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and Employment Dynamics

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Macroeconomic Regimes, Technological Shocks and Employment Dynamics

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Abstract

In this work we investigate the interrelations among technology, output and employment in the different states of the U.S. economy (recessions vs. expansions). More precisely, we estimate different threshold vector autoregression (TVAR) models with TFP, hours, and GDP, employing the latter as threshold variable, and we assess the ensuing generalized impulse responses of GDP and hours as to TFP shocks. We find that positive productivity shocks, while spurring GDP growth, display a negative effect on hours worked at least on impact, independently of the state of the economy. In the 1957-2011 period, the effects of productivity shocks on employment are abundantly negative in downturns, but they are not significantly different from zero in good times. However, the impact of TFP shocks in different business cycle regimes depends on the chosen sample: after the mid eighties (1984-2011), productivity shocks increase hours during recessions. Finally, we express and test some conjectures that might have caused the changes in the responses in different time periods.

JEL Codes: E32, O33, C32, E63, E20

Keywords: technology shocks, employment, threshold vector autoregression, generalized impulse response functions

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1 Introduction

In this work, we estimate several threshold vector autoregression (TVAR) models to investigate the interrelations between productivity, output and employment in different states of the U.S. economy (recessions vs. expansions).

The debate about the (positive or negative) impact of technology on employment has always had a central role in economic theory (see Vivarelli, 2007, for a survey) from Ricardo to the recent discussion about the possible job destroying effects of robots. At the business-cycle frequencies, the impact of productivity shocks on employment is not completely settled. In Real Business Cycle (RBC) models, TFP shocks positively affect output and hours worked both in the short-run and in the long-run. However, several contributions (e.g., Gali, 1999; Francis and Ramey, 2005; Basu et al., 2006) have questioned such results, finding that productivity has a negative impact on worked hours in the short-run. Yet, the effects of technology shocks on employment appear to be milder since the mid eighties (e.g., Galí and Gambetti, 2009).

Recently, a stream of literature has found that non-linearities in the economic system can lead to different impact of (monetary and fiscal) shocks according to the state of the economy (see e.g. Auerbach and Gorodnichenko, 2012a) and financial markets (Mittnik and Semmler, 2013; Ferraresi et al., 2014). Technology shocks can be highly dependent on the state of the economy as their effects can be deeply intertwined with (i) the monetary policy regimes (see e.g. Gali and Rabanal, 2004); (ii) the dynamics of labor markets and investment volatility (e.g. Justiniano and Primiceri, 2008; Nucci and Riggi, 2011); (iii) the changing nature of recessions and the role played by financial markets (see, e.g., Petrosky-Nadeau, 2013).

In line with the conjectures coming from the aforementioned literature, we investigate the possible interrelations between technology, output and employment in a non-linear, state dependent framework. More precisely, we estimate over several time spans (the longest being 1957:1-2011:4) different threshold vector autoregression (TVAR) models with TFP, hours, and GDP, employing the latter variable as threshold. We then assess the dynamics of the ensuing generalized impulse response functions (GIRF) to study whether TFP shocks affect differently hours and GDP in recessions vis-à-vis recessions. Finally, we also analyze the presence of possible structural break in the relationship between productivity and employment considering different sub-samples (1957-1979 vs. 1984-2011).

We find that positive TFP shocks spur GDP growth, but display a negative effect on hours worked at least on impact, independently of the state of the economy. In the longest time period, the effects of productivity shocks on employment are abundantly negative during downturns, but they are not significantly different from zero in good times. In that, our work generalizes the results of Gali (1999) and Basu et al. (2006). We also find

that the dynamics of hours worked in the aftermath of a technology shock is mostly due to the response of the number of employees rather than hours per worker. Adjustments via the extensive margin appears then more relevant than those occurring along the intensive margin.

Moreover, our results suggest that the chosen time period affect how hours and GDP react to TFP shocks in good or bad times. Prior to the mid eighties, the results are in line with those obtained in the longest period. However, since the Great Moderation, positive productivity shocks increase hours during recessions. Such results are preserved also when the Great Recession is taken into account. Our analysis generalizes the results in Gali et al. (2003) and Galí and Gambetti (2009) about the milder effects of TFP shocks on employment during the Great Moderation. Indeed, we show that low growth periods are responsible for the observed switch in the pattern. Finally, we search for possible explanations for the observed switch. Although we did not find a silver-bullet explanation, changes in the responses of different series suggest that monetary and fiscal policies, investment and financial frictions exerted a relevant role via aggregate demand.

The rest of the paper is organized as follows. In Section 2, we revise the related literature. In Section 3, we present the data and our methodology. We discuss our main results in Section 5. In Section 6 we study possible transmission mechanisms for our time-varying results. Finally, in Section 7, we conclude.

