The renewable energy consumption and growth in the G-7 countries: Evidence from historical decomposition method

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Abstract

This paper aims to analyze the time-varying effects of renewable energy consumption on economic growth and *vice versa* for the G-7 countries. To this end, the historical decomposition method with bootstrap is utilized. The findings show that the effect of economic growth on renewable energy consumption is highly time-varying and strongly positive during the whole analysis period for Germany, Italy and the United States. Although the result is usually analogous in most periods for Canada, France, Japan and the United Kingdom, the contribution of economic growth on renewable energy consumption is reversed in some periods. Additionally, the effect of renewable energy consumption on economic growth shows remarkable time-variations for all the G-7 countries, but does not produce a consistent direction of effect over the entire analysis period. For Germany, Italy and the United Kingdom, renewable energy consumption appears to be a driving force for economic growth during nearly in the whole time period after early 1990s.

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1. Introduction

According to the International Energy Agency (IEA), carbon dioxide (CO_2) emissions from fuel combustion human activities play a vital role in climate change [39]. The use of energy is by far the most important factor among others (i.e., agriculture, industrial processes etc.) which produce greenhouse gases such as CO_2, methane (CH_4) and nitrous oxide (N_2O). Energy demand for most of the fossil fuels stems from worldwide economic growth, and the apparent weight of fossil fuels in the total primary energy supply continues to increase today. According the 2015 IAE report, fossil fuels account for about 82% of the global primary energy supply, and this ratio has not changed much in the last 40 years. This is an indication of the fact that the studies carried out in order to reach a sufficient level of awareness regarding greenhouse emissions globally are not very successful. For most countries, one of the most important reasons behind this recklessness is to ensure economic growth as energy use has an undeniable effect on economic growth.

One of the key policies to reduce greenhouse gas emissions without undermining energy use is undoubtedly shifting from fossil fuels to renewable energy sources. Unlike fossil fuels, non-biomass[1] renewable energy sources (geothermal, hydropower, solar and wind) do not cause direct greenhouse gas emissions. Recently, there has been a declining tendency in the demand for fossil fuels due to the expanding use of renewable energy sources. In addition to the environmental problems, energy price volatility, energy dependency, energy supply security, climate change and the possible exhaustion of fossil fuels have led developed countries to put emphasis on renewable energy than fossil fuels sources. The European Union (EU) has assumed a leading role to take serious steps with regards to renewable energy, to develop new strategies and to set targets for member countries. For instance, all the EU countries agreed on a new EU renewable energy target, which is increasing the share of renewable sources in gross final consumption to at least 20% by 2020 and 27% by 2030 [19].

The key macro-economic objectives agreed by policy makers are stable and sustainable economic growth and development in the modern world. In the last three decades, countries trying to reduce the use of non-renewable energy sources but to meet the ever-increasing energy demand have increased renewable energy production significantly [2].

[1] Biomass is the organic material obtained from plants and animals. It is also accepted as a renewable source of energy.

Following these developments, academics and policy makers have developed an interest in examining the relationship between renewable energy and economic growth. The causality relationship between renewable energy consumption, economic growth and carbon emissions has become more prominent during 2009-2016, and the studies have employed a wide variety of econometric methods, especially vector autoregression (VAR), vector error correction (VECM) and Granger causality methods (see e.g., Adewuyi and Awodumi [1]). Generally, Granger causality methods and variations are used in these studies to determine four causality hypotheses of interest. The *growth hypothesis* implies that energy consumption plays a significant role in economic growth, and thus, there is a unidirectional causality from energy consumption to economic growth. A unidirectional causality from economic growth to energy consumption suggests that the *conservation hypothesis* is supported. In this case, implementing the energy conservation policy is logical since economic growth leads to an increase in energy use. On the other hand, if the relationship between energy consumption and economic growth and *vice versa* mirrors each other, two possibilities will arise. When there is a bidirectional dynamic relationship between these two variables, the *feedback hypothesis* is supported, whereas if there is no dynamic links between the two variables, the *neutrality hypothesis* is supported.

The causal relationship between renewable energy consumption and economic growth has recently been investigated in a number of studies. The number of academic studies which involve different countries, various econometric tools and different analysis periods has gradually increased. While the majority of recent studies are country-based studies which use time-series data, others have focused on a group of countries using panel data. The results obtained from these studies reveal some level of agreement with unidirectional causality findings, but a full agreement has not been reached in the literature [1]. The evidence obtained until now can be best described as mixed, if not confusing, requiring new studies to explain the inconclusive findings.

In a recent study, Kocak and Sarkguneşi [26] revealed the statistically significant effect of renewable energy consumption on economic growth in Balkan and Black Sea Countries for the 1990–2012 period using panel co-integration and its variations. With a different approach, Kahia et al. [24] argued that renewable energy policies have a crucial and positive effect on economic growth in MENA countries. Using the panel error correction model for eleven MENA Net Oil Importing Countries (NOICs) from 1980 to 2012, Kahia et al. [23] also found bidirectional causality between renewable energy use and economic growth. Enriching the analysis using different methods, i.e. autoregressive distributed lag (ARDL) model, VECM Granger causality and innovation accounting approaches, Shahbaz et al. [38] support feedback hypothesis regarding renewable energy consumption and economic growth for Pakistan. Using rolling window approach (RWA), they revealed that renewable energy consumption, capital, and labor have a positive effect on economic growth except few quarters. Using a dynamic panel data model, Saidi and Mbarek [37] found that bidirectional causality exists between renewable energy consumption and real GDP per capita for nine developed countries over the 1990-2013 period. Moreover, Ocal and Aslan [31] maintained that renewable energy consumption has positive effects on economic growth for the new EU member countries by utilizing the asymmetric causality test and the ARDL approach. Chang et al [14] investigated the causal link between renewable energy consumption and economic growth in G-7 countries employing the heterogeneous panel Granger causality method and found bidirectional evidence with regard to this relation. Destek and Aslan [16] found evidence that renewable energy consumption plays a vital role in economic growth in Peru, Greece and South Korea among 17 emerging countries. Furthermore, more recent studies such as Amri [4], Bhattacharya et al. [11], Destek [17], Lu [27], Saad and Taleb [35], Troster et al. [40] investigated the bi-directional causality between renewable energy consumption and economic growth and reached different results for various countries and country groups.

Apart from the recent studies above, relatively older academic studies in the literature also examined the relationship between renewable energy consumption and economic growth. For example, Al-mulali et al. [2], Apergis and Payne [7,8], Azlina [9], Bildirici [12], Chien and Hu [15], Fang [20], Halkos and Tzeremes [21], Menegaki [29], Ocal and Aslan [31], Sadorsky [36] and Yildirim et al. [43] investigated the relationship between renewable energy consumption and economic growth for different countries (specific or groups), time episodes, and analytical/methodological approaches and reached mixed evidence and diverse policy implementations based on the four hypotheses explained above.

Studies in the literature appear to presume that the relationship between renewable energy consumption and economic growth remained constant during the analysis period. These assumptions seem to be very unrealistic as the time interval used in most analysis is subject to many structural changes. Balcilar et al. [10] maintains that if the time series data contain structural changes, econometric models used to analyze causal relationships between variables may lead to inaccurate deductions. In the case of structural change, the dynamic relationship between variables may not be stable at different sub-samples. Eventually, there would be misleading consequences of making a stable dynamic link assumption between renewable energy consumption and economic growth for a very long period of time in a country where there have been many technological changes in the field of renewable energy, and where extraordinary situations such as heavy economic depression and even a war were experienced. We estimate rolling and recursive VAR models and carry out parameter stability tests of Andrews [5], Andrews and Ploberger [6], Hansen [22], Nyblom [30]. The parameter stability tests showed that the VAR model formed by economic growth and renewable energy consumption series does not have stable parameters, implying that the time varying nature of the data should be taken into account. For this reason, we believed that it would be more appropriate to use a time-varying econometric analysis method in this study to fill a major gap in the literature.

The main purpose of this study is to further analyze the dynamic interdependency between renewable energy consumption and economic growth using historical decomposition (hereafter, HD) technique as proposed by Burbidge and Harrison [13] with bootstrap confidence interval for the G-7 countries. Using historical decompositions, we estimate the individual contributions of each shock (i.e. the energy consumption shock and the economic growth shock) to the movements in renewable energy consumption and economic growth over the sample period. In other words, for each country, the effect of energy consumption shock on economic growth and the effect of economic growth shock on energy consumption and *vice versa* are estimated so that the four hypotheses (conservation, growth, neutrality and feedback) for the relationship between economic growth and renewable energy consumption can be analyzed. With the HD method, we can examine the effect of renewable energy consumption on economic growth for each year during the analysis period, as well as the effect of economic growth on renewable energy consumption in a time-varying way. The methods that analyze the causality relationship between renewable energy consumption and growth in the literature do not examine the effects of shocks on the business cycle during expansion and contraction periods, and thus produce inconsistent results. In addition, the use of traditional impulse response analyses is insufficient to investigate the relative shocks on business cycle behavior since conventional methods also ignore the impact of sequential shocks neutralizing each other. The historical decomposition method used in this study examines the cumulative effects of shocks of renewable energy consumption on reel GDP and *vice versa* and thus overcomes the deficiencies in the literature presenting new viewpoints. Hence, there is a great advantage over the constant coefficient models that produce a single result from the entire analysis period, and more realistic energy policy implications can be made in accordance with the real economic environments where the relationship between the variables is constantly fluctuating. The main assumption and contribution related to the analysis is that in any G-7 country, the relationship between renewable energy consumption and economic growth cannot be fixed when periods of economic expansion/contraction or significant developments in the consumption of renewable energy sources (e.g. technological advancement which lessens energy use per output unit) are experienced. The empirical results obtained by the HD method in this study support this assumption strongly.

