.4]
η	Gamma(0.3,0.3)	[0 - Inf)
ρ_1	Normal(0.5,0.075)	[0.2,0.8]
ρ_2	Normal(0.5,0.1)	[0.2,0.8]
ρ_3	Normal(1.5,0.1)	[1,2]
τ_1	Normal(0.5,0.05)	[0.5,0.9]
τ_2	Normal(0.5,0.025)	[0.05,0.99]
η_u	Gamma(0.3,0.3)	[0 - Inf)
ρ_u	Uniform(0,1)	[0.001,0.999]

Source: Own elaboration.

E Robustness checks

Figure E1: Comparison of b and b_u estimates - Baseline Model vs. Unit root model

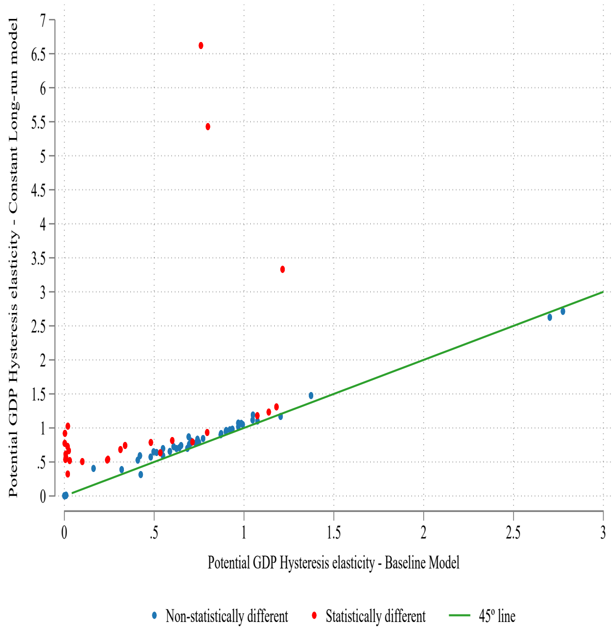
(a) Comparison of potential GDP hysteresis elasticities (b) Comparison of NAIRU hysteresis elasticities



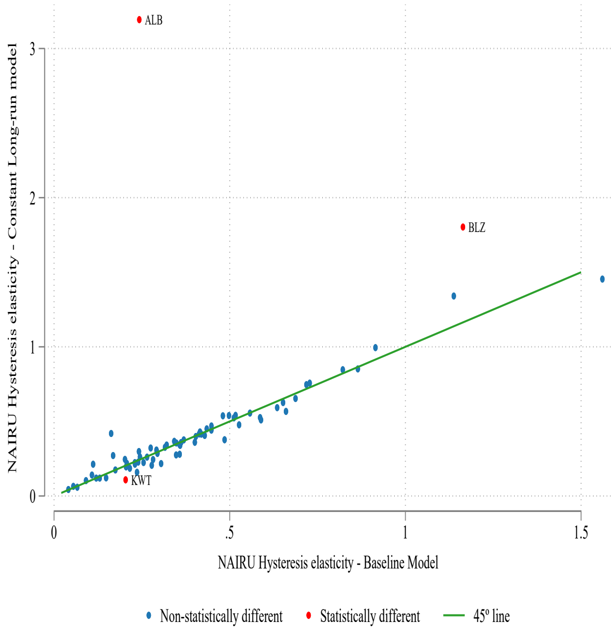
Source: Author's calculations using data from WEO.

Figure E2: Comparison of b and b_u estimates - Baseline Model vs. Constant Long-run model

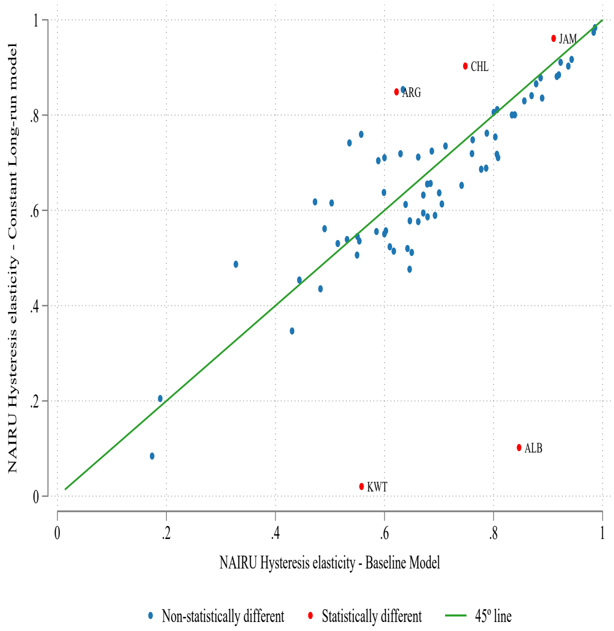
(a) Comparison of potential GDP hysteresis elasticities