2   Related literature

Our work is related to two different streams of literature. The first one studies the effects of technology shocks on output and employment (Gali, 1999; Basu et al., 2006). According to this literature technology shocks generate negative comovements between productivity and hours worked and between output and hours which are at odds with results from standard real business cycle (RBC) models that postulate positive relationships (see Ramey, 2016; Gali and Rabanal, 2004, for a comprehensive discussion). This strand of research is complemented by further evidence about the time varying effects of technology shocks, which are thought to have become less contractionary during the Great Moderation era (e.g., Gali et al., 2003) (see Section 6). Moreover, Ng and Wright (2013) find that labor productivity turns from procyclical to countercyclical since the mid eighties (see also Fernald and Wang, 2015). However, the debate about the effects of technology shocks on employment and output is not completely settled, as different specifications and identification strategies may yield possibly different results (e.g., Gali and Rabanal, 2004; Christiano et al., 2003; Fernald, 2007; Dedola and Neri, 2007; Lindé, 2009), even though most results convey the message of contractionary effects of tech shocks with

respect to hours worked at least in the short-run.[1]

The second stream of empirical literature studies regime switching in macroeconomic dynamics. This relatively new strand of research has blossomed in the aftermath of the Great Recession and it studies the asymmetric effects of fiscal and monetary policies as well as of other real and financial shocks, depending of the state of the economy. Generally, such studies resort to a wide set of regime switching models ranging from threshold vector autoregressions (TVAR), to vector smooth transition autoregressions (VSTAR) and Markov-Switching models. Regimes shifts are usually sparked by threshold variables related to the state of the real economy (recession or expansion, see e.g., Auerbach and Gorodnichenko, 2012b,a; Bachmann and Sims, 2012), or to financial markets (see e.g. Mittnik and Semmler, 2013; Ferraresi et al., 2014).[2]

3   Methodology

In order to assess whether the response of hours and GDP with respect to technology shocks depends on the state of the economy, recessions vis-à-vis expansions, we estimate a bunch of threshold vector autoregression models (TVAR) which display a number of appealing features. First, the threshold variable is considered as endogenous. This allows one to study regime switches, which result from shocks hitting another variable within the system. Second, TVARs are very simple to estimate: within each regime, the parameters can be recovered by ordinary least squares (OLS). However, once estimated, the state dependent dynamics of TVARs allows for non-linear and asymmetric impulse-response functions.

Let us consider a TVAR model with two regimes. Given the vector of endogenous variables (y) and the threshold variable $(w$, belonging to $y)$, the model can be represented as follows:

$$y_t = c_j + \sum_{i=0}^{p} A_{j,i} y_{t-i} + \epsilon_{t,j}, \tag{1}$$

where c_j is a constant vector; $j = 1$ if $w_{t-d} < r$ and $j = 2$ otherwise; r is the value of the threshold; d is the lag of the threshold variable relevant for regime changes; p is the autoregressive order; and $A_{j,i}$ is the matrix of coefficients of regime j and lag i. Each regime is characterized by a variance-covariance matrix Σ_j. Note that the TVAR model

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[1]The main differences arise because of i) hours entering the relation in first-differences (Gali, 1999; Francis and Ramey, 2005) vs. levels (Christiano et al., 2003); ii) long-run restrictions and adjusted TFP measure of technology (Gali, 1999; Basu et al., 2006) vs. sign restrictions (Dedola and Neri, 2007); identification of different sources of technical change (Fisher, 2006). In the present work we stick to first differenced hours, so as to avoid to uncover spurious regime change. Nevertheless, our results are broadly robust to different specifications. Moreover, we identify technology shocks by using the adjusted measure of TFP proposed by Fernald (2012), in line with Basu et al. (2006).

[2]On the theoretical side, Canzoneri et al. (2016) develop a model which accounts for time-varying fiscal multipliers depending upon the state of the economy (recessions vs. expansions).

is linear within each regime, but the changes in the parameters across regimes account for non-linearities.

TVARs can be estimated via OLS conditional on the threshold variable, w_{t-d}, the number of regimes and the lag order p. Identification can be performed employing standard procedures used in the linear framework (e.g. Cholesky).

Before estimation and identification, one has first to test for linearity. We apply a battery of Tsay (1998) tests in order to evaluate the null hypothesis that our VAR models are linear. If the null is rejected, there are multiple regimes, and we can estimate a threshold model. As suggested by Tsay (1998), we select the lag of the threshold variable according to the maximum test statistic. Once the lag order is fixed, we search over the (observed) threshold values and choose the ones which minimize the sum of squared residuals.[3]