The paper analyzes the historical decomposition of renewable energy consumption on economic growth and *vice versa* in the G-7 countries (Canada, France, Germany, Italy, Japan, UK and USA) using annual time series data for the period from 1960 to 2015 except Germany. Due to data availability, the time series for Germany covers the 1970-2015 period. Using the bootstrap inference in a VAR system, which is a nonparametric and data-based method proposed by Efron [18], we calculate the HDs and the confidence intervals for the HDs for both variables. The estimation results show that the time-varying effects of economic growth on renewable energy consumption are significantly positive in Germany, Italy and United States in all observed time periods. However, for other G-7 countries, this effect is positive and dominant mostly throughout the analysis period, but not for some short-term periods. Findings about the effect of renewable energy consumption on economic growth suggest that this time-varying effect is not dominant in any of the G-7 countries over the entire analysis period. However, it can be said that the trend towards renewable energy sources after the beginning of the 1990s is more encouraging for Germany, Italy and the United Kingdom than the other G-7 countries.

The rest of this paper is organized as follows. The second section provides a detailed explanation about the HD methodology. Section 3 discusses the empirical results, and the concluding remarks are given in the last section.

2. Methodology

Using the historical decomposition approach, we study the time-varying effect of renewable energy consumption on economic growth and *vice versa*. Let REN_t denote the renewable energy consumption in time t and GDP_t denote the Gross Domestic product at time t. Assume that a 2-dimensional vector y_t=(ΔLogREN$_t$, ΔLogGDP$_t$)′ follows a VAR process of order p denoted VAR(p) process. The VAR (p) process can be expressed as follows [28]:

$$y_t = c + A_1 y_{t-1} + ... + A_p y_{t-p} + u_t, \tag{1}$$

where y_t is formed by the logarithms of differenced renewable energy consumption and real GDP data, c is a (2×2) vector of constants, A_i are (2×2) coefficient matrices, u_t is the 2-dimensional *white noise* or *innovation process*, that is, $E(u_t)=0$, $E(u_t u_t')=\Sigma$ and $E(u_t u_s')=0$ for all $s\neq t$. Similar to the variance decompositions and impulse response functions in a VAR model, the historical decompositions are based upon the moving average (MA) representation of the VAR. The MA representation can be written as:

$$\begin{aligned} y_t &= JY_t = CJ + \sum_{i=0}^{\infty} JM^i J'JU_{t-i}, \\ &= \mu + \sum_{i=0}^{\infty} \Phi_i u_{t-i} \end{aligned} \tag{2}$$

where,

$$Y_t = \begin{bmatrix} y_t \\ y_{t-1} \\ . \\ . \\ . \\ y_{t-p+1} \end{bmatrix}, \quad C = \begin{bmatrix} c \\ 0 \\ . \\ . \\ . \\ 0 \end{bmatrix}, \quad M = \begin{bmatrix} A_1 & A_2 & . & . & . & A_{p-1} & A_p \\ I_2 & & . & . & . & 0 & 0 \\ 0 & I_2 & . & . & . & 0 & 0 \\ . & & . & & & . & . \\ . & & & . & & . & . \\ . & & & & . & . & . \\ 0 & 0 & . & . & . & I_2 & 0 \end{bmatrix}, \quad U_t = \begin{bmatrix} u_t \\ 0 \\ . \\ . \\ . \\ 0 \end{bmatrix},$$

$\mu = JC$, $\Phi_i = JM^i J'$ $u_{t-i} = JU_{t-i}$.

We can decompose the covariance matrix as $\Sigma_u = PP'$, where *P* is a lower triangular matrix and defining $\Theta_i = \Phi_i P$ and $w_{t-i} = P^{-1} u_{t-i}$, equation (2) can be represented as

$$y_t = \sum_{i=0}^{\infty} \Theta_i w_{t-i} , \tag{3}$$

Let us consider *T* as a base period which runs from observation 1 in our sample. We can decompose equation (3) subsequent to *T* easily as follows:

$$y_{t+j} = \sum_{i=0}^{j-1} \Theta_i w_{T+j-i} + \sum_{i=j}^{\infty} \Theta_i w_{T+j-i} , \tag{4}$$

where the first element of the right hand side, $\sum_{i=0}^{j-1} \Theta_i w_{T+j-i}$, is a part of y_{t+j} that represents the shocks after time *T*. On the other hand, $\sum_{i=j}^{\infty} \Theta_i w_{T+j-i}$ is the base projection, that is, it is the forecast of y_{t+j} that depends on information at time *T*. The first part of the expression in equation (4) is used for determining the effects of shocks on particular variable(s) up to time *T* with respects to actual series. In other words, the first part of the equation gives us the MA matrices of each period of analysis. The contributions of all kinds of shock to each dependent variable can be obtained from the MA matrices for each period.

The one standard deviation confidence intervals are estimated by the bootstrap method [12]. The bootstrap procedure is implemented following the steps below:

Step 1: Calculate the uncorrelated residuals of each equation from the estimated VAR model (e.g. $Y_t = \hat{c} + \sum_{i=0}^{p} \hat{A}_i Y_{t-i} + \hat{e}_t$,) with a big enough *p*.

Step 2: Draw bootstrap N samples from each $(T \times 1)$ residual vector of each equation, where the residuals are pre-centered on the mean. Denote these vectors as $e^*_{j,n}$ with *j=1,2* and *n=1,2,…,N* where *N* is the number of bootstrap samples.

Step 3: Taking the initial conditions for *p* as $Y^*_t = Y_t$, generate *N* pseudoseries $Y^*_{t,n} = \hat{c} + \sum_{i=0}^{p} \hat{A}_i Y_{t-i} + \hat{e}^*_{t,n}$ using the artificial residuals obtained from Step 2.

Step 4: Estimate the VAR model using the new series obtained from Step 3 and compute the HD as mentioned before:

$$y^*_{T+j,b} = \sum_{i=0}^{j-1} \Theta^*_i w^*_{T+j-i} + \sum_{i=j}^{\infty} \Theta^*_i w^*_{T+j-i} \tag{5}$$

3. Empirical Results

The empirical estimation in the study uses annual data of renewable energy consumption and reel GDP on the G-7 countries which are Canada, France, Germany, Italy, Japan, United Kingdom and United States over the 1960-2015 period except Germany due to data unavailability. The data for Germany covers the period from 1970 to 2015. The renewable energy consumption data is obtained from the OECD database [32] and measured in thousand tones (tone of oil equivalent). The real GDP data is sourced from the World Development Indicators (WDI) of 2017 [42] and it is in real local currency units at the base year of 2010 prices. A logarithmic transformation is applied to renewable energy consumption and real GDP data for all the G-7 countries. To investigate the dynamic nexus between the renewable energy consumption and real GDP series for G-7 countries, we first test for a unit root in renewable energy consumption and GDP series of G-7 countries using the familiar Z_α test of Phillips [34] and Phillips and Perron [33]. The Z_α test uses a statistic combining $T(\hat{\alpha}-1)$ with a semi-parametric adjustment for serial correlation, where T is the sample size and $\hat{\alpha}$ is the Ordinary Least Squares (OLS) estimate of the first order autoregressive parameter. The Z_α test depends on GLS detrending. Z_α test results are given in Table 1. Panel A of Table 1 reports Z_α unit-root test results for the log levels of the renewable energy consumption series with a constant and a linear trend in the test equation, while Panel B of Table 1 reports Z_α unit-root test results for the first differences of the log real GDP series with only a constant in the test equation. We see from column 2 of Table 1 that Z_α unit root test fails to reject the null hypothesis of nonstationarity for the log levels of the renewable energy consumption and real GDP series considered at 5% significance level for G-7 countries. However, we cannot reject the null hypothesis of a unit for both of the series. The test results reported in column 3 of Table 1 further show that the first differences of the log renewable energy consumption and log real GDP series do reject the null of a unit root. Therefore, the Z_α unit root test results indicate that the renewable energy consumption and real GDP series of the G-7 countries both conform to I(1) processes.

Table 1

Z_{α} unit root test results for the renewable energy consumption and real GDP series.

(1) Country	(2) Level[a]	(3) First Difference[b]
Panel A: renewable energy consumption		
Canada	-0.978	-7.063***
France	-1.903	-8.325***
Germany	-0.922	-5.054***
Italy	-0.719	-8.166***
Japan	-2.573	-9.541***
United Kingdom	-1.196	-7.708***
United States	-1.608	-7.367***
Panel B: real GDP		
Canada	-1.986	-5.050***
France	-1.581	-3.685***
Germany	-1.846	-5.858***
Italy	0.311	-4.436***
Japan	-2.739	-4.139***
United Kingdom	-0.789	-4.928***
United States	-1.257	-5.269***

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

[a]A constant and a linear trend are included in the test equation; one-sided test of the null hypothesis that a unit root exists; 1%, 5% and 10%significance critical value equals -3.557, -2.916 and -2.596, respectively.

