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International Evidence on Time-Variation in Trend Labor Productivity Growth

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Abstract

This paper provides international evidence on time-variation in trend productivity growth, based on the dataset for hours worked constructed by Ohanian & Raffo (2012). Applying both the endogenous break tests of Bai & Perron (1998, 2003) and the Stock & Watson (1996, 1998) TVP-MUB methodology, substantial evidence of time-variation in trend productivity growth is detected for most countries. For either Japan, or countries belonging to the Eurozone, evidence points towards a significant growth decline over the last several decades. Weaker evidence is reported for the United States, for which the 1990's productivity acceleration is estimated to have been overall mild, and of a temporary nature.

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Keywords: Labor productivity; structural break tests; time-varying parameters; median-unbiased estimation; bootstrapping; Monte Carlo integration.

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"Productivity isn't everything, but in the long run it is almost everything (Krugman, 1994)."

1 Introduction

The assessment of trend labor productivity growth plays a key role in the formulation of public policy decisions. A mis-estimation of its true underlying equilibrium trend growth rate may potentially lead to serious policy mistakes. For instance, Orphanides (2003) argues that part of the Great Inflation in the United States should be attributed to the FED's measurement problems, in real time, of the productivity slowdown which took place at the beginning of the 1970's. In the long-run, it plays a central role for the management of public pension systems and government debt. International differences in such trends, with possible persistent changes in the trend growth rate, are at the core of many important economic policy debates. While there is ample evidence on the development of trend labor productivity growth in the US, the question of whether the trend growth rate of labor productivity has changed significantly in other industrialized economies is rarely examined formally.

This paper provides international evidence on time-variation in trend labor productivity growth for a sample of 15 OECD economies since 1960. The main contribution of this analysis is to extend the study of time-variation in trend labor productivity growth to a broad set of countries over a long time horizon. Most of the recent empirical work has focused on the United States and discussed the productivity acceleration that was observed in the second half of the 1990's.[1] For instance, Benati (2007) uses a broad set of econometric techniques to study time-variation in labor productivity growth. He shows that labor productivity growth should be generally regarded as time-varying and confirms the high-low-high pattern in the growth rate of U.S. labor productivity. So far, only few papers provide international evidence on changes over time in equilibrium productivity growth. Benati (2007) finds evidence of a significant productivity slowdown in the aggregate Eurozone. Ben-David & Papell (1998) study changes in the rate of growth of annual real GDP per capita for the years 1950 through 1990. For 54 out of 74 countries in their sample they detect a growth slowdown. However, using data on output *per capita* rather than output per hours worked might well provide a distorted picture of the evolution of productivity. By comparing average productivity growth rates across countries and sub-samples, Gust & Marquez (2000) find that U.S. productivity growth had been lower than in the other G-7 member economies between 1980 and 1995, and higher afterward. Turner & Boulhol (2011) examine the difference in labor productivity growth between the United States and the EU15 countries between 1970 and 2007. Based on endogenous break tests, they report that developments in information technology likely caused shifts in labor productivity growth across countries.

The empirical strategy taken in this paper features two alternative approaches borrowed from Benati (2007). First, endogenous break tests of Bai & Perron (1998, 2003) are applied in order to detect shifts at unknown points in the sample in the mean of trend labor productivity growth. As shown *via* Monte Carlo by Cogley & Sargent (2005) and Benati (2007), however, a limitation of endogenous break tests is that they often exhibit a very low power when the series under investi-

[1] See for example Gordon (1999); Oliner & Sichel (2000); Hansen (2001); Roberts (2001); Oliner & Sichel (2002).

gation is characterized by 'slow and continuous drift', which is typically formalized by assuming random-walk time-variation in the coefficients. Because of this, the more flexible time-varying parameters median-unbiased estimation (henceforth, *TVP-MUB*) methodology proposed by Stock & Watson (1996, 1998) is considered, which is precisely based on the notion that the data generating process (DGP) is characterized by random-walk drift in the coefficients. A key attractiveness of Stock and Watson's (1996, 1998) methodology is that it allows a researcher to *test* for the presence of random-walk time-variation in the data, and then to *estimate* its extent. On the other hand, the corresponding Bayesian approach—originally pioneered, within a multivariate framework, by Cogley & Sargent (2002)—suffers from the fundamental limitation that the estimated trends it produces for the variables of interest are typically quite sensitive to a researcher's prior on the extent of random-walk time-variation (the parameter which, e.g., both Cogley and Sargent and Primiceri call λ).[2]

The main results may be summarized as follows:

- Based on the Bai & Perron (1998, 2003) methodology, substantial evidence of structural breaks in 10 out of 15 countries is found. Evidence suggests that a group of six countries (among them Canada, France and Japan) experienced a structural break between 1969Q3 and 1972Q4, which is a period strongly affected by the first oil price shock. For Germany and Norway the break occurred around the time of the second oil price shock in 1979. Lastly, for four countries the results indicate a break around in the early years of the new millenium.

- Based on the Stock & Watson (1996, 1998) TVP-MUB methodology, evidence of time-variation for 13 out of 15 countries is detected. Strong evidence of time-variation is found for Japan—for which trend labor productivity growth fell from around 8% in 1960Q1 to 1% in 2013Q4—and for the countries belonging to the Eurozone.