After the TVAR is estimated, the next step consists in analyzing the impulse response functions. In a non-linear setup, the reaction of an endogenous variable to a shock depends on the past history, the state of the economy and the size of the shock under study at time 0, and the size and the sign of all the shocks hitting the economy within the period of interest (a shock at time t may indeed trigger a switching of regime till time $t+d$, where d is the estimated lag of the threshold). In order to average out the influences of history and of all other shocks, simulation methods are necessary to recover the generalized impulse response functions (GIRF; Koop et al., 1996). In particular, if we define ε_t as the shock to the variable we are interested in, a horizon m, and a history Ω_{t-1}, we can define the GIRF as:

$$GIRF = E\left[X_{t+m}|\varepsilon_t, \varepsilon_{t+1} = 0, \ldots, \varepsilon_{t+m} = 0, \Omega_{t-1}\right] -$$
$$E\left[X_{t+m}|\varepsilon_t = 0, \varepsilon_{t+1} = 0, \ldots, \varepsilon_{t+m} = 0, \Omega_{t-1}\right] \quad (2)$$

The algorithm employed to derive the generalized impulse response function is described in Appendix B. In a nutshell, the idea is to simulate the model for any possible starting point over the time horizon of interest by feeding the system with bootstrapped shocks and to repeat the exercise by adding a new shock of a specific size (one time the standard deviation of the fundamental shock in the linear model). The procedure is done hundreds times with newly generated series of bootstrapped residuals. The responses to shocks specific to a particular regime is recovered by averaging out the simulation results. As suggested in Zheng (2013) and Schmidt (2013), we compute confidence bands by bootstrapping the TVAR residuals (see Appendix B for the algorithm). In the GIRF presented below, we report 68% confidence bands as suggested by Sims and Zha (1999).[4]

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[3]Alternatively, we can select the lag of the threshold according to the sum of squared residuals. Our results are nevertheless robust to the estimation method employed.

[4]Codes for linearity tests, estimation, GIRFs and bootstrapped confidence bands are written in Gretl, an open-source software available at `http://gretl.sourceforge.net/`.

4   Data and model

We use quarterly U.S. time series. Our main sample goes from 1957:1 to 2011:4. Such a time span allows us to increase the minimum number of observations in each regime and to perform a relatively large number of sub-exercises.[5]

Our main model contains (according to Cholesky order) adjusted total factor productivity (TFP), GDP and hours worked.[6] Quarterly data about adjusted TFP and hours worked are drawn from Fernald (2012).[7]

We first estimate the model over the whole sample and then we focus on different sub-periods in order to account for possible structural breaks. First, we exclude the Great Recession, letting our sample go to the second quarter of 2008. We then perform an investigation in the spirit of Galí and Gambetti (2009) to separate the pre-Volcker era (1957:1-1979:2) from the Volcker-Greenspan-Bernanke period (1984:1-2011:4).[8] Finally, we also jettison the Great Recession from the Great Moderation, considering the period 1984:1-2008:2 and show that our results are not qualitatively affected.[9]

We order adjusted TFP first in our TVAR, as the residuals of such equation should not be contemporaneously correlated with the other ones. This is in line with theoretical macroeconomic literature (e.g. real business cycle models) as well as with the method employed by Basu et al. (2006).[10] We then place GDP and finally hours worked. In other words, we assume that shocks to GDP are contemporaneously transmitted to hours worked (i.e., higher production require more labor input, but not viceversa).[11]

Our threshold variable is a moving average of lag four of the quarterly rate of change of GDP, which in turn is nothing but a rescaled yearly rate of change (see Figure 9 in

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[5]The dates refer to the dependent variables. For example, in a VAR(4) the first observation used according to our convention is 1956:1. The first observation is chosen in order to use a uniform sample for all our exercises. Moreover, the sample ends in 2011:4 as when our empirical analysis was performed, this was the last stable observation of National Accounts data according to the subsequent vintages from FRED. The data is available from the authors upon request.

[6]Our main series are displayed together with NBER recessions bands in Figure 9 in Appendix C.

[7]In a recent contribuion Sims (2016) shows that subsequent vintages of utilization adjusted TFP are not highly correlated with each other. Here we use the vintage produced in September 2014. However, for the sake of comparison, we have checked with a more recent vintage and results do not qualitatively change.

[8]Whereas there are good reasons to exclude the Volcker recession period (1979:3-1982:3) from the analysis, we consider as a starting point of the Great Moderation the first quarter of 1984 as it is widely accepted in the literature (e.g., Stock and Watson, 2012). Our results do not qualitatively change by slightly shifting the beginning/end of samples.

[9]Our results are also unaffected by the choice of a shorter Volcker-Greenspan period consistent with Gali et al. (2003). Moreover, we also check for an alternative sub-sampling strategy, in line with the trend breaks in labor productivity growth identified by Fernald (2007). Again, the observed changes are not driven by breaks in labor productivity growth but by a single fundamental shift from the mid 80s.

[10]It is indeed very likely that total factor productivity, once purged from cyclical capacity utilization, does not respond to business cycle fluctuations within the same quarter. In fact, whereas standard TFP is highly correlated with GDP growth (0.8); utilization adjusted TFP is not (0.2).