[b]A constant is included in the test equation; one-sided test of the null hypothesis that a unit root exists;1%, 5% and 10% critical values equals -4.133, -3.493, and -3.175, respectively.

In conjunction with historical decomposition approach, this study investigates the dynamic nexus between the renewable energy consumption and reel GDP series on the G-7 countries to help satisfy the needs of policymakers and academicians for a coherent economic interpretation of both historical data and forecasts. As far as stationary VAR variables are concerned, historical decomposition methods are taken into account rather than structural impulse responses analysis as these analysis cannot be applied to integrated or co-integrated variables in levels without making changes, and also the presence of a stationary MA representation of Data Generating Process is required for these analyses. A case considered in this study is a VAR model covering the renewable energy consumption and reel GDP series for G-7 countries (see Kilian and Lütkepohl [25] for more discussion). The Z_{α} unit root test results reported in Table 1 indicate that the renewable energy consumption and reel GDP time series for G-7 countries contain a unit root. Thus, we take the first difference of both series for G-7 countries for this analysis. Although differencing of time series makes the VAR system stable, it causes information loss as well, which is an undeniable fact. To determine the lag length for each VAR model, we reduce the lag of the VAR model in a stepwise manner from

10 to 1 using sequential likelihood ratio (LR) test statistics. The optimum lag orders of the VAR model for Canada, France, Germany, Italy, Japan, United Kingdom and United States are 7, 6, 3, 6, 8, 10 and 6, respectively.

The full sample VAR model assumes the parameters to be constant over the entire sample period and further assumes that no structural breaks or regime shifts exist in the sample. However, the parameter values in the VAR model may shift due to structural changes and dues business cycle regime shift. Consequently, the patterns of predictive power between the renewable energy consumption and reel GDP series may change over time. Moreover, it is wrong to believe that large and persistent structural impulse response analyses may explain the business cycle in real output. The impulse response used in VAR analysis depends on single positive shocks. However, the business cycle variation in real output results from a sequence of shocks with different magnitude and signs. Thus, it will not be sufficient to explain business cycle using the impulse response analysis because it is based on a single positive shock applied to the system as previously stated. A subsequent negative shock may destroy the impact of a positive shock during a business cycle period on real output, which is a widespread situation. To overcome this outstanding problem, we use the historical decomposition method, which allows us to examine the cumulative effects of shocks on business cycle and to account for the variability of relative shocks (see Kilian and Lütkepohl [25] for more discussion).

There are several stability tests to examine the stability of VAR models [6]. The estimated parameters resulting from undetected unstable relationships can lead to serious consequences because of biased inferences as noted by Hansen [22] in addition to inaccurate forecasts mentioned by Zeileis et al. [44]. Hence, we test the stability of the parameters to examine the stability of the coefficients of the VAR model composed of the renewable energy consumption and reel GDP series for the G-7 countries before investigating the predictive content between these series. To test the stability of the VAR model parameters, we use three different statistics (*Sup-F*, *Mean-F* and *Exp-F*) proposed in the study by Andrews [5] and Andrews and Ploberger [6]. These *F*-tests of Andrews [5] and Andrews and Ploberger [6] test the null hypothesis of no structural change against the alternative hypothesis of a single shift of unknown timing. The results of the parameter stability test performed for renewable energy consumption and reel GDP prices are reported in Table 2. In this study, the critical values and the *p*-values are derived using the parametric bootstrap distribution obtained using 2,000 replications generated from a VAR model with constant parameters as elaborated by Andrews [5].

Table 2. Parameter stability tests

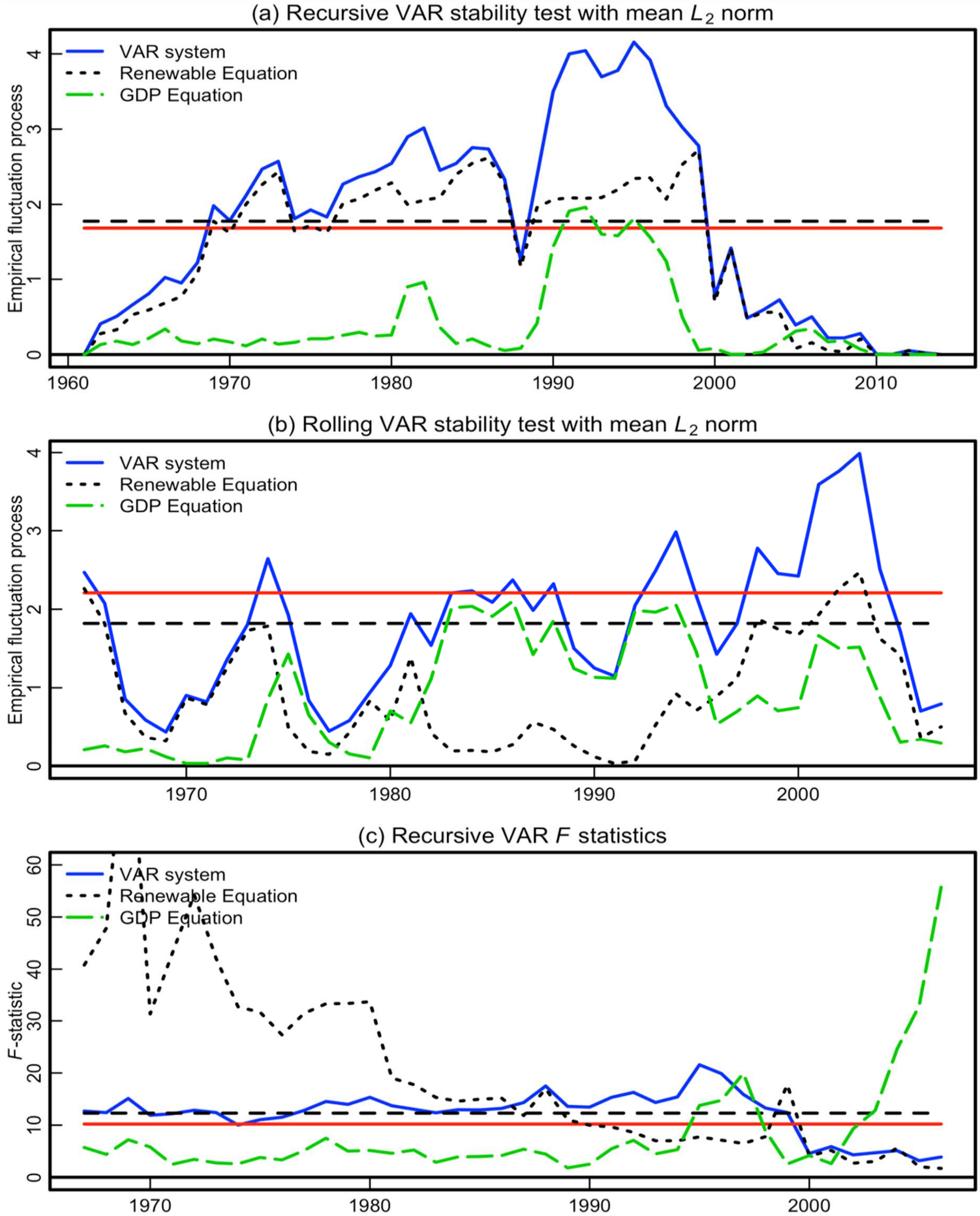
	Sup-F	*Mean-F*	*Exp-F*
	Renewable Equation		
Canada	91.059***	20.599***	41.84
France	56.268***	15.216***	24.608***
Germany	24.705***	10.562***	9.230***
Italy	80.685***	32.050***	36.654
Japan	370.594***	44.910***	181.608
UK	83.671***	18.342***	38.146
US	24.471***	7.260**	8.745***
	GDP Equation		
	Sup-F	***Mean-F***	***Exp-F***
Canada	55.721***	8.191**	24.172***
France	36.187***	4.537	14.582***
Germany	309.456***	22.328***	151.039
Italy	29.589***	8.161**	11.345***
Japan	14.600**	6.542**	5.012**
UK	35.781***	9.264***	14.306***
US	19.775***	5.021	6.549***
	VAR System		
	Sup-F	***Mean-F***	***Exp-F***
Canada	21.575**	12.299**	7.890**
France	18.117*	10.570**	7.110**
Germany	49.721***	20.167***	21.173***
Italy	22.493**	14.962***	9.216***
Japan	26.122***	11.040**	9.618***
UK	33.725***	12.325**	13.231***
US	13.632	5.974	4.289

Note: The parameter stability tests exhibit non-standard asymptotic distributions. With the parametric bootstrap procedure, Andrews [5] and Andrews and Ploberger [6] report the critical values and p-values for the non-standard asymptotic distributions of these tests. Additionally, according to Andrews [5], trimming from both ends of the sample is required for the *Sup-F, Mean-F* and *Exp-F*. Hence, the tests are applied to the fraction of the sample in (0.15, 0.85), i.e., a 15% trimming from each end of the sample. We calculate the critical values of the tests using 2,000 bootstrap replications.

According to the results given in Table 2, all tests reject the null hypothesis of parameter constancy at the 5% level (at 10% only in one case) for the single renewable energy consumption equation, single reel GDP equation and the VAR system. Therefore, considering the business cycle regimes and other above-mentioned factors, we use the historical decomposition method to study the cumulative effects of shocks of renewable energy consumption on reel GDP and *vice versa*.