(b) Comparison of NAIRU hysteresis elasticities



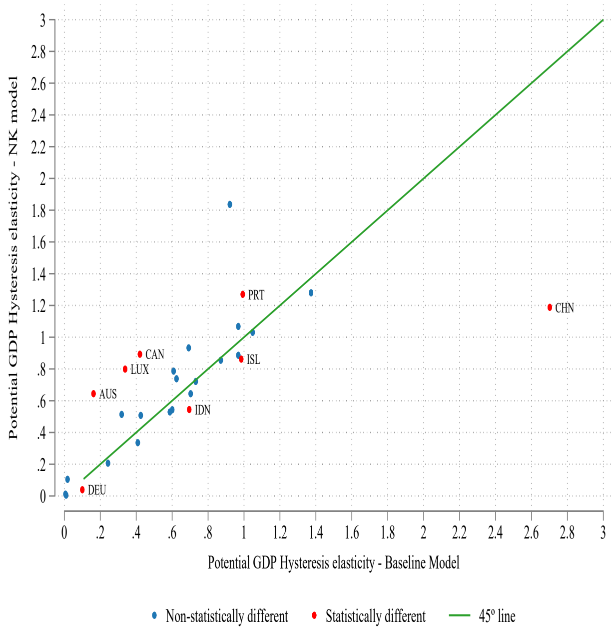
(c) Comparison of NAIRU persistences



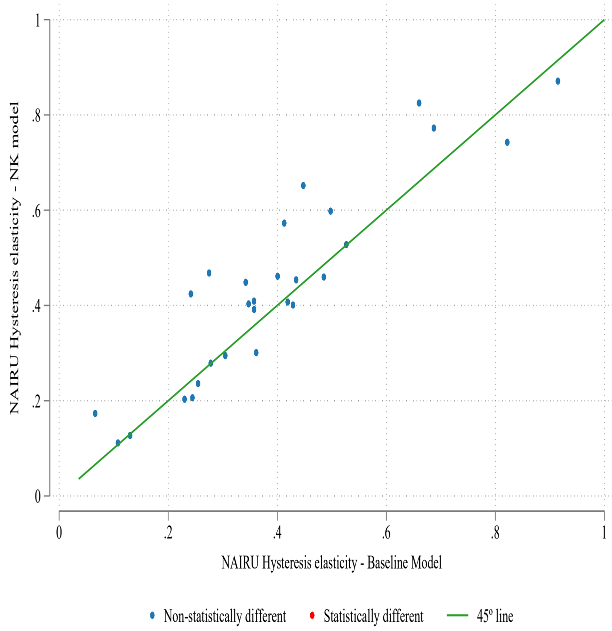
Source: Author's calculations using data from WEO.

Figure E3: Comparison of b and b_u estimates - Baseline Model vs. New Keynesian model

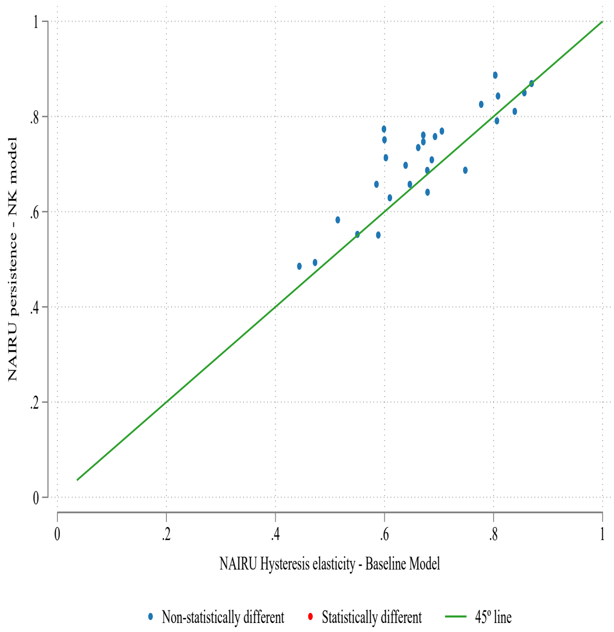
(a) Comparison of potential GDP hysteresis elasticities



(b) Comparison of NAIRU hysteresis elasticities



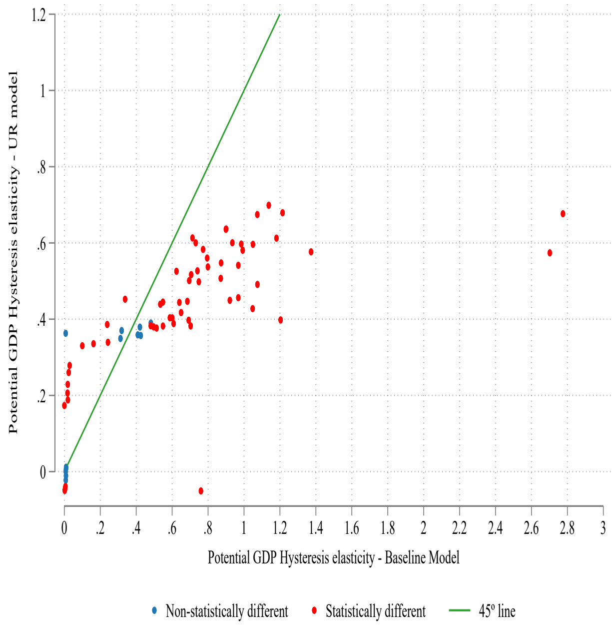
(c) Comparison of NAIRU persistences



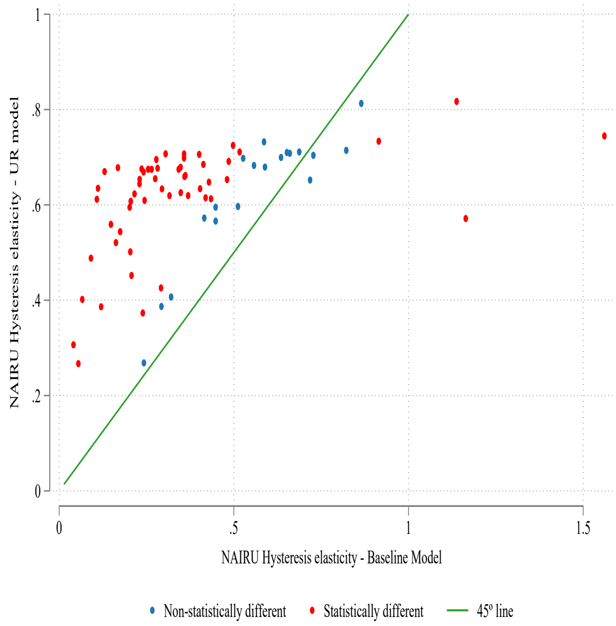
Source: Author's calculations using data from WEO.

Figure E4: Comparison of b and b_u estimates - Baseline Model vs. Model with literature informed *a priori* distributions

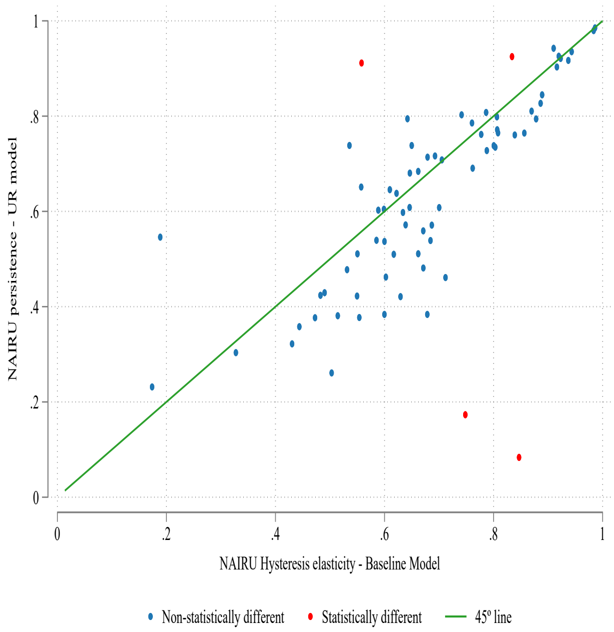
(a) Comparison of potential GDP hysteresis elasticities