[11]This ordering is questionable since more hours worked should return, within the quarter, higher value added (in terms of wages). However, our results do not change if we swap the two series in the system.

Table 1: Augmented Dickey-Fuller (GLS) tests applied to the MA(4) of the growth rate of GDP (threshold variable) in the different sub-samples ($p-values$ in parentheses). Lag structure chosen according to modified AIC down from 4 lags. GDP: aggregate terms or normalized with the civilian population.

Period	GDP	Specification	Results
1957:1-2011:4	aggregate	constant; 4 lags	-4.47 (0.000)
1957:1-2008:2	aggregate	constant; 4 lags	-4.64 (0.000)
1957:1-2011:4	normalized	constant; 4 lags	-4.38 (0.000)
1957:1-2008:2	normalized	constant; 4 lags	-4.46 (0.000)
1957:1-1979:2	aggregate	constant; 4 lags	-3.23 (0.001)
1984:1-2011:4	normalized	constant; 4 lags	-2.54 (0.011)
1984:1-2008:2	normalized	constant; 4 lags	-2.50 (0.012)
1957:1-1979:2	normalized	constant; 4 lags	-3.01 (0.003)
1984:1-2011:4	normalized	constant; 4 lags	-2.59 (0.009)
1984:1-2008:2	normalized	constant; 4 lags	-2.62 (0.009)

the Appendix C). Yearly rates of change can be considered a rough measure to extract business cycle components (Giannone et al., 2009) with the advantage that we can track their dynamics endogenously within the TVAR. Moreover, modern macroeconomic theory has justified it as a general source of multi regime dynamics (Canzoneri et al., 2016). In order to assess the mean reverting properties of the threshold variable within the different examined samples we run a battery of augmented Dickey-Fuller (GLS) tests, whose results are reported in Table 1. The null hypothesis of the presence of a unit root is rejected for all the tested series.

In Section 6 below, we will shed some light on the possible interactions between the Great Moderation and the effects of technology shocks in alternative regimes. More specifically, we will augment our three dimensional TVAR model with a variable at the time concerning inflation (so as to check for monetary policy); private and public investment; consumption and private inventories; credit markets interest rates; nominal and real wage (see Section 6 for a discussion of the series included in this analysis and Appendix A for more details about the data employed). Such exercises will be performed imposing the same threshold values of the benchmark model.

5   Results

Let us now present the main results obtained by our empirical analysis. We structure the discussion in three parts. First, in Section 5.1 we present the results obtained for the full sample (1957-2011). We then consider the pre Volcker and post mid eighties sub-samples (cf. Section 5.2). Finally, in Section 5.3, we assess the robustness of our results as to different i) threshold values; ii) series entering the TVARs; iii) sub-sampling choices.

Table 2: Tsay tests. MA(4) of the growth rate of GDP (threshold variable). GDP: aggregate terms or normalized with the civilian population.

Sample	Employment	Test Statistic (*pvalue*)	Lag
1957:1-2011:4	aggregate hours	31.30 (0.002)	1
1957:1-2008:2	aggregate hours	39.16 (0.000)	1
1957:1-2011:4	normalized hours†	35.58 (0.000)	1
1957:1-2008:2	normalized hours†	34.32 (0.001)	1
1957:1-2011:4	hours per worker	22.42 (0.033)	4
1957:1-2008:2	hours per worker	23.03 (0.027)	4
1957:1-2011:4	employees	40.76 (0.000)	2
1957:1-2008:2	employees	51.69 (0.000)	2
1957:1-1979:2	aggregate hours	24.70 (0.016)	1
1984:1-2011:4	aggregate hours	19.51 (0.077)	3
1984:1-2008:2	aggregate hours	23.80 (0.022)	2
1957:1-1979:2	normalized hours†	24.17 (0.019)	1
1984:1-2011:4	normalized hours†	24.26 (0.019)	3
1984:1-2008:2	normalized hours†	18.13 (0.112)	2
1957:1-1979:2	hours per worker	27.76 (0.006)	3
1984:1-2011:4	hours per worker	25.86 (0.011)	3
1984:1-2008:2	hours per worker	17.79 (0.122)	1
1957:1-1979:2	employees	36.06 (0.000)	1
1984:1-2011:4	employees	28.37 (0.005)	2
1984:1-2008:2	employees	28.53 (0.005)	2

$\dagger$ MA(4) of normalized GDP rate of growth as threshold variable.