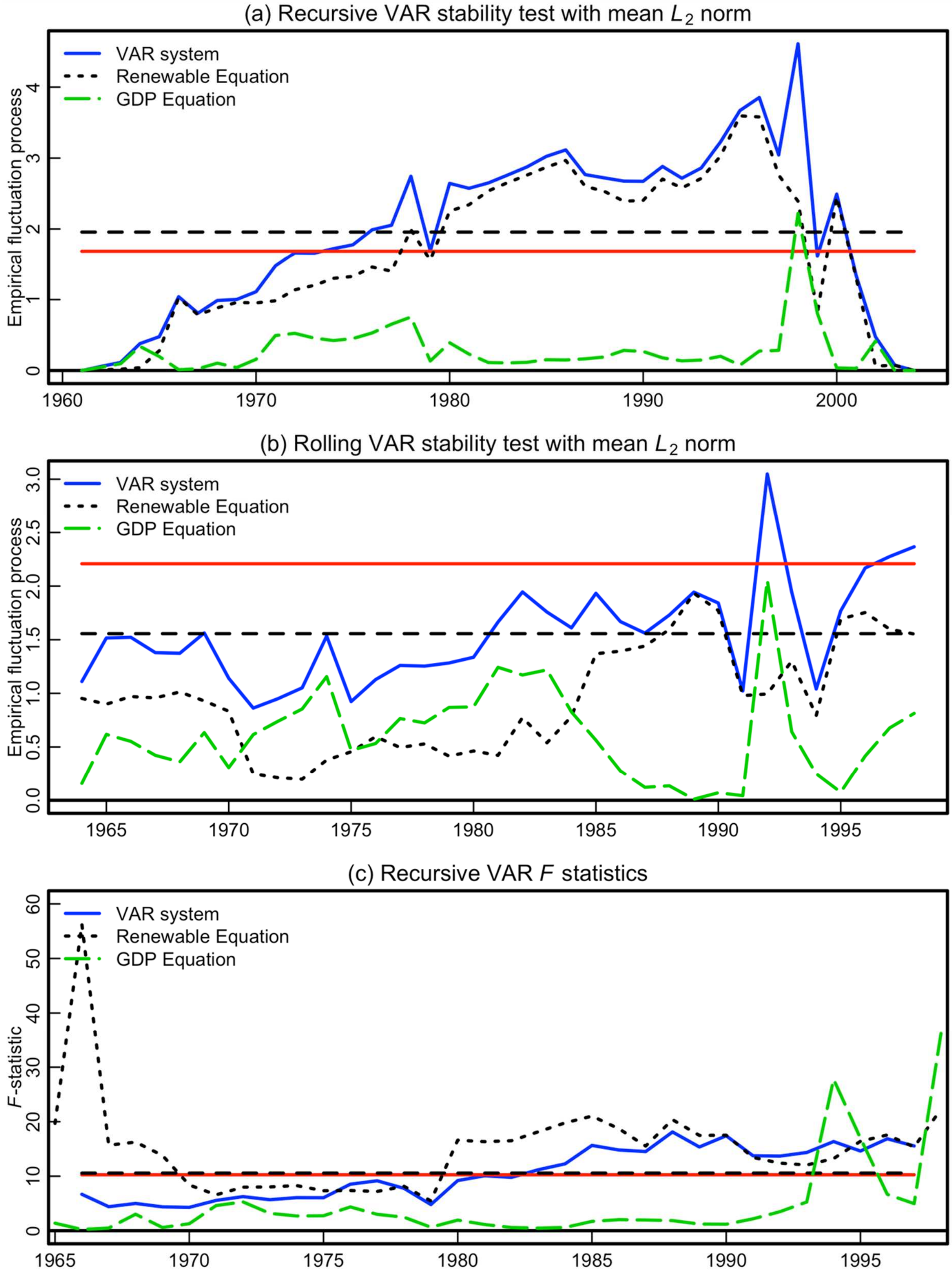
In addition to the *Sup-F*, *Mean-F* and *Exp-F* tests of Andrews [5] and Andrews and Ploberger [6], we also estimate the VAR model using recursive and rolling-window regression techniques since the parameter constancy tests demonstrate structural change and business cycle in the sample as pointed out by the evidence given in Table 2. For the recursive estimator, we start with a benchmark sample period and then add one observation at a time keeping all the observations in prior samples. Thus, with each iteration, the sample size grows by one. Prediction results are obtained by the rolling window estimator advancing the fixed length benchmark sample one step after each iteration. Namely, we keep constant window size adding one observation from the forward direction and dropping one from the end. For the recursive and moving window models, we estimate a VAR model covering the renewable energy consumption and reel GDP series using the lag order 7, 6, 3, 6, 8, 10 and 6 for Canada, France, Germany, Italy, Japan, United Kingdom and United States by the LR, respectively. For the recursive and rolling-window parameter stability, we use three tests, namely recursive VAR stability test with L_2 norm of Hansen [22] and Nyblom [30], rolling VAR stability test with mean L_2 norm of Hansen [22] and Nyblom [30], and recursive VAR stability F test for the renewable energy consumption equation, real GDP equation and the VAR model. The estimation results for recursive and rolling-window parameter stability are reported in Figures 1-7. These analyses which use sup norm indicate that parameter stability for both individual equations and VAR systems can be rejected. This means that we cannot reject a persistent temporary deviation from the normal parameter levels. However, it can be rejected against a single-break alternative. To sum up, in this analysis, the fact that the parameters of the VAR models used for the G-7 countries are not stable. Thus, we use the HD method because of the superior features of the historical decomposition method described above against other methods used in the literature when the impact of the series on each other is time-varying. Using the HD method, we could examine the cumulative effects of both renewable energy consumption shocks on business cycle variation in real output and economic growth shocks on business cycle variation in energy consumption during the whole analysis period.

Figure 1: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for Canada



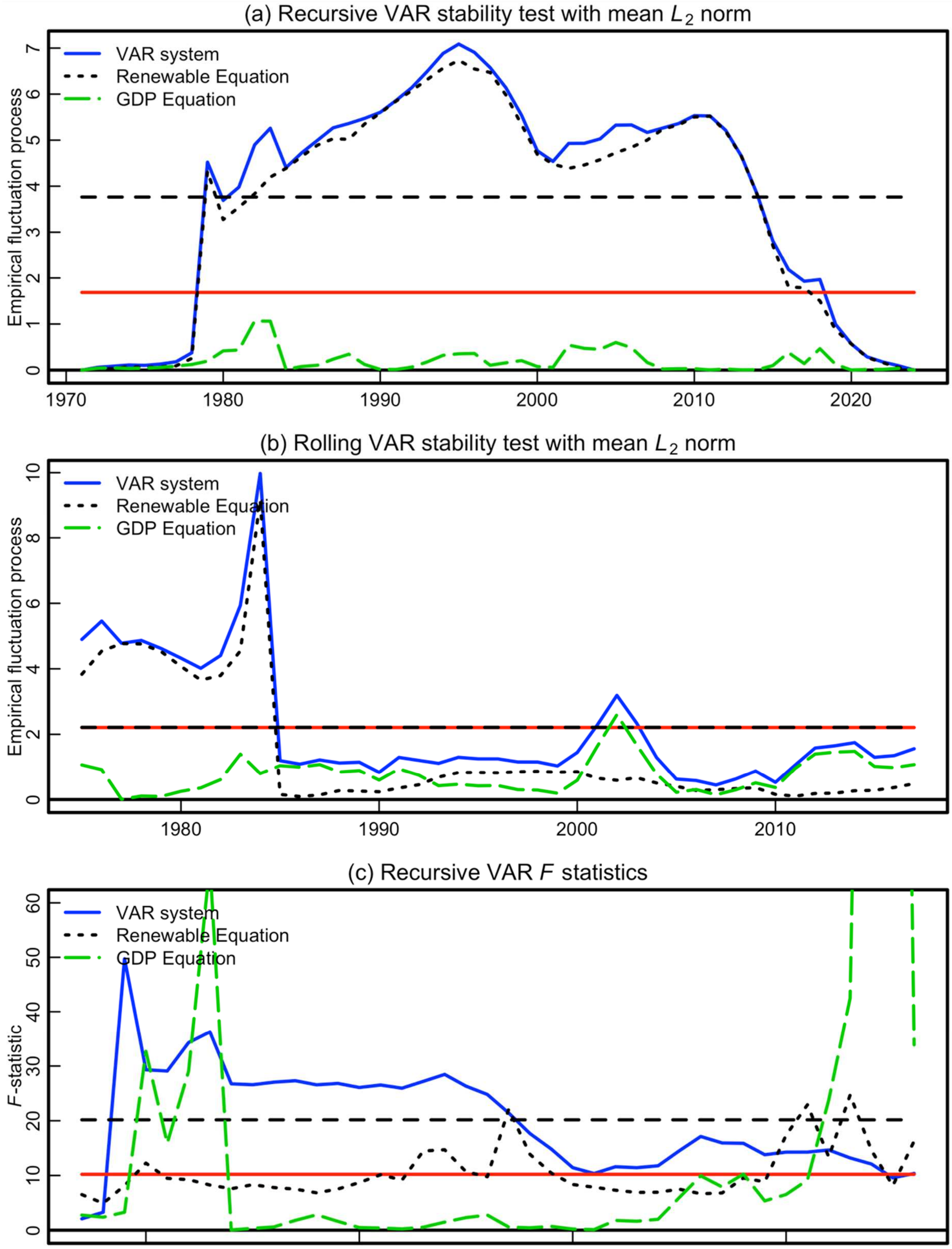
Note: (a) Recursive VAR stability L_2-test (b) Rolling VAR stability L_2-test. (c) Recursive VAR stability F-test. Horizontal dashed line denotes mean statistics while horizontal straight line denotes 5% critical value.