(b) Comparison of NAIRU hysteresis elasticities



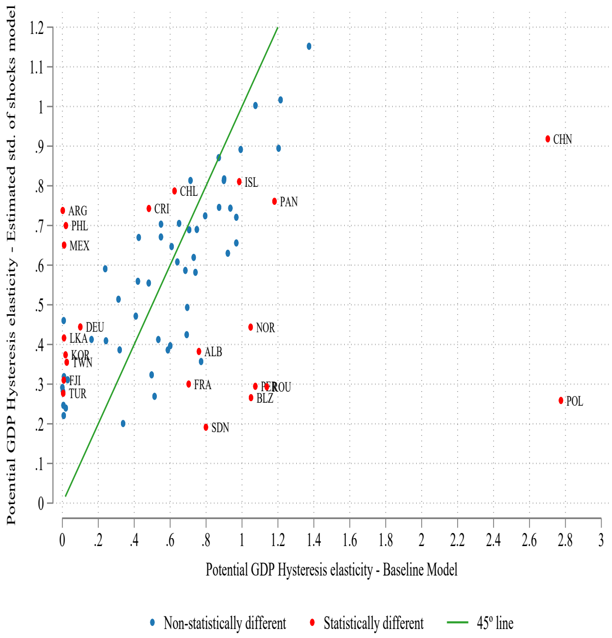
(c) Comparison of NAIRU persistences



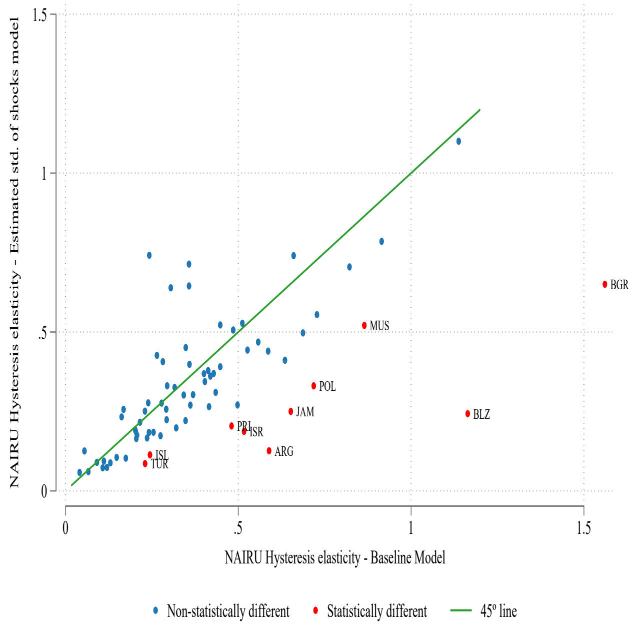
Source: Author's calculations using data from WEO.

Figure E5: Comparison of b and b_u estimates - Baseline Model vs. Model with estimated standard deviations of shocks

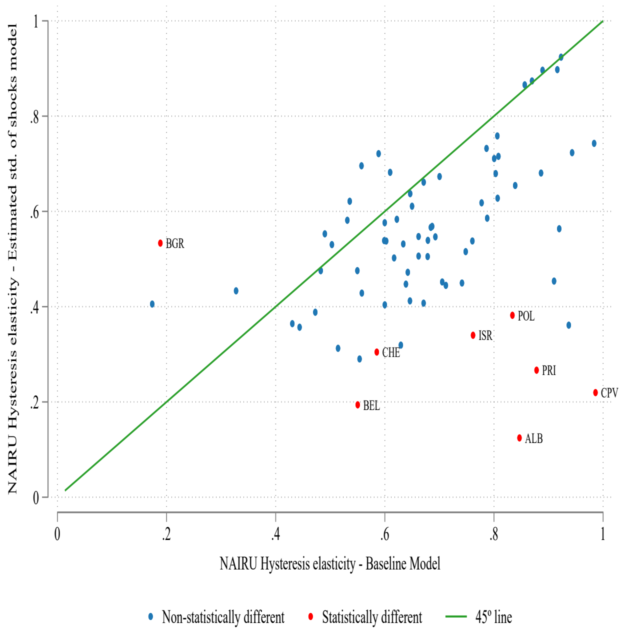
(a) Comparison of potential GDP hysteresis elasticities