Figure 1: Threshold variable (black line), threshold value (red line) and estimated recessions (shaded area) in the main sample (1957-2011).
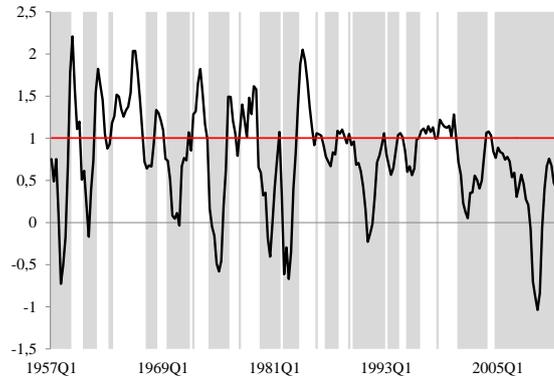
5.1 Full sample period

We begin by performing Tsay linearity tests. As shown in Table 2, the Tsay test rejects linearity (Figure 2). The max test statistics is reached at lag one, which we then impose in our estimation procedure. The estimated threshold (the four quarter average of GDP growth rates) is 1% and it leaves 85 observations in expansions and 135 in recessions.

Figure 1 reports the threshold variable together with the threshold value and the estimated recessions. It suggests that after the mid eighties, the drop in GDP volatility has induced a fall in the mean of the threshold variable, possibly making the estimated threshold too high, so that the model spends too much time in the recession regime (more on this in section 5.2 below).

Let us now consider the estimated impulse response function of GDP and hours worked hours as to positive technology shocks (cf. Figure 2). The GIRFs show that TFP shocks spur GDP in expansions, whereas their impact is much milder and not significantly different from zero during recessions. In contrast, positive technology shocks considerably reduce employment during downturns, whereas their effects are negligible during expansions (Figure 2).

Our results suggest the existence of state dependent transmission channels of technology shocks to output and employment. In that, they *generalize* the findings of Gali (1999) suggesting that the real-business-cycle explanation of business cycles is not credible as it implies a positive correlation between productivity and hours. Indeed, we find that such results are mainly due to the behavior of the economy during recessions. Technological shocks do not appear to be a credible way out of recessions. This is in line with recent macroeconomic research that points to the role of aggregate demand as escape route from a recession.

We then try to shed more light on the effects of technology shocks by comparing the