Figure 2: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for France



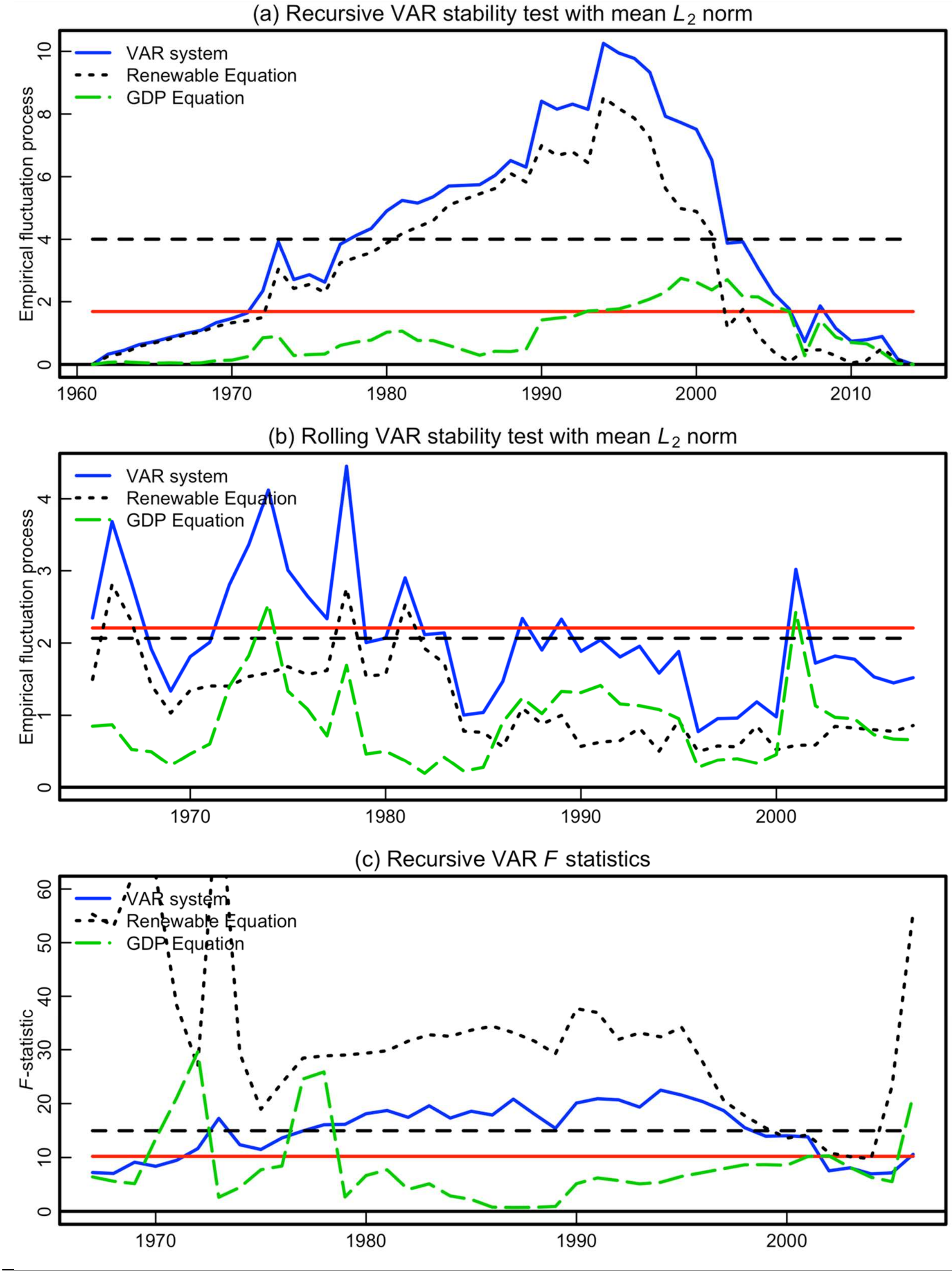
Note: See note to Figure 1.

Figure 3: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for Germany



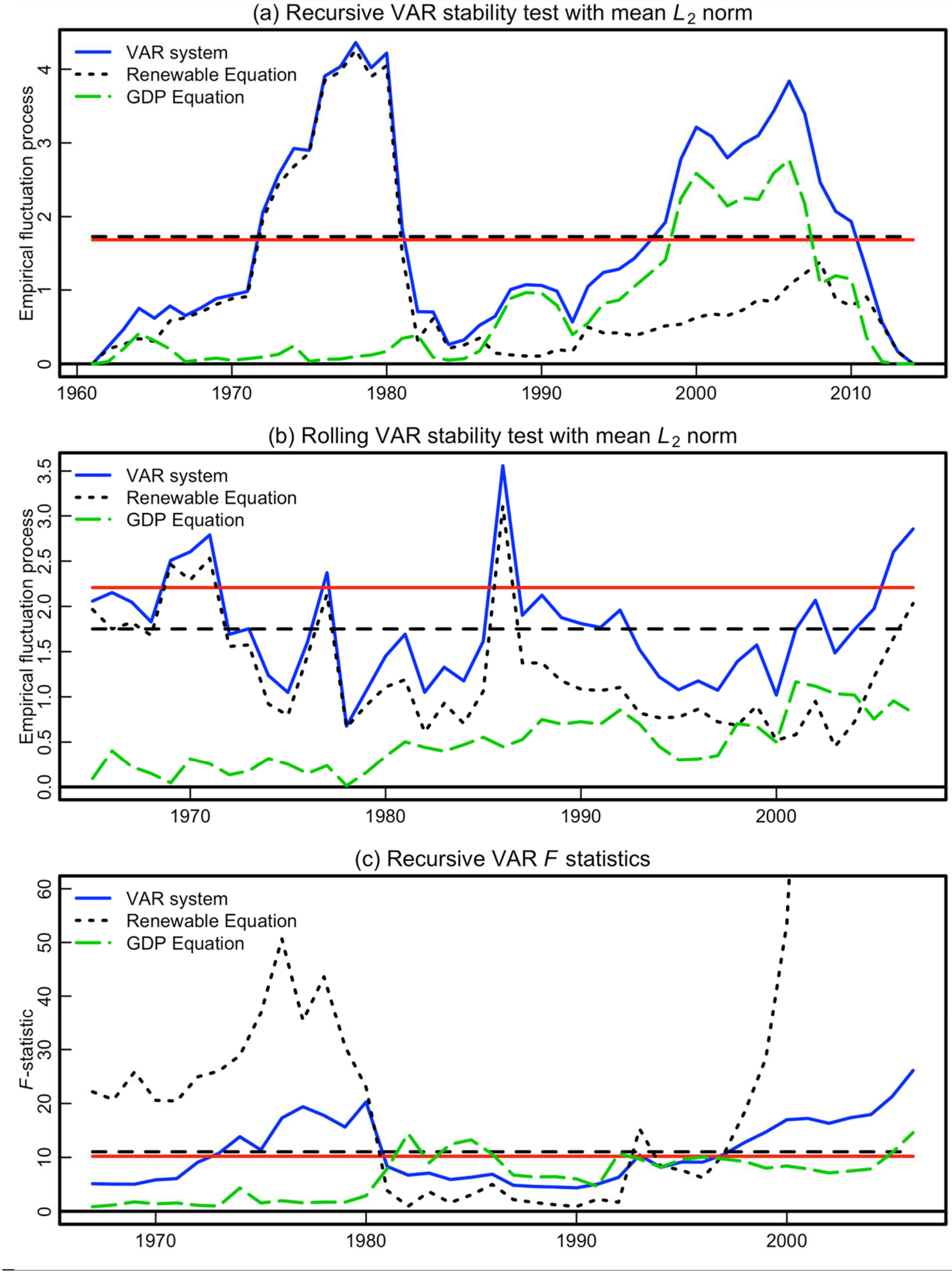
Note: See note to Figure 1.