- For the United States, weak evidence of time-variation in trend labor productivity growth is detected. On the one hand, the null of no structural break cannot be rejected based on the Bai & Perron (1998, 2003) test. As for the Stock & Watson (1996, 1998) TVP-MUB methodology, evidence points towards the well known U-shaped pattern between 1960 and 2000. Interestingly, however, the 1990's productivity acceleration is estimated to have been comparatively mild, and only temporary. Since the turn of the millennium productivity growth has substantially decreased, reaching a minimum of 1.6% in 2013Q4, and thus reverting back to the values observed at the beginning of the 1990's.

The rest of the paper is organized as follows. Section 2 presents the data used in the analysis and Section 3 explains the two different methodologies applied. The results are presented in Section 4. Section 5 concludes.

[2] Extensive evidence on this can be provided. E.g., Benati (2015) shows that the three priors for the extent of random-walk time-variation used by Cogley & Sargent (2002), Primiceri (2005), and Cogley (2005) produce materially different estimates of U.S. trend GDP growth, especially since the turn of the millennium.

2 Data

To construct series for labor productivity, high quality data on hours worked and output from Ohanian & Raffo (2012) is used. For most countries, the quarterly series span from the first quarter of 1960 through the fourth quarter of 2013.[3] Their measure of total hours worked draws from a variety of international sources such as national statistical offices, establishment and household surveys, taking into account of important differences across countries such as paid vacation or sick days.[4] Total hours worked are defined as hours worked per worker times employment, normalized by the size of the working age population (persons aged 16-64). Labor productivity is defined simply as total output divided by total hours worked.[5]

Figure 1 presents the evolution of the log-levels of labor productivity. Although labor productivity clearly follows an upward trend in all countries, differences in the shapes of the trend are evident. Whereas countries such as Canada, France, Germany, Italy and Japan show a broadly concave pattern, there are countries such as Australia, South Korea and, to a lesser extent, the United States for which the trend follows nearly a straight line. An exception is represented by Spain, which, *even in logs*, exhibits an apparently exponential trend. It has to be noticed, though, that since the bursting of the housing bubble, Spanish labor productivity has collapsed, which suggests that the near-exponential trend shown in Figure 1 most likely simply reflects the bubble in the housing sector.

3 Methods

The methodology on detecting structural breaks and time-variation in trend labor productivity growth is borrowed from Benati (2007) and presented in continuation.

3.1 Endogenous break test

The analysis begins by testing for multiple structural breaks at unknown points in the sample in the mean of labor productivity growth, based on the methodology of Bai & Perron (1998, 2003) and following exactly the recommendations of Bai & Perron (2003).[6] The series of labor productivity growth are regressed on a constant, using the covariance matrix estimator from Newey & West (1987) to control for autocorrelation and/or heteroskedasticity in the residuals. Rather than relying on the asymptotic critical values tabulated in Bai & Perron (1998), both critical and p-values are bootstrapped via the *modified* Diebold & Chen (1996) procedure, setting the number of bootstrap

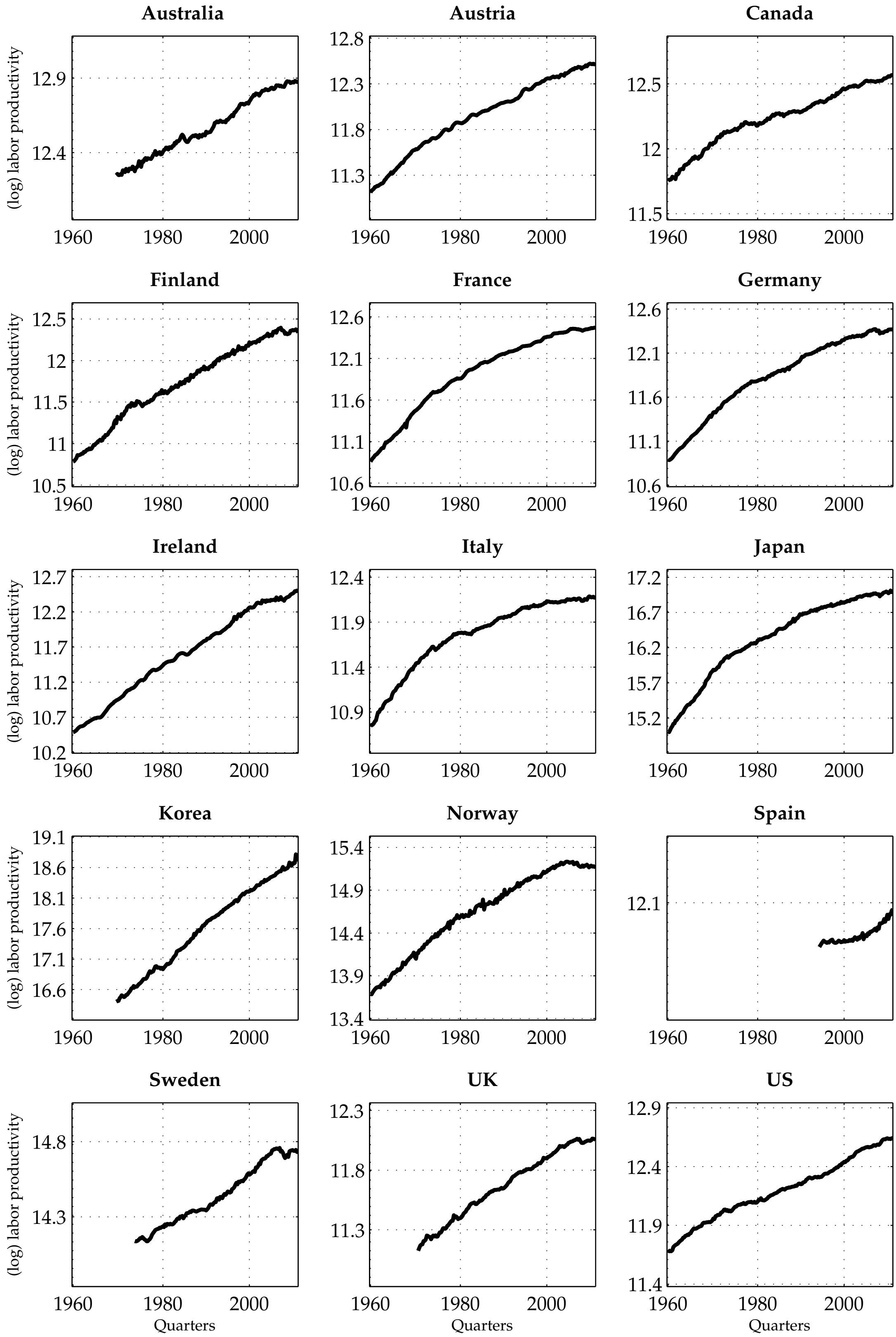
[3] Specifically, the sample periods are the following: Austria, Canada, France, Germany, Ireland, Italy, Japan, Norway, United States 1960Q1-2013Q4, Finland 1961Q1-2013Q4, Australia, South Korea 1970Q1-2013Q4, United Kingdom 1971Q1-2013Q4, Sweden 1974Q1-2013Q4, Spain 1995Q1-2013Q4.