Figure 2: Generalized impulse response functions. Cumulative response of hours (upper row) and GDP (bottom row) with respect to a 1% standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs. expansions (right column). 68% confidence bands. Sample: 1957-2011.
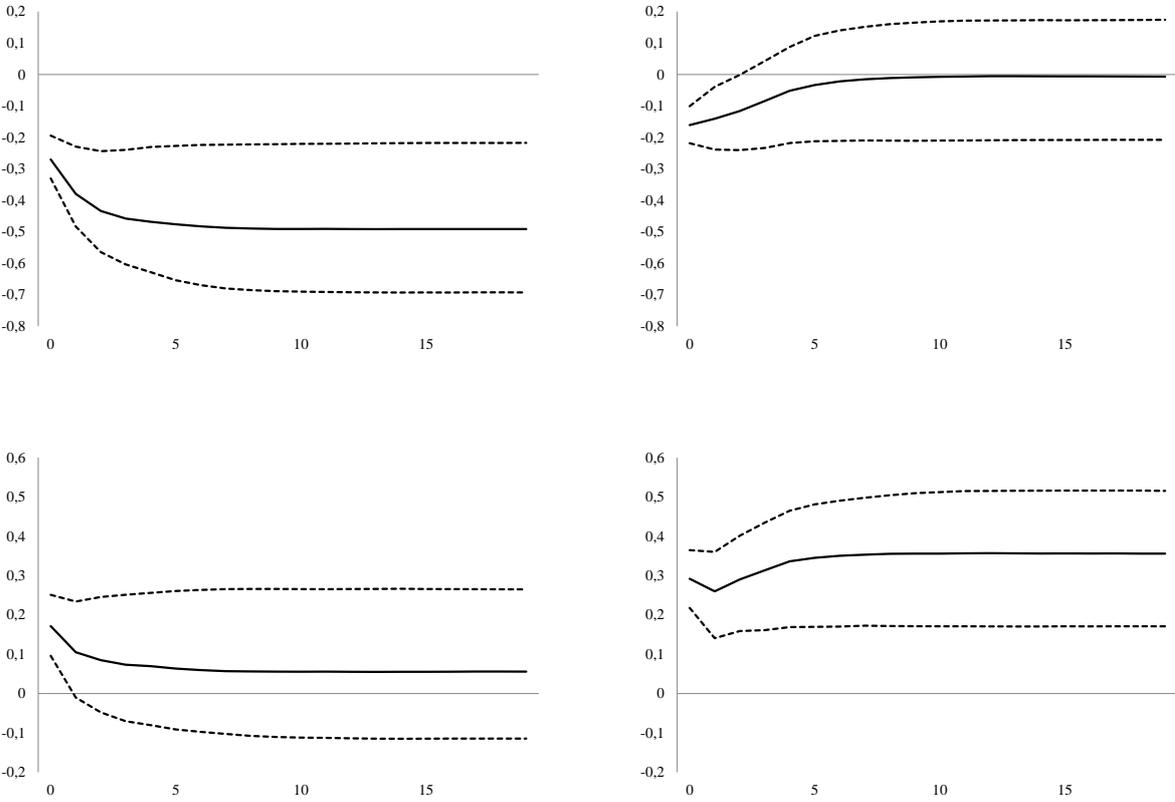
Figure 3: Generalized impulse response functions. Cumulative response of average weekly
hours (upper row) and of the number of employees (bottom row) with respect to a 1%
standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs.
expansions (right column). Sample: 1957-2011.
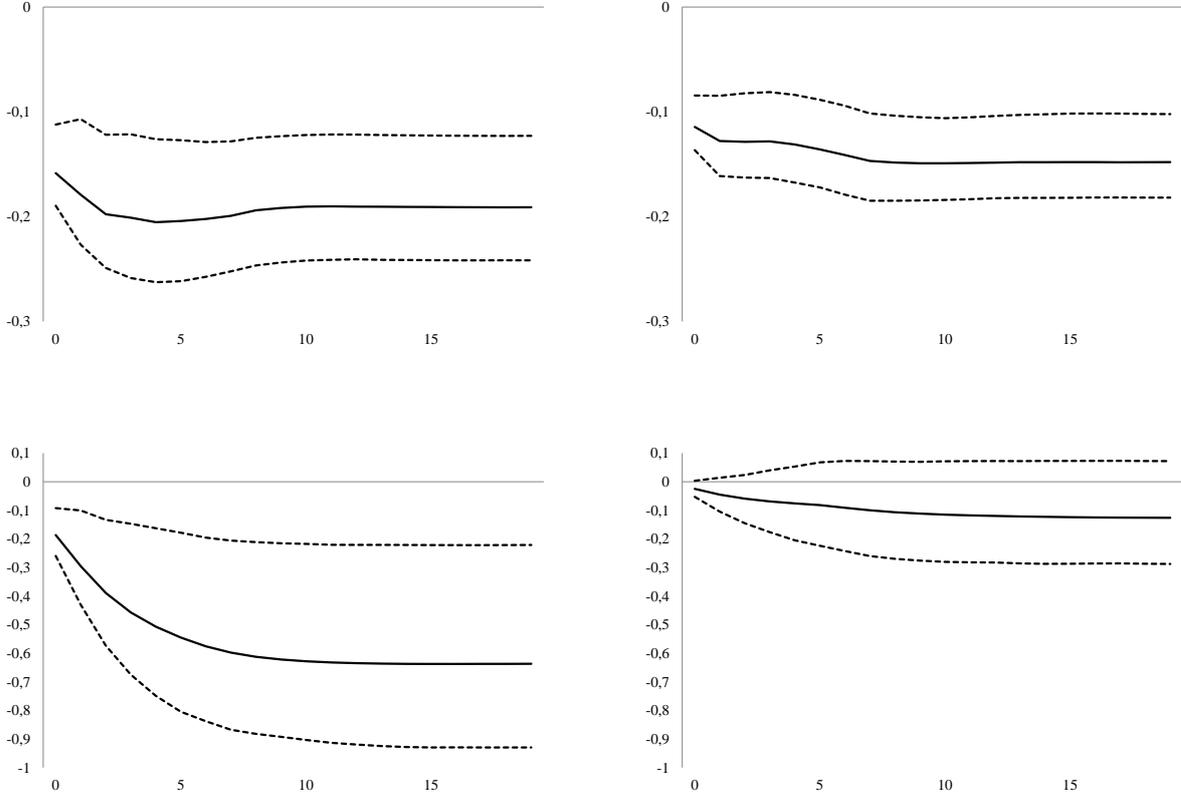
response of employment over the extensive margin (i.e. number of employees) vis-à-vis
the intensive one (i.e. hours per worker). More specifically, we replace total hours in
the TVAR model with either the number of employees or the average weekly hours, we
test for linearity (Table 2), estimate the models and compute the ensuing GIRFs. Let
us start with average weekly hours (Fernald and Wang, 2015). The impulse response
functions depict quite similar patterns in the two macroeconomic regimes (cf. Figure
3). On the contrary, the reaction of the number of employees mimics closely that of total
hours, suggesting that most of the labor adjustment is done over the extensive margin (see
Figure 3). Indeed, the stronger and negative effects of productivity shocks on employment
in the low growth regime depend mostly on the lower number of employees. Such evidence
again supports the idea that aggregate demand can have a key role in the transmission
of technology shocks.

Figure 4: Threshold variable (black line), threshold value (red line) and estimated recessions (shaded area) in our sub-samples (1957-1979 vs. 1984-2011).