(b) Comparison of NAIRU hysteresis elasticities



(c) Comparison of NAIRU persistences

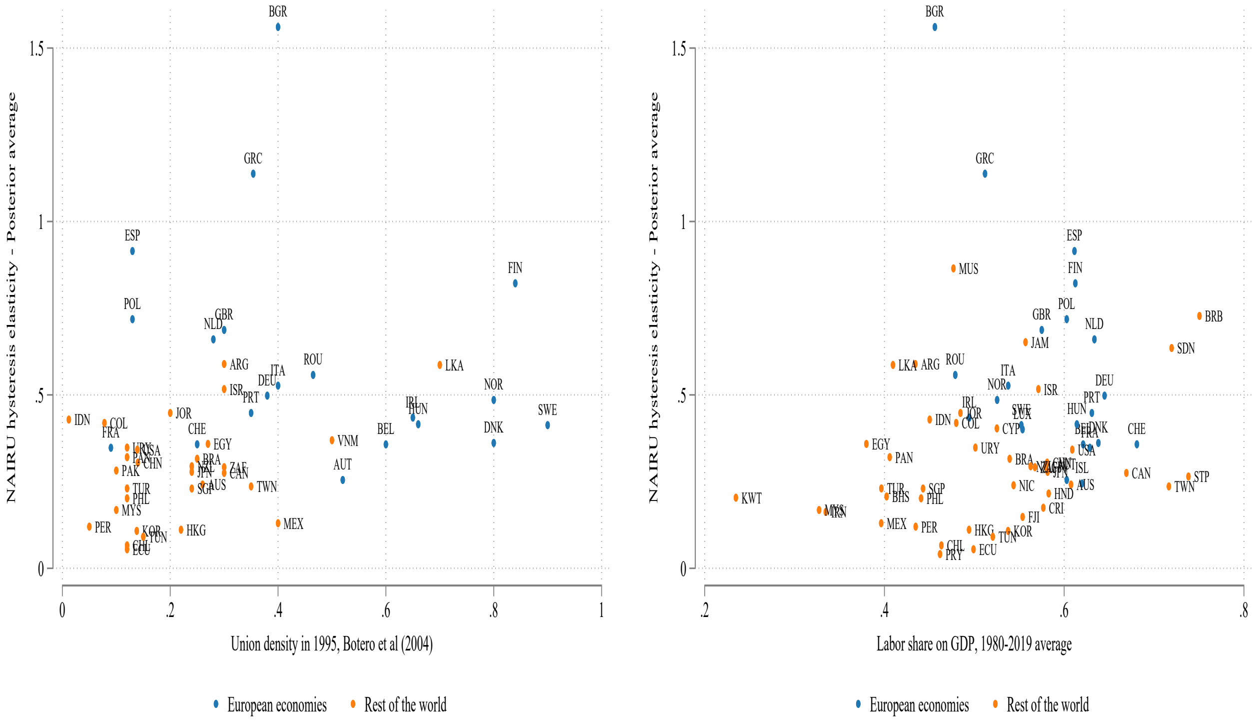


Source: Author's calculations using data from WEO.

F Sources of cross-country variation

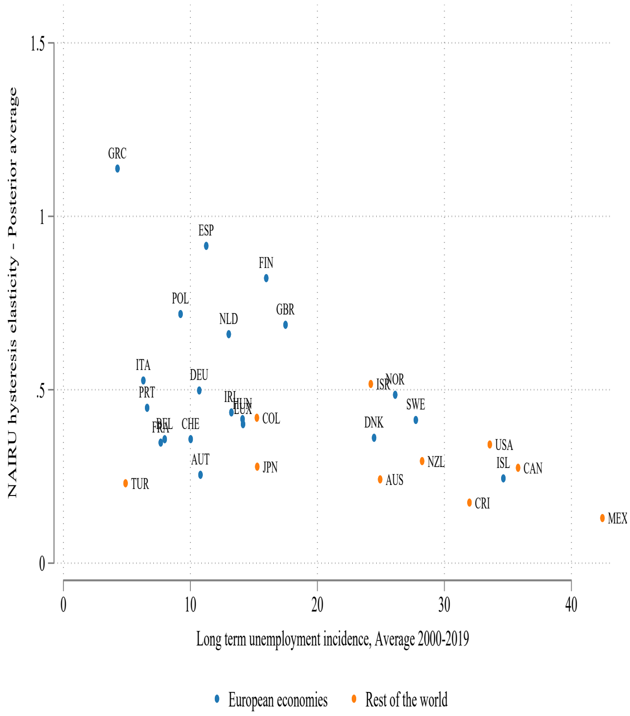
Figure F1: Correlation of the NAIRU hysteresis elasticities with insiders-outsiders key variables

(a) Union density in 1995 | (b) Labour share on GDP, 1980-2019 average



Source: Author's calculations using data from WEO and World Penn Tables and La Porta et al. (2008) data.

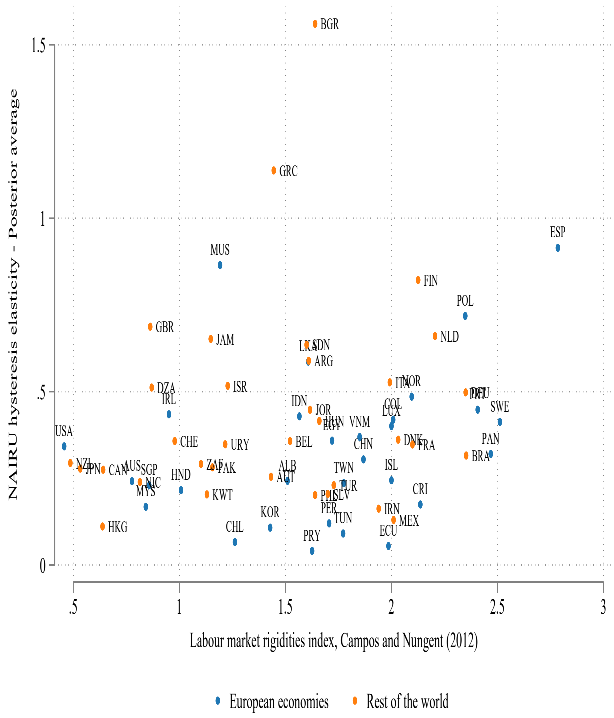
Figure F2: Correlation of the NAIRU hysteresis elasticities with long-term unemployment incidence



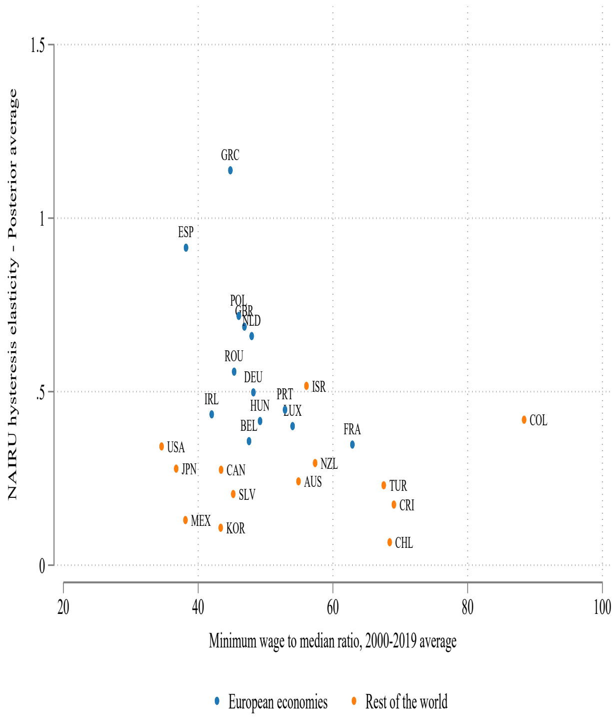
Source: Author's calculations using data from WEO and OECD data.