[4] For more information on the construction of the hours worked series the reader is referred to Ohanian & Raffo (2012). In summary, the authors take first the high quality annual series, mainly drawn from national statistical agencies, and adjust them for cross-country differences. Second they use quarterly series based on national sources where available and backcast them e.g. with data from establishment surveys. Third, the quarterly series is adjusted in such a way to match the higher quality annual series.

[5] In logs we have $lp_t = y_t - h_t$.

[6] See Bai & Perron (2003) section 5.5, 'Summary and Practical Recommendations'.

Figure 1: The raw series: Labor productivity in log-levels



Notes: All series are in logs. Labor productivity is defined as total output divided by total hours worked (hours worked per worker times employment).

replications to 1,000.[7] First, the *UDmax* and *WDmax* double maximum test statistics are considered. Conditional on both statistics being significant at the 10% level—thus indicating the presence of at least one break—it is decided on the number of breaks by sequentially examining the $sup - F(l+1|l)$ test statistics, starting from $sup - F(2|1)$. Finally, symmetric 15% trimming is imposed, the maximum allowed number of structural changes is set to m=4, and confidence intervals for estimated break dates are computed according to Bai (1997a).

As shown *via* Monte Carlo by Cogley & Sargent (2005) and Benati (2007), endogenous break tests of Bai & Perron (1998, 2003) often exhibit a very low power when the series under investigation is characterized by 'slow and continuous drift', which is formalized *via* random-walk time-variation in the coefficients. An econometric way of formalizing the notion of gradual change in the underlying data generating process is via time-varying parameters models, which is precisely based on the idea that the DGP be characterized by (a small extent of) random-walk drift in the coefficients.

3.2 Time-varying parameters median unbiased estimation.

The Stock & Watson (1996, 1998) TVP-MUB methodology is applied to the following AR(p)-process:[8]

$$y_t = \mu + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \ldots + \phi_p y_{t-p} + u_t = \theta' z_t + u_t, \tag{3.1}$$

in which y_t is the rate of growth of labor productivity, θ=[μ, ϕ_1, ..., ϕ_p]$'$ and z_t=[1, $y_{t-1,t}$,..., $y_{t-p,t}$]$'$. The lag order, p, is selected based on the Akaike information criterion,[9] for a maximum possible number of lags P=6. With a single exception discussed below, concerning the issue of how to tackle the possible presence of heteroskedasticity in the data—for which a solution along the lines of Boivin (2004) is adopted—the methodology closely follows Stock & Watson (1996).

Letting θ_t=[μ_t, $\phi_{1,t}$, ..., $\phi_{p,t}$]$'$, the time-varying parameters version of Equation 3.1 is given by:

$$y_t = \theta_t' z_t + u_t \tag{3.2}$$

$$\theta_t = \theta_{t-1} + \eta_t \tag{3.3}$$

with η_t i.i.d. $\mathcal{N}(0_{p+1}, \lambda^2\sigma^2 Q)$, with 0_{p+1} being a $(p+1)$-dimensional vector of zeros; σ^2 being the variance of u_t; Q being a covariance matrix; and $\mathbb{E}[\eta_t u_t] = 0$. Following Nyblom (1989) and Stock & Watson (1996, 1998), Q is normalized to $Q = [\mathbb{E}(z_t z_t')]^{-1}$. Under such a normalization, the coefficients on the transformed regressors, $[\mathbb{E}(z_t z_t')]^{-1/2} z_t$, evolve according to a $(p+1)$-dimensional standard random walk, with λ^2 being the ratio between the variance of each 'transformed innovation' and the variance of u_t.[10]

The procedure starts with the estimation of $\hat{\theta}_{OLS}$, the computation of the residuals, $\hat{u}_t$, and the estimation of the innovation variance, $\hat{\sigma}^2$. Then follows an *exp*-Wald joint test for a single break at an unknown point in the sample in μ and ρ—with ρ defined as the sum of the AR coefficients

[7] See Benati (2007), footnote 13 for details.