(a) 1957-1979

(b) 1984-2011
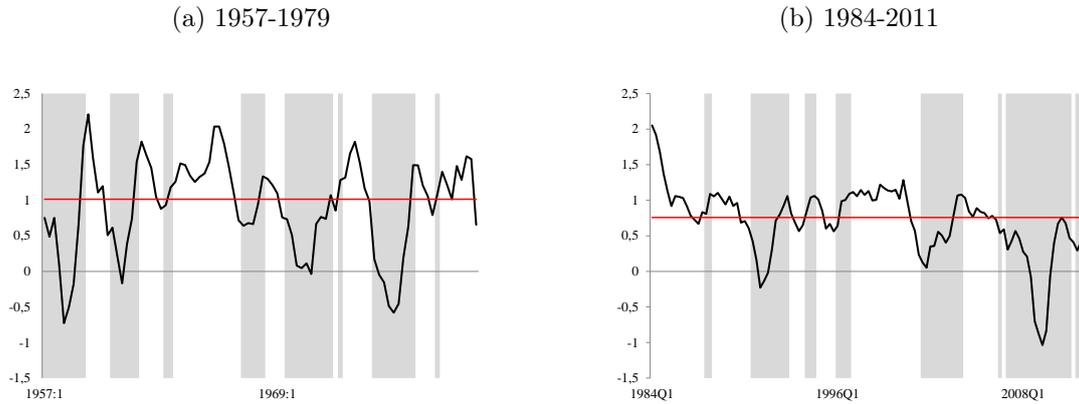
5.2 Evidence from sub-sampling: Pre Volcker vs. the Great Moderation & the Great Recession

The relationship between technology, output and employment may be subject to structural breaks and change over time. Indeed, as shown by e.g. Gali et al. (2003) and Galí and Gambetti (2009) among others, since the mid eighties, the effects of technology shocks on hours worked have become milder. Moreover, Figure 1 suggest that the behavior of the threshold variable seems to have mutated during the Great Moderation.

Building on the existing literature, we assess whether such a dynamics is present also in a state dependent framework, as the phenomena which contributes most to the changes within the linear relation may differently impinge it according to the state of the economy. For instance, if the response of employment depends to some extent to the degree of accommodation of monetary policy, and if the transmission channels activated by the latter are more effective in recessions (or expansions), we should expect the effects of switches in the monetary policy regime (e.g., the parameters of the Taylor rule) to impact differently in recessions vis-à-vis expansions.

In order to perform our analysis we divide the sample into two sub-periods. In particular, we consider a pre-Volcker era (1957:1-1979:2) and a Volcker-Greenspan-Bernanke period (1984:1-2011:4), which includes the Great Recession.[12] The inclusion of the Great Recession in our second sub-sample follows from Ng and Wright (2013) who claim that the post mid 80s recessions share a relevant set of common features (e.g., financial origins; jobless recoveries; tight credit in the ensuing expansions), among which is the shift of labor productivity from procyclical to countercyclical (see also Fernald and Wang, 2015).

The Tsay tests reject linearity in both samples, as reported in Table 2, even though

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[12]We follow Gali et al. (2003) and exclude the 1979:3-1982:2 period from the analysis. Moreover, following the existing literature about the timing of the Great Moderation, we start our second sub-sample in 1984:1 (see e.g., Stock and Watson, 2003).