Figure 4: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for Italy



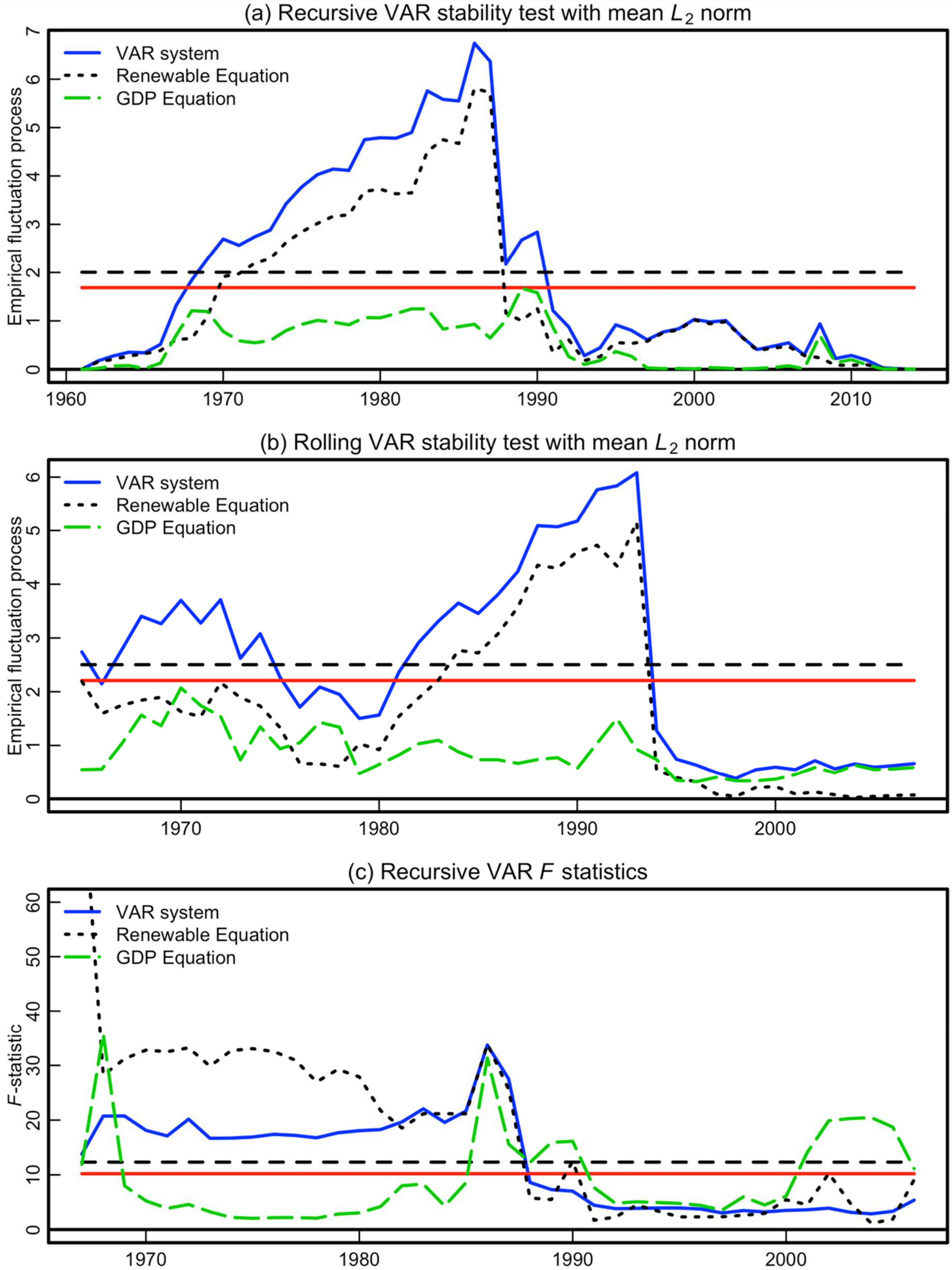
Note: See note to Figure 1.

Figure 5: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for Japan



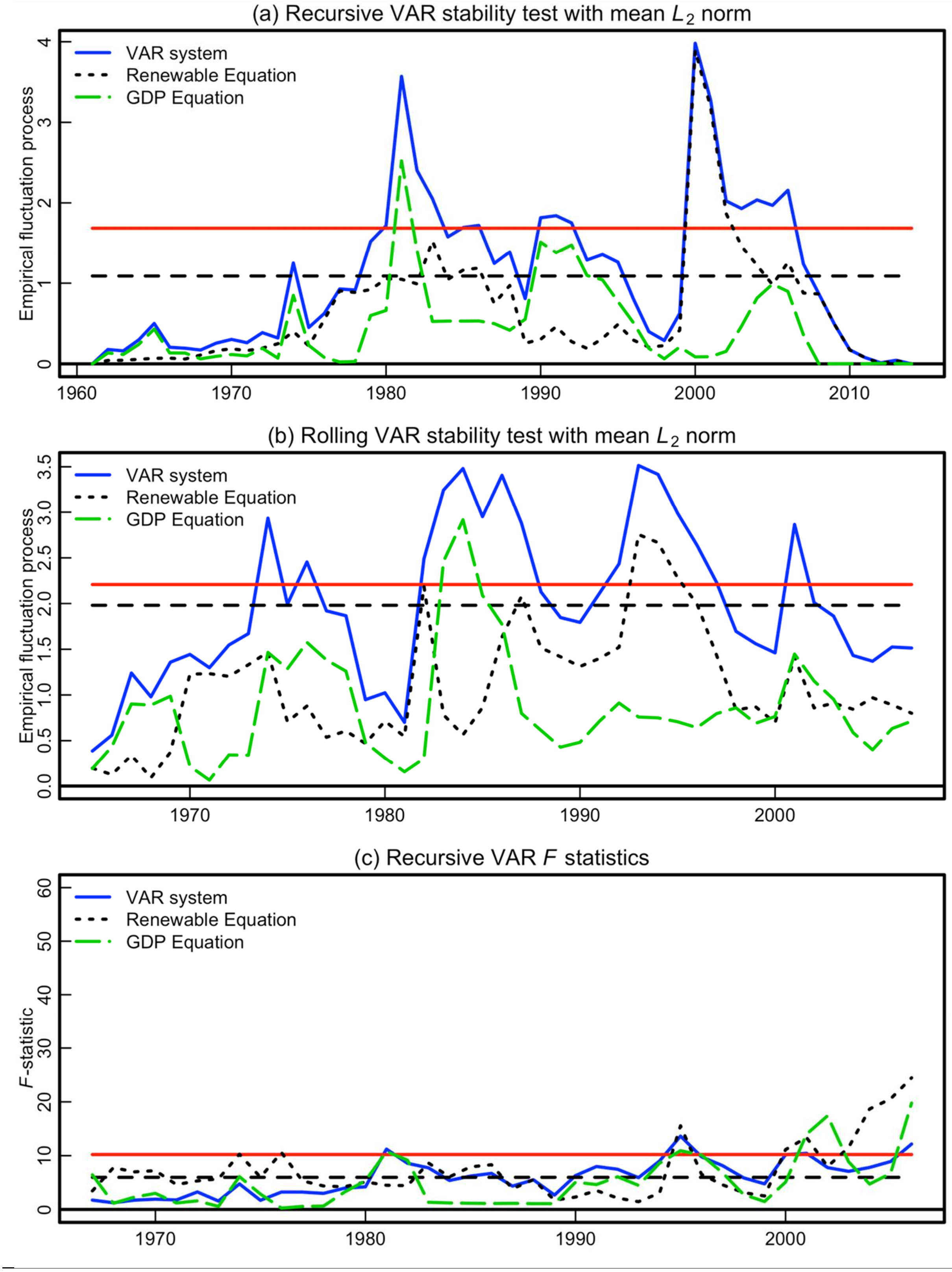
Note: See note to Figure 1.

Figure 6: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for UK



Note: See note to Figure 1.

Figure 7: Recursive VAR stability test with mean L_2 norm, rolling VAR stability test with mean L_2 norm and recursive VAR stability F test results for US



Note: See note to Figure 1.

Figure 8 provides the time series plot of the logarithm of renewable energy consumption for the G-7 countries over the study period. The renewable energy consumption follows a decreasingly growing trend in Canada. In Germany and Italy, renewable energy consumption follows an increasing trend after flattening out until the early 1990s. In France and United Kingdom, a completely different renewable energy consumption curve is observed. For France, the slightly increasing consumption rate showed a drastic shift at the end of the 1960s and has become stagnant since then. In the United Kingdom, a slight upward trend was observed in renewable energy consumption from 1960 to the late 1980s, and then this consumption showed a linear growing trend from the early 1990s with a big jump in 1987. Japan's graph of renewable energy consumption indicates that the consumption line with a tendency to increase linearly throughout the whole analysis period appears to have been broken at the beginning of the 1980s. Finally, the renewable energy consumption of United States tracks the linear growing path up to 1985, and then it goes on a stagnant path until it catches a linear growth tendency after 2000. The logarithm of the real GDP series is plotted in Figure 9 for the G-7 countries. From 1960 to the present day, the real GDP growth of the G-7 countries appears to show a decreasingly growing character.