[8] In what follows, most of the technical details are omitted for the sake of brevity. The interested reader can find them in Benati (2007), Section 3, or in Stock & Watson (1996, 1998).

[9] An alternative, qualitatively similar set of results based on the Schwartz Information Criterion is not reported here, but is available from the author upon request.

[10] To be precise, given that the Stock-Watson methodology is based on local-to-unity asymptotics, λ is actually equal to the ratio between τ, a small number which is fixed in each sample, and T, the sample length.

in our estimation equation—using the Newey & West (1987) covariance matrix estimator to control for possible autocorrelation and/or heteroskedasticity in the residuals. Finally, the matrix Q is estimated as in Stock & Watson (1996),

$$\hat{Q} = \left[T^{-1} \sum_{t=1}^{T} z_t z_t' \right]^{-1}. \tag{3.4}$$

The empirical distribution of the test statistic is computed by considering a 100-point grid of values for λ over the interval $[0, 0.1]$. The median-unbiased estimate of λ is derived as that particular value for which the median of the simulated empirical distribution of the test is closest to the test statistic previously computed based on the actual data. Finally, the p-value based on the empirical distribution of the test is computed, conditional on the particular value for λ in the grid, based on the extension of the Stock & Watson (1996, 1998) methodology provided in Benati (2007).

Next, time-varying estimates of equilibrium productivity growth rates and, crucially, confidence bands around these estimates are computed. Both filter and parameter uncertainty are fully taken account of *via* Monte Carlo integration.[11] In particular, uncertainty about the true extent of random-walk time-variation is captured by the deconvoluted probability density function (PDF) of $\hat{\lambda}$.[12] The deconvolution of the median-unbiased estimates of λ is important because a p-value above 10% (as for example in the case of the United States, where it is 13.3%) should be regarded as significant evidence against time variation if and only if the researcher has convincing reasons to believe in time-invariance.

Tests for multiple structural breaks at unknown points in the sample in the innovation variance, $\hat{\sigma}^2$, are performed along the lines of Boivin (2004). Break dates are estimated combining the *exp*-Wald test statistic from Andrews (1993) and Andrews & Ploberger (1994) with the Bai (1997b) method of estimating multiple breaks sequentially, one at a time. The critical values have been bootstrapped as in Diebold & Chen (1996), and 15% symmetric trimming has been imposed. Finally, confidence intervals for the estimated break dates are computed as in Bai (1997b).

Based on the median-unbiased estimates of λ, on the deconvoluted PDFs of $\hat{\lambda}$, and on the estimated breaks in the innovation variance, the time-varying equilibrium rates of labor productivity growth together with their corresponding confidence bands are then estimated.

4 Results

This section first reports the results from the structural break tests and then presents evidence from the time-varying parameters median unbiased estimation.

4.1 Endogenous break test

Table 1 reports the results from the Bai & Perron (1998, 2003) structural break tests. The null hypothesis of no structural break cannot be rejected based on either the *UDmax* and *WDmax* test

[11] Specifically, this is done based on the modification of the Hamilton (1985, 1986) Monte Carlo integration procedure described in Appendix C of Benati (2007).

[12] Which is done via the procedure described in Appendix B of Benati (2007).

statistic for Australia, South Korea, Spain, Sweden and the United States. For all other countries, the double maximum tests indicate that the null of no structural break in the mean of labor productivity growth can be rejected at the 10% significance level. Turning to the number of breaks, results from the $sup - F(l+1|l)$ tests suggest that both France and Norway experienced two structural breaks (1974Q3 and 2002Q3 for France, and 1980Q1 and 2004Q1 for Norway), whereas for the remaining eight countries the null hypothesis of one structural break *versus* the alternative of two structural breaks was not rejected.

Table 1: Tests for multiple breaks at unknown points in the sample in the mean based on Bai & Perron (1998): Double maximum tests, $sup - F(l+1|l)$-test statistics, and estimated break dates

	Double maximum tests$^{(i)}$		$sup - F(l+1\|l)$**-tests**$^{(i)}$		**Break dates**$^{(ii)}$
Country	UDmax	WDmax	$F(2\|1)$	$F(3\|2)$	
Australia	3.108	3.484			—
Austria	21.408 **	21.408 **	5.241		1969Q4 [1967Q4; 1973Q1]
Canada	7.435 **	7.435 *	2.416		1973Q1 [1972Q3; 1986Q4]
Finland	5.107 **	5.108 **	2.291		1973Q3 [1962Q2; 1990Q1]
France	37.781 **	42.154 **	32.254 **	5.166	1974Q3 [1974Q1; 1978Q2]
					2002Q3 [2001Q3; 2005Q3]
Germany	38.419 ***	38.419 **	4.324		1979Q2 [1974Q4; 1981Q2]
Ireland	7.526 **	9.203 **	2.119		2003Q4 [1975Q2; 2005Q2]
Italy	49.526 ***	49.526 ***	8.149		1974Q2 [1973Q3; 1976Q3]
Japan	52.08 ***	52.08 ***	8.174		1973Q2 [1971Q3; 1974Q4]
South Korea	3.932	4.408			—
Norway	15.263 ***	15.263 ***	1.816 *	0.57	1980Q1 [1965Q1; 2001Q1]
					2004Q1 [2003Q3; 2009Q4]
Spain	3.062	3.062			—
Sweden	6.275	8.148			—
United Kingdom	16.721 **	16.721 **	1.694		2003Q4 [2002Q3; 2010Q1]
United States	5.728	7.549			—

Note: (i) ***, ** and * significant at 1%, 5% and 10%, respectively; (ii) Estimated break dates and 90% confidence intervals.