Figure F3: Correlation of the NAIRU hysteresis elasticities with labour market rigidities

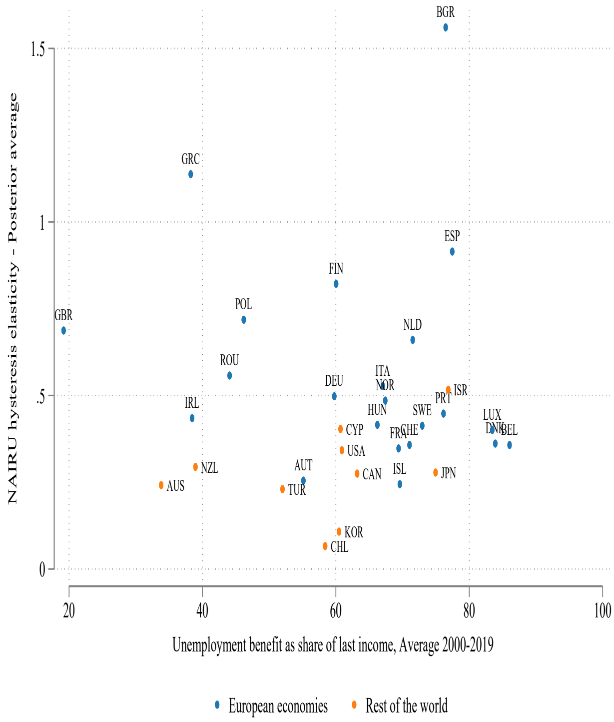
(a) Labour market rigidities index, Nugent (2012)



(b) Minimum wage to median wage ratio, 2000-2019



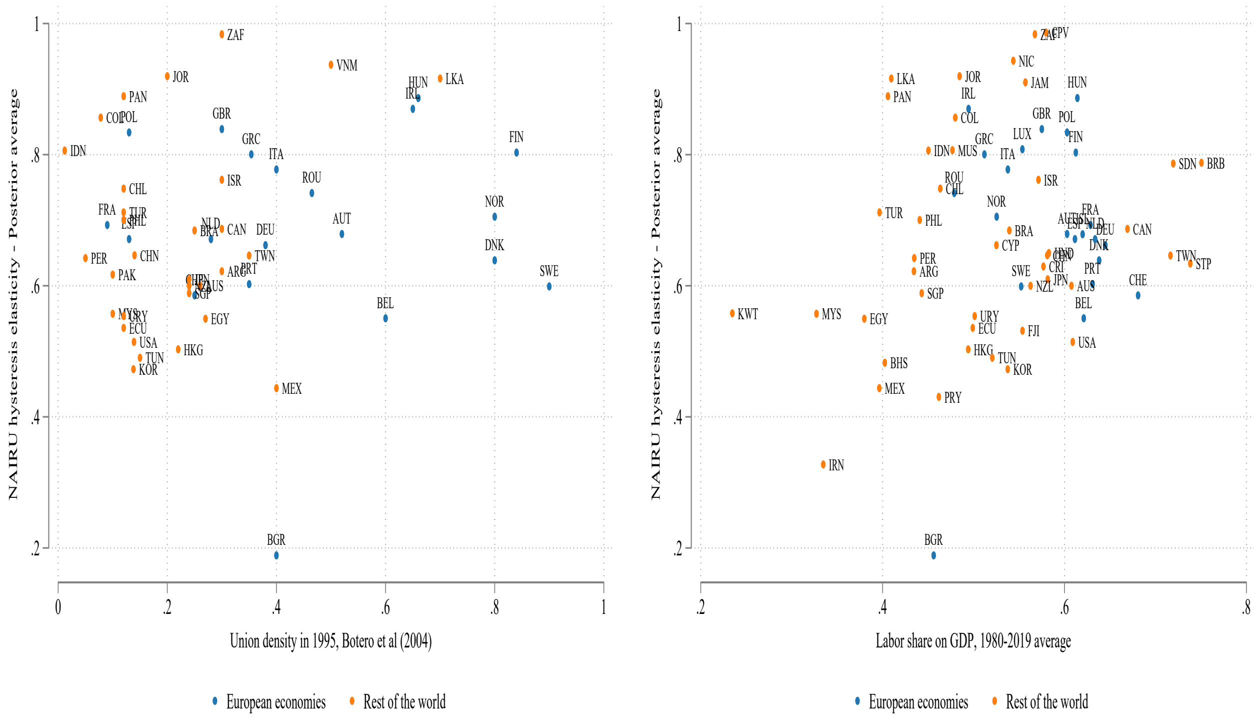
(c) Unemployment benefits, 2000-2019



Source: Author's calculations using data from WEO, Nugent (2012) and OECD data.

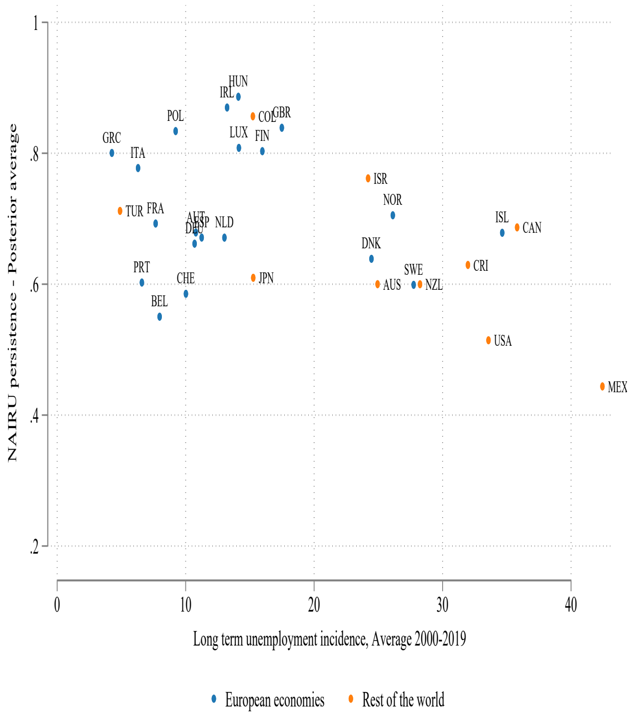
Figure F4: Correlation of the NAIRU persistence with insiders-outsiders key variables

(a) Union density in 1995 (b) Labour share on GDP, 1980-2019 average



Source: Author's calculations using data from WEO and World Penn Tables and La Porta et al. (2008) data.