Figure 8: Time Series plot of the log of renewable energy consumption for the G-7 countries

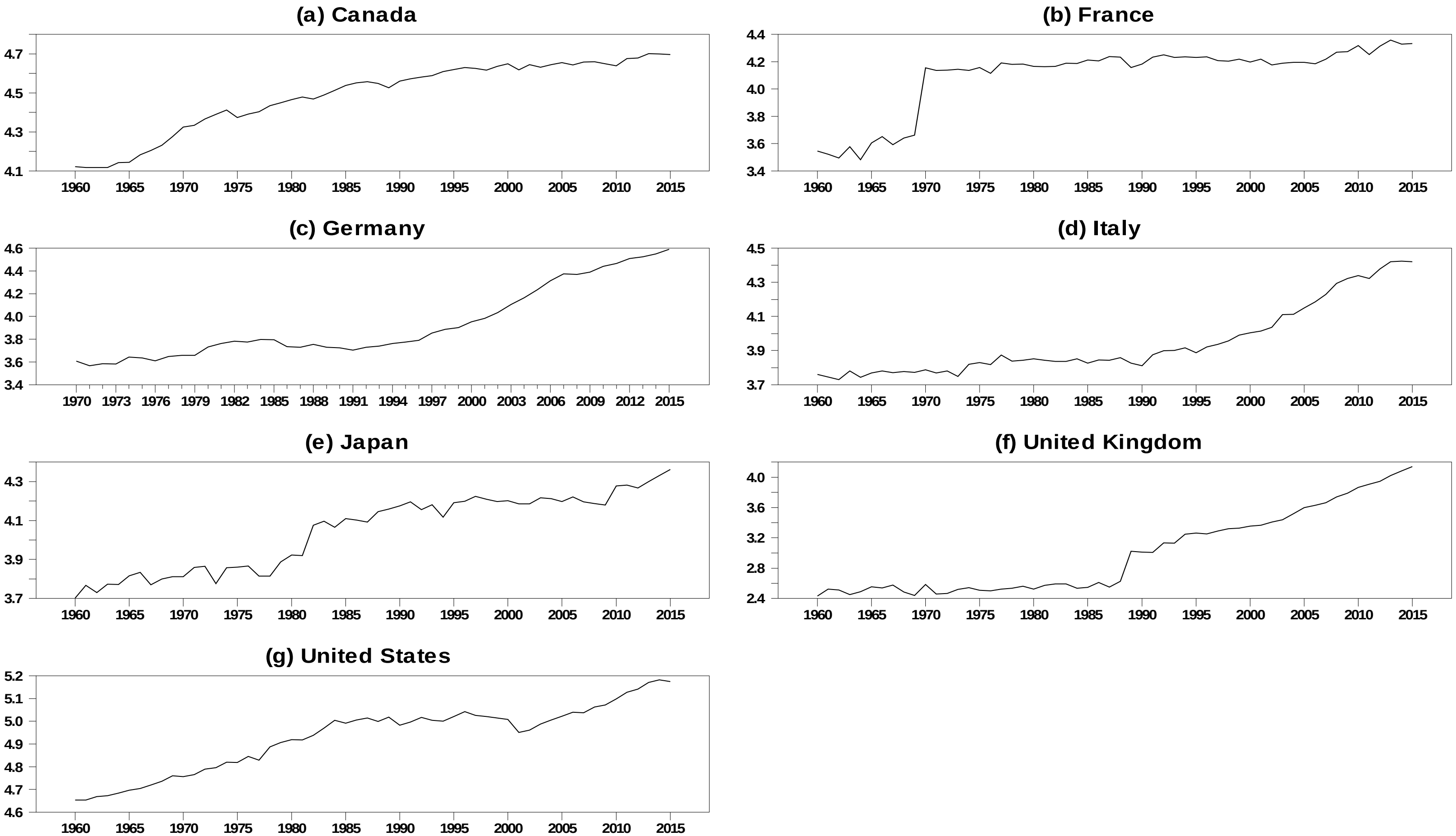


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Figure 9: Time Series plot of the log of the real GDP series for the G-7 countries

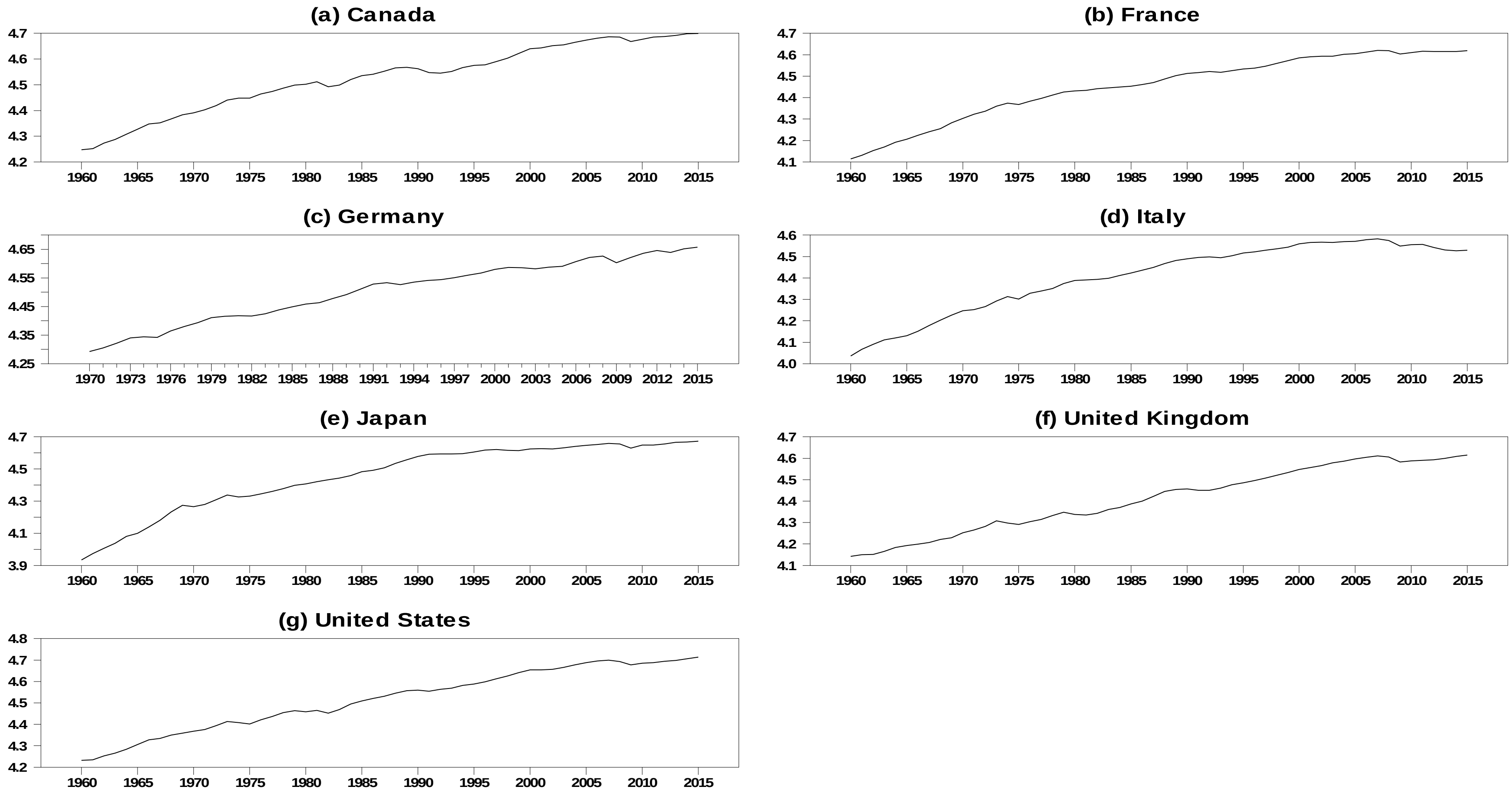
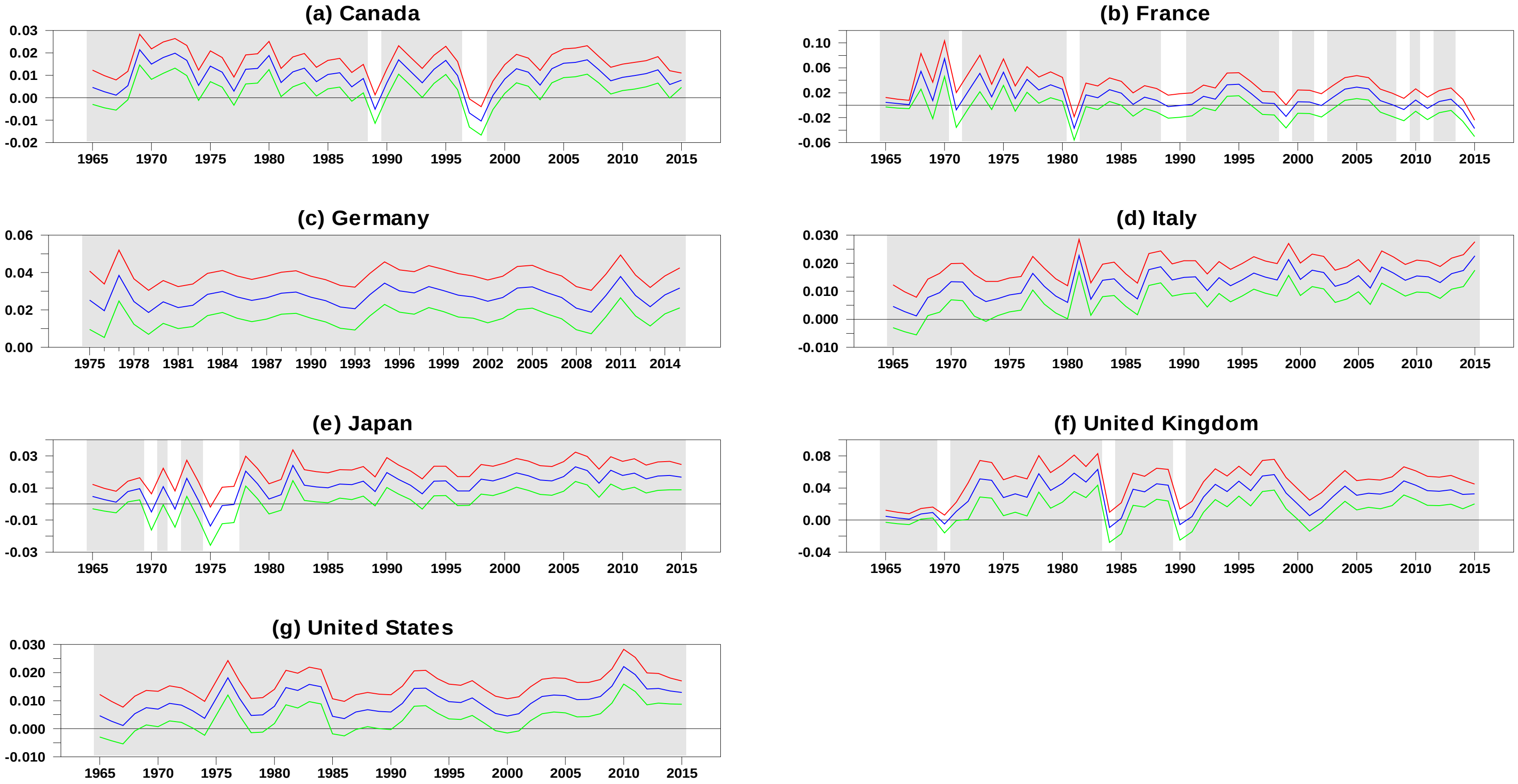