Next, Table 2 reports the estimated mean productivity growth rates for each sub-sample. In all countries the mean labor productivity growth was higher in the first sub-sample than in the second or third. The largest fall in mean productivity growth was experienced by Japan, where a decrease of 5.76 percentage points (from 8.24% to 2.48%) is estimated. Canada displays the smallest decline (1.86 percentage points). Over all countries for which a significant structural break is detected, labor productivity growth is found to fall on average by 3.5 percentage points.

Evidence for countries belonging to the European Union points towards a significant productivity slowdown since the early 1960s, as reported, e.g., by Turner & Boulhol (2011). Maybe surprisingly, no break dates are identified for the United States. Several studies have reported evidence of structural changes in U.S. labor productivity growth. For example, Roberts (2001), Fernald (2007) and Kahn & Rich (2007) find significant evidence of variation in trend productivity growth. Using endogenous break tests, Fernald (2007) finds a statistically significant break in 1973Q2.[13] Benati (2007) however studies 12 different U.S. labor productivity series and only identifies a break date for the the overall manufacturing sector.[14]

[13]His data are private-business labor productivity growth from 1950Q2 to 2004Q2.

[14]A key point here is that, as discussed by Benati (2007), evidence of breaks in U.S. trend productivity growth is fragile, as it crucially depends on the specific sample period and vintage of data used by the author.

Table 2: Tests for multiple breaks at unknown points in the sample in the mean based on Bai & Perron (1998): Estimated mean productivity growth by sub-sample

	Sub-periods			Mean growth$^{(i)}$		
Country	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3
Australia	1970Q1-2013Q4			1.53		
Austria	1960Q2-1969Q3	1969Q4-2013Q4		4.80	2.25	
Canada	1960Q2-1972Q4	1973Q1-2013Q4		3.00	1.14	
Finland	1960Q2-1973Q2	1973Q3-2013Q4		5.35	2.56	
France	1960Q2-1974Q2	1974Q3-2002Q2	2002Q3-2013Q4	5.53	2.59	0.75
Germany	1960Q2-1979Q1	1979Q2-2013Q4		4.66	1.83	
Ireland	1960Q2-2003Q3	2003Q4-2013Q4		4.34	1.69	
Italy	1960Q2-1974Q1	1974Q2-2013Q4		6.42	1.49	
Japan	1960Q2-1973Q1	1973Q2-2013Q4		8.24	2.48	
South Korea	1970Q1-2013Q4			5.26		
Norway	1960Q2-1979Q4	1980Q1-2003Q4	2004Q1-2013Q4	4.88	3.05	0.02
Spain	1995Q1-2013Q4			0.96		
Sweden	1974Q1-2013Q4			1.59		
United Kingdom	1971Q2-2003Q3	2003Q4-2013Q4		2.73	0.64	
United States	1960Q1-2013Q4			1.84		

Note: (i) Annualized mean labor productivity growth in percent (%).

4.2 Time-varying parameters median unbiased estimation

The estimation results for the *exp*-Wald joint test are reported in Table 3.[15] Overall, the results confirm the findings reported in the previous section. Strong evidence of random-walk time-variation is found for all countries except for Canada (for which λ is exactly 0) and the United States (it is to be noticed, however, that for the U.S. the MUB estimate of λ is equal to 0.0125). For Finland, Sweden and South Korea, the null hypothesis of time-*in*variance is rejected at the 5% significance level.

Table 3: Results based on Stock and Watson's (1996, 1998) TVP-MUB methodology: exp-Wald test statistics and median-unbiased estimates of λ

Country$^{(i)}$	exp-Wald$^{(ii)}$		$\hat{\lambda}$
Australia	13.995	***	0.0333
Austria	13.159	***	0.0375
Canada	3.903		0
Finland	5.931	*	0.0167
France	29.56	***	0.05
Germany	40.632	***	0.0542
Ireland	33.266	***	0.0458
Italy	16.488	***	0.0375
Japan	23.452	***	0.0417
South Korea	2.632	*	0.025
Norway	20.388	***	0.0458
Sweden	5.532	*	0.0208
United Kingdom	9.17	**	0.0292
United States	4.03		0.0125

Note: (i) Spain is not considered as its sample period is too short; (ii) ***, ** and * significant at 1%, 5% and 10%, respectively.

[15] Spain is omitted as its sample period is too short for estimation.

Table 4: Tests for multiple breaks at unknown points in the sample in the innovation variance based on Andrews & Ploberger (1994) and Bai (1997b)