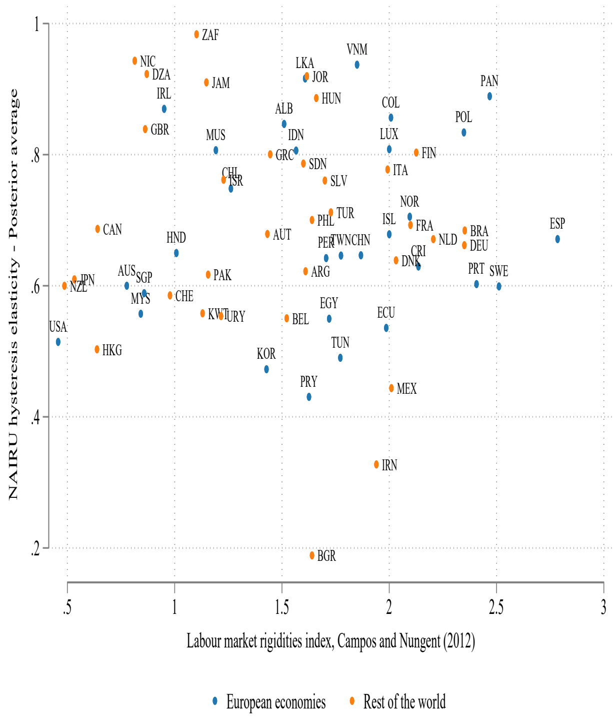
Figure F5: Correlation of the NAIRU persistence with long-term unemployment incidence



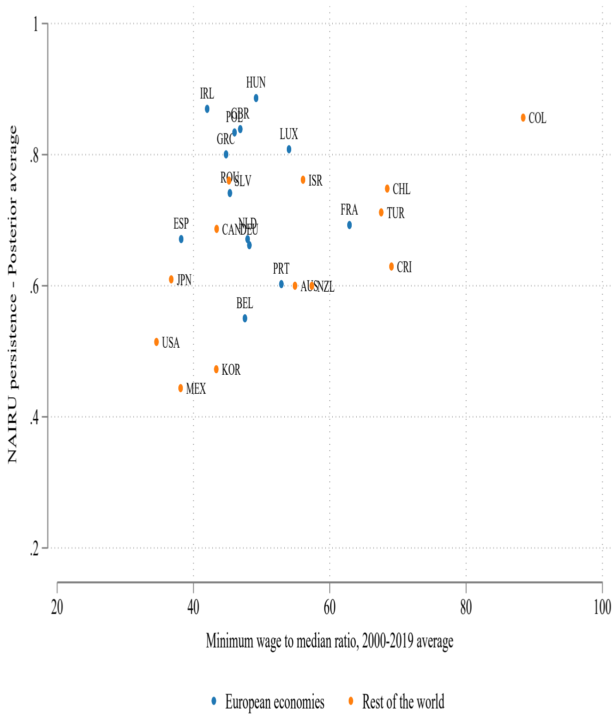
Source: Author's calculations using data from WEO and OECD data.

Figure F6: Correlation of the NAIRU persistence with labour market rigidities

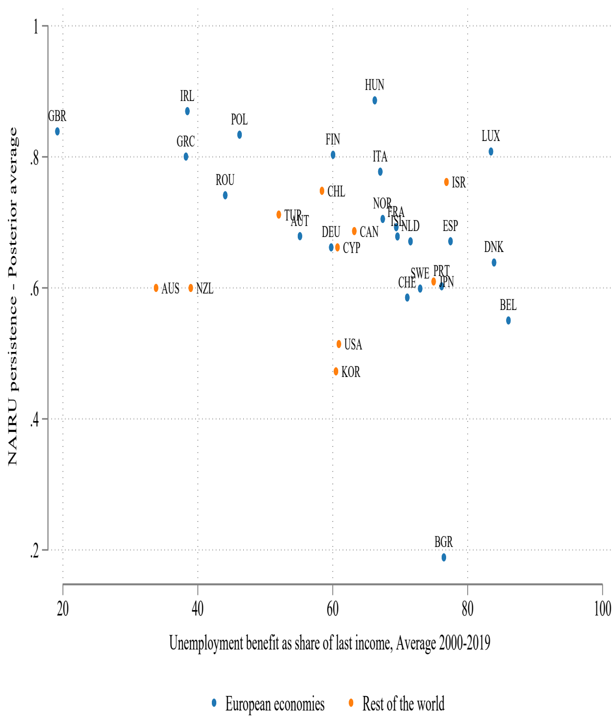
(a) Labour market rigidities index, Nugent (2012)



(b) Minimum wage to median wage ratio, 2000-2019



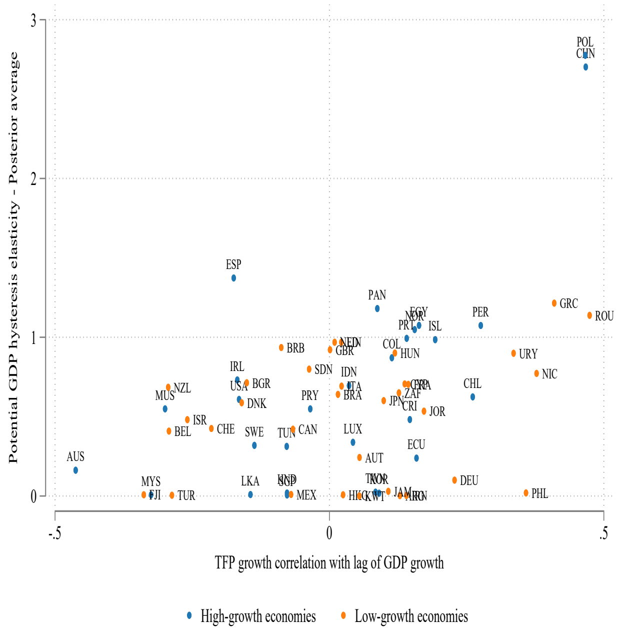
(c) Unemployment benefits, 2000-2019



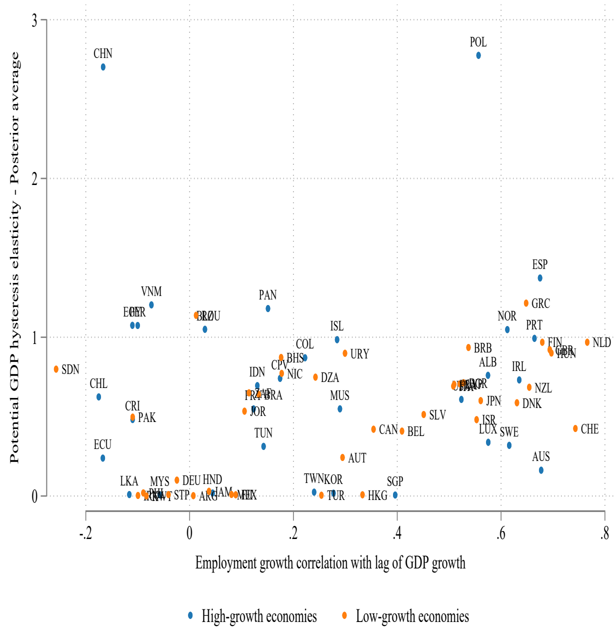
Source: Author's calculations using data from WEO, Nugent (2012) and OECD data