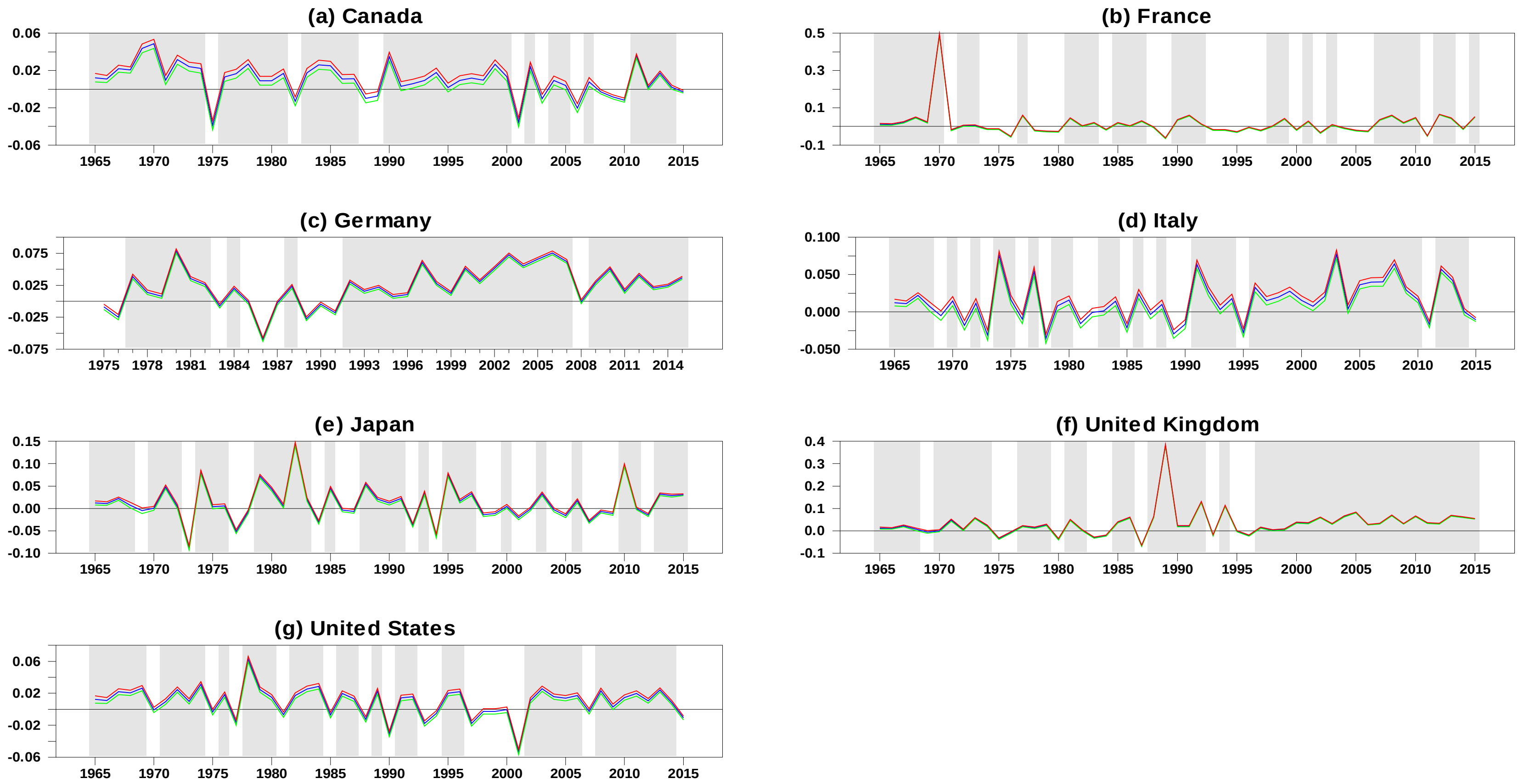
Figure 10 reports the estimates of economic growth shocks on renewable energy consumption. 95% confidence intervals for the HDs are also given in each Figure. The estimation results demonstrate that generally the effect of economic growth on renewable energy is positive for all the G-7 countries during the analysis period. In Germany, Italy and the United States, the effect of economic growth on renewable energy consumption is significantly positive over the entire analysis period; while in other countries the contribution of economic growth to renewable energy consumption is close to zero or gets even a negative value in a few times. That is, energy conservation policies implemented in all the G-7 countries have become a very important tool in combating global warming. Moreover, the effect of economic growth on renewable energy consumption is slightly increasing in Italy, Japan and the United States, while this effect is decreasing in France and is stagnant in Canada and Germany. Looking at the individual results for Japan, the contribution of economic growth to renewable energy consumption fluctuates during the first and second oil crises and then becomes stagnant after that period. To sum up, economic growth requires renewable energy needs during all the analysis period for Germany, Italy and the United States; on the other hand, it increases energy needs in other countries during all the analysis period except for some short time intervals.

Figure 10: The effect of economic growth on renewable energy consumption



Note: The line in the middle represent the effect of the growth shock on the renwable energy consumption with surrandin lines representing the 95% confidence limits. Shaded refions denote the periods where the effect of the growth shock are postitive.

Figure 11: The effect of renewable energy consumption on economic growth



Note: The line in the middle represent the effect of the renewable energy shock on economic growth with surrandin lines representing the 95% confidence limits. Shaded refions denote the periods where the effect of the renewable energy shocks are postitive.

The estimation results for renewable energy consumption effect on economic growth are shown in Figure 11. Findings about the effect of renewable energy consumption on economic growth indicate that the relationship is not fixed in any G-7 country. In all G-7 countries, this relationship is time-varying over the study period. The weakening nexus from renewable energy consumption to economic growth since the early 1980s started to rise again in 1986 with a negative dip in Germany. During the 2008 Global Financial Crisis, the growth theory lost its power again, but it has recovered after that time. Especially since the early 1990s, we can say that in Germany, the use of renewable energy is the driving force for economic growth. A similar situation seems to be the case for Italy and the United Kingdom. On the other hand, the estimation results show that in France, Japan and the United States, this relationship follows a mixed path during the analysis period. In other words, we cannot say that the growth theory works strongly in all periods, or at least for a certain period of time. These results clearly show that the effect of renewable energy consumption on economic growth varies over time. Unlike previous studies[2], it is not possible to assume a constant causality relationship throughout the analysis period for these countries.

4. Conclusion

This paper attempted to assess the time-varying effects of renewable energy consumption on economic growth and *vice versa* for the G-7 countries. For this purpose, the analysis used the historical decomposition approach to determine the relationship, and the bootstrap method to compute confidence intervals. The previous literature used full sample econometric methods to determine the causal nexus between renewable energy consumption and economic growth. The major drawback of these studies is the assumption that the relationship between the variables is constant over time. Our study fills the gap in the literature and allows us to make policy implications by incorporating structural changes in the period of analysis with regards to the relationship between renewable energy consumption and economic growth.

The estimation results provide clear evidence that the effect of economic growth on renewable energy consumption is time-varying and positive in all the time periods for Germany, Italy and the United States. For Canada, France, Japan and the United Kingdom, the contribution of economic growth to renewable energy consumption is close to zero or

[2] A few efforts estimated by full sample models such as Chang et al. [14] and Tugcu et al. [41] concludes the importance of renewable energy for economic growth in the G-7 countries in all the analysis period.

even falls below horizontal line in some periods. In other words, the reported findings substantially contradict the conservation hypothesis for all the G-7 countries in all the analysis periods. Other findings regarding the effect of renewable energy consumption on economic growth provide diverse results; that is, a positive shock in the consumption of renewable energy on economic growth seems not to produce a prevailing outcome over the entire analysis period. After the early 1990s, the use of renewable energy in Germany, Italy and United Kingdom has become the driving force for economic growth except for a few time intervals. It is conceivable for these countries to invest in renewable energy technologies or to switch to renewable energy from fossil fuels in these time intervals. In other countries, there is no evidence that the growth theory operates for a long period of time. For future research, it would be interesting to investigate the time-varying effects of renewable energy consumption on economic growth and *vice versa* for developing and underdeveloped countries.

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