Country$^{(i)}$	Break dates$^{(ii)}$	exp-Wald$^{(iii)}$	Sub-periods	Std. dev.$^{(iv)}$
Australia	1986Q3 [1976Q3; 1996Q3]	4.61 ***	1970Q2-1986Q2	5.5 [5.05; 6.04]
			1986Q3-2013Q4	3.38 [3.10; 3.71]
Austria	1968Q3 [1962Q1; 1975Q1]	6.41 ***	1960Q2-1968Q2	4.38 [4.06; 4.76]
	2002Q3 [2002Q1; 2003Q1]	2.39 **	1968Q3-2002Q2	2.06 [1.43; 2.24]
			2002Q3-2013Q4	4.42 [4.10; 2.03]
Canada	1973Q1 [1961Q3; 1984Q3]	2.03 *	1960Q2-1972Q4	1.42 [1.19; 1.09]
	1987Q2 [1976Q4; 1997Q4]	13.21 ***	1973Q1-1987Q1	3.45 [3.20; 3.76]
			1987Q2-2013Q4	2.16 [2.00; 1.42]
Finland	1969Q3 [1967Q4; 1971Q2]	4.70 *	1960Q2-1969Q2	5.18 [4.80; 5.64]
			1969Q3-2013Q4	8.32 [7.71; 9.06]
France	1969Q3 [1964Q4; 1974Q2]	14.63 ***	1960Q2-1969Q2	6.62 [6.13; 7.20]
			1969Q3-2013Q4	1.94 [1.80; 2.11]
Germany	1968Q1 [1965Q2; 1970Q4]	1.68 **	1960Q2-1967Q4	2.50 [2.31; 2.72]
			1968Q1-2013Q4	3.70 [3.42; 4.02]
Ireland	1996Q3 [1996Q2; 1996Q4]	23.33 ***	1960Q2-1996Q2	2.19 [2.03; 2.39]
			1996Q3-2013Q4	9.89 [9.15; 10.75]
Italy	1976Q2 [1969Q1; 1983Q3]	6.27 ***	1960Q2-1976Q1	6.30 [5.89; 6.85]
			1976Q2-2013Q4	3.29 [3.03; 3.56]
Japan	—	0.53	1960Q2-2013Q4	5.12 [4.53; 6.85]
South Korea	1991Q2 [1985Q3; 1997Q1]	2.72 **	1970Q2-1991Q1	7.89 [7.25; 8.67]
	1997Q2 [1996Q3; 1998Q1]	2.31 **	1991Q2-1997Q1	3.27 [3.00; 3.59]
	2007Q1 [2006Q3; 2007Q3]	2.17 **	1997Q2-2006Q4	6.25 [5.74; 6.88]
			2007Q1-2013Q4	13.02 [11.99; 14.30]
Norway	1995Q1 [1986Q4; 2003Q2]	10.17 **	1960Q2-1996Q4	9.92 [9.19; 10.79]
			1995Q1-2013Q4	5.54 [5.13; 6.02]
Sweden	1993Q3 [1992Q4; 1994Q2]	8.39 ***	1974Q2-1993Q2	1.98 [1.75; 2.18]
			1993Q3-2013Q4	3.72 [3.40; 4.10]
United Kingdom	1980Q3 [1974Q4; 1986Q2]	5.19 **	1971Q2-1980Q2	6.64 [6.09; 7.30]
			1980Q3-2013Q4	2.77 [2.54; 3.08]
United States	1982Q2 [1970Q2; 1994Q2]	3.59 **	1960Q2-1982Q1	3.19 [2.95; 3.49]
			1982Q2-2013Q4	2.09 [1.94; 2.28]

Note: (i) Spain is not considered as its sample period is too short; (ii) Estimated break dates and 90% confidence intervals; (iii) ***, ** and * significant at 1%, 5% and 10%, respectively; (iv) Estimated standard deviation and 90% confidence intervals.

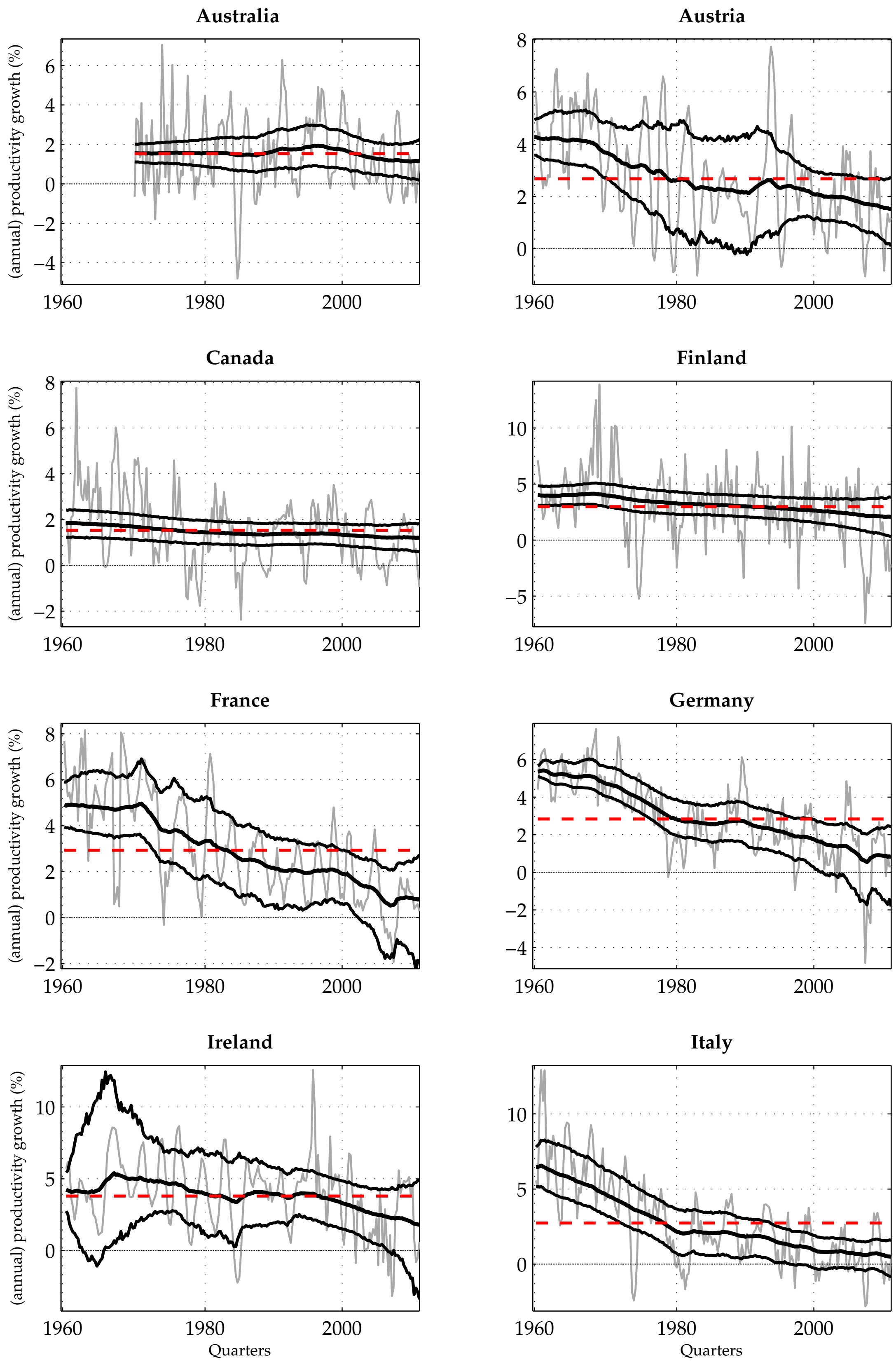
Table 4 presents the results for the estimation of a structural break in the innovation variance. With the single exception of Japan, at least one break in the innovation variance is identified for either country. For one group of countries, the break in volatility has been estimated in the late 1960's (Austria, Finland, France and Germany). Another clustering of break dates is observed in the middle of the 1990's (Ireland, Sweden, South Korea and Norway). For Austria, Finland, France and Italy, the significant change in volatility roughly coincides with the estimated break dates in labor productivity growth reported in Table 2. Among all the detected breaks, volatility is significantly lower after the break in nine cases, while it is higher in eight cases. The largest decrease in volatility has been experienced by France (from 6.6 down to 1.9), whereas Ireland has experienced the highest volatility increase (from 2.2 up to 9.9).