Figure F7: Correlation of the potential GDP hysteresis elasticities with the procyclicality of production function factors

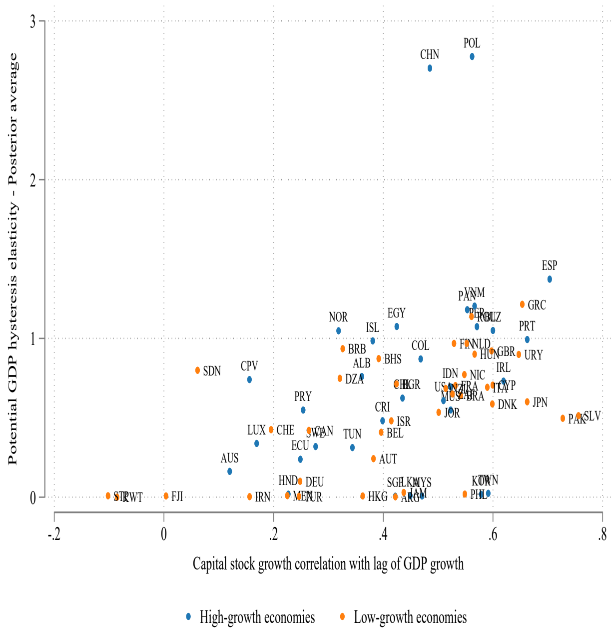
(a) TFP growth



(b) Employment growth



(c) Capital stock growth



Source: Author's calculations using data from WEO and Penn World tables.

G Baseline estimates by country

Table G1: Baseline estimates by country, over region and economy size

	b		b_u		a_u	
	Mean	90% HDI	Mean	90% HDI	Mean	90% HDI
Europe						
DEU	0.10	[0 - 0.3]	0.50	[0.14 - 0.88]	0.66	[0.32 - 1]
GBR	0.92	[0.7 - 1.13]	0.69	[0.35 - 1.05]	0.84	[0.65 - 1]
FRA	0.70	[0.38 - 1.04]	0.35	[0 - 0.62]	0.69	[0.3 - 1]
ITA	0.69	[0.42 - 0.97]	0.53	[0.2 - 0.84]	0.78	[0.52 - 1]
ESP	1.37	[1 - 1.6]	0.91	[0.66 - 1.14]	0.67	[0.49 - 0.87]
POL	2.78	[2.43 - 3.11]	0.72	[0.55 - 0.88]	0.83	[0.7 - 0.97]
NLD	0.97	[0.75 - 1.2]	0.66	[0.28 - 1.08]	0.67	[0.35 - 1]
CHE	0.43	[0 - 0.74]	0.36	[0 - 0.68]	0.59	[0.19 - 1]
BEL	0.41	[0.1 - 0.7]	0.36	[0 - 0.65]	0.55	[0.17 - 1]
SWE	0.32	[0 - 0.54]	0.41	[0.08 - 0.71]	0.6	[0.21 - 1]
AUT	0.24	[0 - 0.53]	0.25	[0 - 0.5]	0.68	[0.27 - 1]
ROU	1.14	[1.06 - 1.21]	0.56	[0.28 - 0.84]	0.74	[0.44 - 1]
IRL	0.73	[0.65 - 0.81]	0.43	[0.24 - 0.63]	0.87	[0.76 - 0.99]
NOR	1.05	[0.81 - 1.28]	0.49	[0.09 - 0.85]	0.71	[0.34 - 1]
PRT	0.99	[0.85 - 1.14]	0.45	[0.22 - 0.68]	0.6	[0.32 - 0.89]
GRC	1.21	[1.08 - 1.35]	1.14	[0.81 - 1.46]	0.8	[0.65 - 0.96]
DNK	0.59	[0.39 - 0.83]	0.36	[0.04 - 0.65]	0.64	[0.26 - 1]
HUN	0.90	[0.8 - 1]	0.42	[0.22 - 0.6]	0.89	[0.78 - 1]
FIN	0.97	[0.81 - 1.14]	0.82	[0.56 - 1.09]	0.8	[0.64 - 1]
BGR	0.71	[0.65 - 0.78]	1.56	[0.65 - 2.07]	0.19	[0 - 0.45]
LUX	0.34	[0 - 0.73]	0.40	[0.07 - 0.73]	0.81	[0.53 - 1]
ALB	0.76	[0.58 - 0.96]	0.24	[0.15 - 0.34]	0.85	[0.21 - 1]
ISL	0.98	[0.85 - 1.12]	0.24	[0.02 - 0.45]	0.68	[0.28 - 1]
Average	**0.84**	**[0.65 - 1.02]**	**0.56**	**[0.45 - 0.67]**	**0.70**	**[0.65 - 0.75]**
America						
BRA	0.61	[0.36 - 0.85]	0.34	[0 - 0.62]	0.51	[0.12 - 0.94]
MEX	0.64	[0.49 - 0.79]	0.32	[0.06 - 0.54]	0.68	[0.29 - 1]
ARG	0.01	[0 - 0.02]	0.13	[0 - 0.31]	0.44	[0 - 0.84]
COL	0.42	[0 - 0.68]	0.28	[0 - 0.51]	0.69	[0.27 - 1]
CHL	0.00	[0 - 0.01]	0.59	[0.41 - 0.77]	0.62	[0.41 - 0.86]
PER	0.87	[0.71 - 1.04]	0.42	[0.2 - 0.65]	0.86	[0.7 - 1]
ECU	0.62	[0.54 - 0.7]	0.07	[0 - 0.13]	0.75	[0.23 - 1]
PRI	1.07	[0.99 - 1.16]	0.12	[0 - 0.23]	0.64	[0.13 - 1]
PAN	0.24	[0 - 0.55]	0.05	[0 - 0.12]	0.54	[0.08 - 1]
CRI	0.80	[0.68 - 0.9]	0.48	[0.23 - 0.72]	0.88	[0.73 - 1]
PRY	1.18	[1.08 - 1.28]	0.32	[0.17 - 0.47]	0.89	[0.79 - 1]
URY	0.48	[0 - 0.73]	0.17	[0 - 0.35]	0.63	[0.18 - 1]
SLV	0.55	[0.44 - 0.65]	0.04	[0 - 0.09]	0.43	[0 - 0.86]
HND	0.90	[0.81 - 0.99]	0.35	[0.1 - 0.59]	0.55	[0.17 - 0.9]
NIC	0.51	[0.19 - 0.84]	0.20	[0 - 0.39]	0.76	[0.34 - 1]
JAM	0.02	[0 - 0.04]	0.22	[0 - 0.41]	0.65	[0.23 - 1]
BHS	0.77	[0.68 - 0.86]	0.24	[0.14 - 0.34]	0.94	[0.89 - 1]
BRB	0.03	[0 - 0.07]	0.65	[0.44 - 0.87]	0.91	[0.82 - 1]
BLZ	0.87	[0.73 - 1.01]	0.21	[0.02 - 0.37]	0.48	[0.08 - 0.83]
USA	0.94	[0.82 - 1.04]	0.73	[0.49 - 0.96]	0.79	[0.61 - 0.97]
CAN	1.05	[0.9 - 1.18]	1.16	[0.16 - 2.2]	0.17	[0 - 0.44]
Average	**0.60**	**[0.47 - 0.73]**	**0.34**	**[0.24 - 0.43]**	**0.66**	**[0.59 - 0.73]**