Figures 2 and 3 show the estimated time-varying equilibrium rates of labor productivity growth. For all countries in the sample, evidence points towards a decrease in trend labor productivity growth rates. Relatively little time-variation is found for Australia, South Korea and Sweden, for which median trend estimates fluctuate close to average productivity growth rates, and average productivity is always within the confidence bands. Although, at first sight, this would seem to point towards no evidence of time-variation, an important point to stress here is that evidence that time-variation is indeed there is provided by the p-values reported in Table 4. Common to these three countries is the fact that median trend estimates have fallen below average productivity growth towards the end of the sample. Canada and Ireland are other countries for which the average growth rate of productivity is contained within the confidence bands over the entire sample. In the case of Canada, average annual labor productivity growth amounts to 1.5%. The median trend estimate has fallen from 1.8% in 1960 to 1.2% by 2013, but remained almost constant between 1980 and 2000.

Turning to the European countries, for Austria, France, Germany, Italy and Norway the figures speak volume: Evidence strongly points towards a collapse in trend labor productivity growth in all of the five countries. Consider as an example the case of France: Equilibrium growth of output per hour worked is estimated to have fallen from 4.9% in 1960Q1 to (so far) 0.8% by the end of 2013. According to the result obtained with the structural break test, the decline can instead be characterized as follows: (*i*) From 1960Q1 to 1974Q3 the median estimate has been nearly constant around 4.9%, (*ii*) it has then progressively decreased until 1992, (*iii*) it has remained roughly constant up to about 2000 and (*iv*) it has, once again, significantly fallen to a minimum of 0.5% in the third quarter of 2008. Qualitatively similar patters can be observed for Italy and Germany, and to a somewhat lesser extent for Austria and Norway.