Table G1: Baseline estimates by country, over region and economy size (continued)

	b		b_u		a_u	
	Mean	90% HDI	Mean	90% HDI	Mean	90% HDI
Africa						
EGY	1.07	[0.86 - 1.29]	0.36	[0.03 - 0.64]	0.55	[0.16 - 1]
ZAF	0.65	[0.46 - 0.84]	0.29	[0.19 - 0.39]	0.98	[0.96 - 1]
DZA	0.75	[0.62 - 0.89]	0.51	[0.37 - 0.66]	0.92	[0.86 - 1]
SDN	0.80	[0.67 - 0.92]	0.64	[0.42 - 0.86]	0.79	[0.61 - 1]
TUN	0.31	[0 - 0.54]	0.09	[0 - 0.2]	0.49	[0.05 - 0.95]
MUS	0.55	[0.35 - 0.8]	0.86	[0.57 - 1.16]	0.81	[0.64 - 0.99]
CPV	0.74	[0.62 - 0.86]	0.29	[0.2 - 0.38]	0.99	[0.97 - 1]
STP	0.01	[0 - 0.02]	0.26	[0 - 0.5]	0.63	[0.21 - 1]
Average	**0.61**	**[0.42 - 0.8]**	**0.41**	**[0.27 - 0.56]**	**0.77**	**[0.66 - 0.88]**
Asia						
CHN	2.70	[2.39 - 2.99]	0.30	[0 - 0.61]	0.65	[0.23 - 1]
JPN	0.60	[0.42 - 0.78]	0.28	[0 - 0.56]	0.61	[0.2 - 1]
IDN	0.70	[0.58 - 0.81]	0.43	[0.19 - 0.67]	0.81	[0.6 - 1]
TUR	0.00	[0 - 0.01]	0.23	[0 - 0.43]	0.71	[0.23 - 1]
KOR	0.02	[0 - 0.04]	0.11	[0 - 0.24]	0.47	[0 - 0.88]
TWN	0.02	[0 - 0.06]	0.24	[0 - 0.48]	0.65	[0.23 - 1]
IRN	0.00	[0 - 0.01]	0.16	[0 - 0.33]	0.33	[0 - 0.66]
PAK	0.50	[0.19 - 0.84]	0.28	[0 - 0.53]	0.62	[0.19 - 1]
MYS	0.01	[0 - 0.02]	0.17	[0 - 0.43]	0.56	[0.17 - 1]
PHL	0.02	[0 - 0.05]	0.20	[0 - 0.37]	0.7	[0.27 - 1]
VNM	1.20	[0.84 - 1.59]	0.37	[0.17 - 0.55]	0.94	[0.86 - 1]
SGP	0.01	[0 - 0.01]	0.23	[0 - 0.44]	0.59	[0.18 - 1]
HKG	0.01	[0 - 0.02]	0.11	[0 - 0.24]	0.5	[0.05 - 0.94]
ISR	0.48	[0.31 - 0.68]	0.52	[0.22 - 0.8]	0.76	[0.49 - 1]
LKA	0.01	[0 - 0.02]	0.59	[0.25 - 0.89]	0.92	[0.81 - 1]
KWT	0.00	[0 - 0]	0.20	[0 - 0.35]	0.56	[0.15 - 1]
JOR	0.53	[0.43 - 0.64]	0.45	[0.28 - 0.6]	0.92	[0.82 - 1]
CYP	0.71	[0.6 - 0.82]	0.40	[0.16 - 0.65]	0.66	[0.4 - 0.93]
Average	**0.42**	**[0.16 - 0.68]**	**0.36**	**[0.3 - 0.41]**	**0.73**	**[0.67 - 0.79]**
Oceania						
AUS	0.16	[0 - 0.39]	0.24	[0 - 0.48]	0.6	[0.17 - 1]
NZL	0.68	[0.53 - 0.85]	0.29	[0.05 - 0.55]	0.6	[0.17 - 1]
FJI	0.01	[0 - 0.02]	0.15	[0 - 0.3]	0.53	[0.15 - 0.99]
Average	**0.28**	**[-0.05 - 0.62]**	**0.31**	**[0.25 - 0.38]**	**0.67**	**[0.64 - 0.71]**
Overall average	**0.62**	**[0.50-0.74]**	**0.40**	**[0.34 - 0.46]**	**0.68**	**[0.64 - 0.72]**