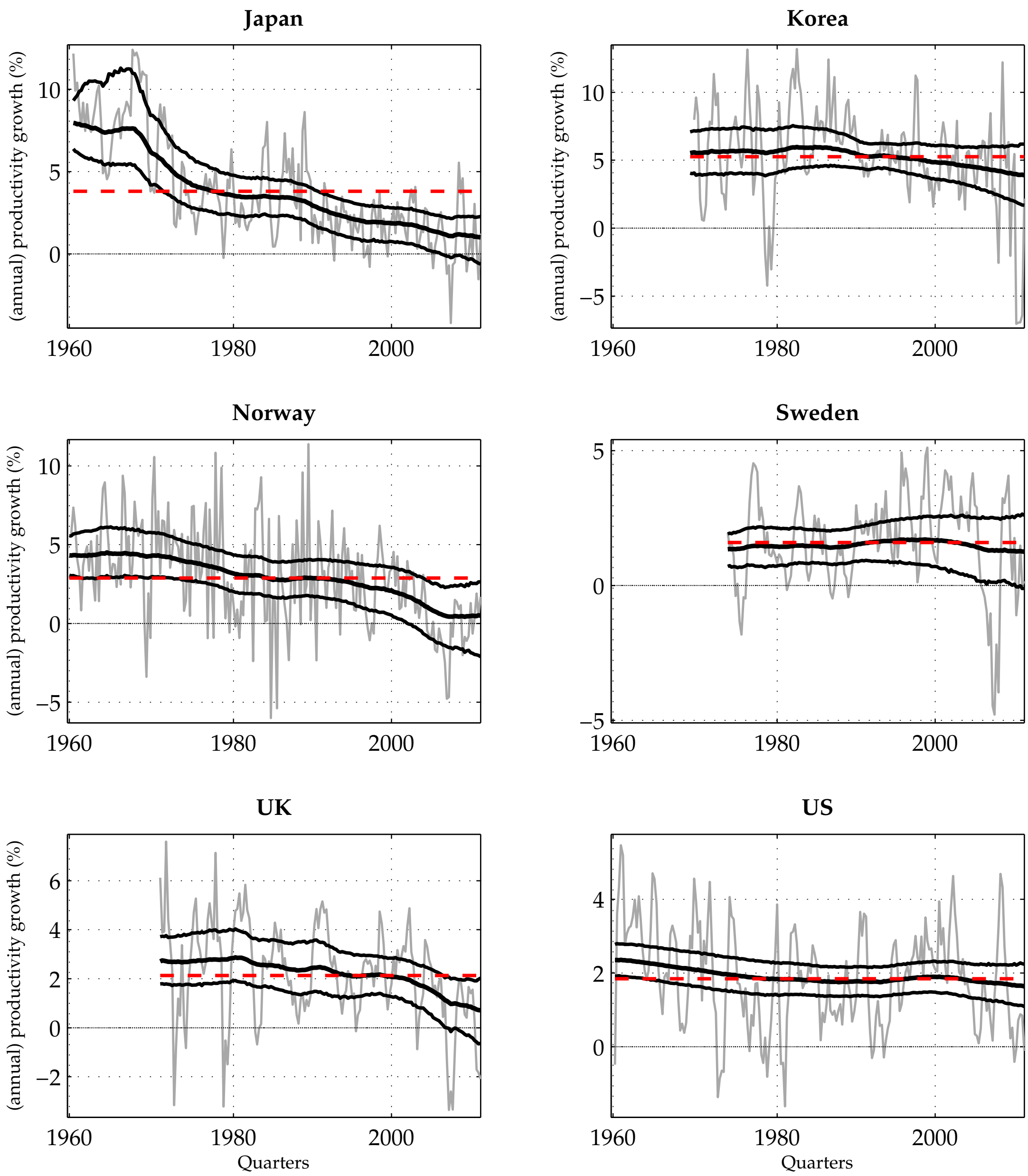
In the United Kingdom, output per hour has declined relatively little in comparison to the other aforementioned European economies. The median trend estimate has been above the average annual productivity growth rate of 2.1% until 1996Q2. As detected by the structural break test, labor productivity growth had fallen significantly from 2003Q4 onwards, to reach a minimum growth rate of 0.7% by 2013Q2. In contrast to the results presented in Benati (2007), substantial evidence of time-variation in trend labor productivity growth is found for Japan. The median trend estimate had almost constantly fallen from 8% annual growth in 1960Q1 to 1% in 2013Q4, crossing the estimated average growth rate of 3.8% as early as in 1979Q1. The decline in labor productivity growth had been especially dramatic in the 1970's, slowed down in the 80's and then again accelerated after 1990.

Figure 2: Time-varying estimates of trend labor productivity growth based on Stock and Watson's TVP-MUB method



Notes: Annual productivity growth; Average productivity growth; Median trend estimate with 5th and 95th percentile of distribution.

Figure 3: Time-varying estimates of trend labor productivity growth based on Stock and Watson's TVP-MUB method (continued)



Notes: Annual productivity growth; Average productivity growth; Median trend estimate with 5th and 95th percentile of distribution.

Evidence for the United States. The development of annual labor productivity growth in the United States deserves a special mention. The results presented in Figure 6 provide evidence of relatively little time-variation, which is consistent with the evidence from the endogenous break tests pointing towards no significant structural break. A closer look at the median trend estimate reveals a pattern which is well in accord with conventional wisdom. First, a marked slowdown of productivity growth can be observed from the beginning of the 1960's to around 1980, with the equilibrium growth rate having fallen from 2.4% to 1.8%. Second, there is a period of stagnation with trend growth staying close to 1.8%. Third, there appears to be a growth resurgence since the mid-1990's, where estimated equilibrium growth increases up to a plateau of 1.9% in 2002Q2.

At least partly, our findings confirm those of Roberts (2001), who also applies the technique of time-varying parameters. He finds that trend productivity growth moved up from around 1.5% by the mid 1990's to about 2.5% by the first quarter of 2001.[16] Finally, towards the end of the observed sample equilibrium growth declines gradually to reach a minimum of 1.6% in 2013Q4. The decline of 0.3 percentage points in the period 2002Q1-2013Q4 is a reversion of labor productivity growth rates back to a level before the productivity acceleration was observed in the 1990's.

5 Conclusion

Overall, the results presented in this paper offer comprehensive evidence that a majority of OECD economies has experienced a substantial slowdown in labor productivity growth. Based on either endogenous break tests, or the more flexible TVP-MUB method proposed by Stock & Watson (1996, 1998), compelling evidence of time-variation in the mean of labor productivity growth for the majority of countries in the sample is reported. The evidence suggests that the resurgence in U.S. productivity growth, which began in the mid-1990's, has only been a temporary phenomenon. It remains to be further clarified, why the emergence of the knowledge economy did not have a more sustainable effect on the trend growth rate of U.S. labor productivity, and what the consequences for the growth development in the Eurozone and the other OECD economies will be.

[16] Roberts (2001) uses nonfarm business sector data from 1947Q1-2002Q4.

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