Figure 5: Generalized impulse response functions. Cumulative response of hours (upper row) and GDP (bottom row) with respect to a 1% standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs. expansions (right column). 68% confidence bands. Sample: 1957-1979.
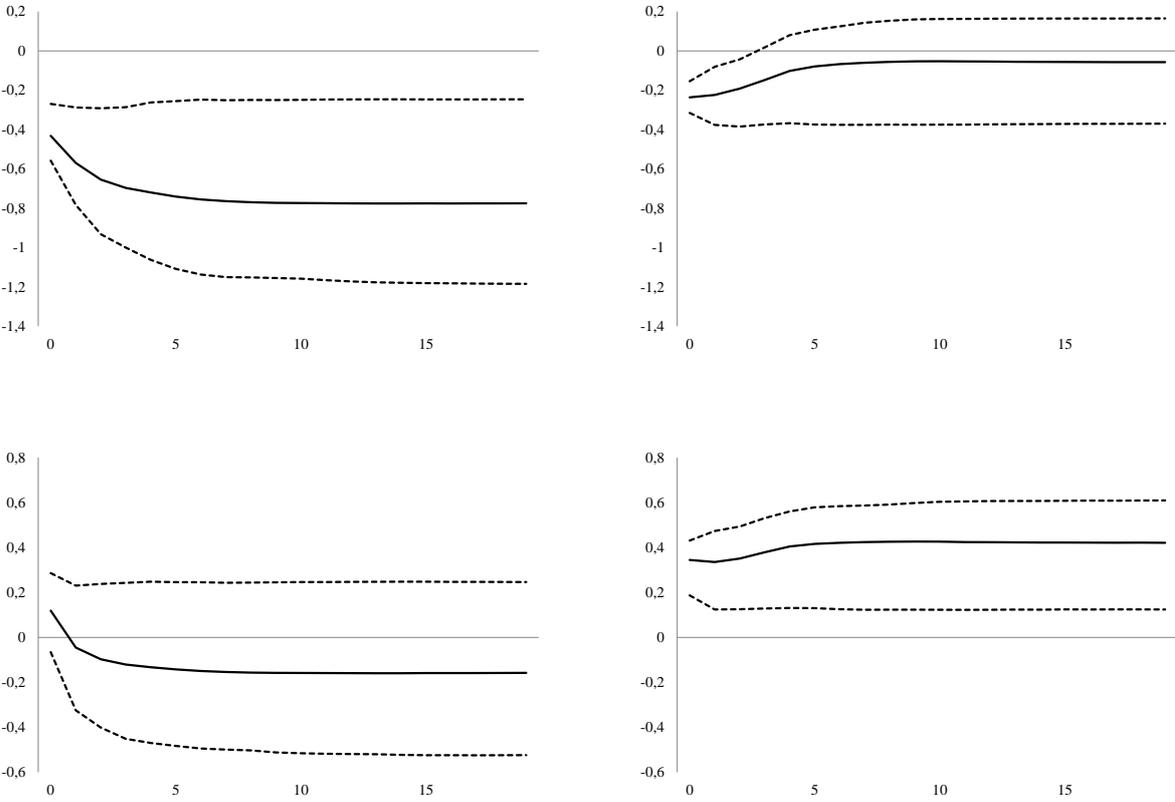
Figure 6: Generalized impulse response functions. Cumulative response of hours (upper row) and GDP (bottom row) with respect to a 1% standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs. expansions (right column). 68% confidence bands. Sample: 1984-2011.
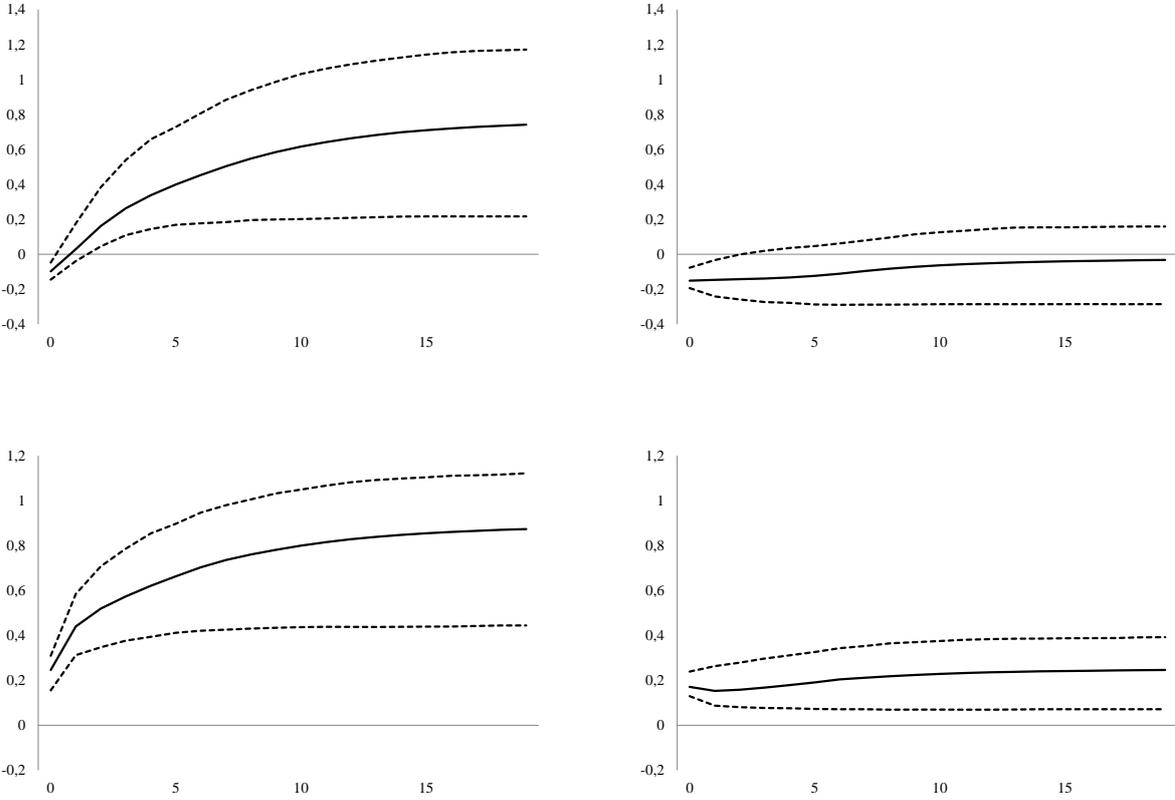
the evidence for the second sub-sample is weaker (10% significance level). However, notice that for the specification in which hours and GDP are normalized with the US population linearity is still rejected at 5%.

Figure 4 displays the threshold variable, the estimated threshold value and recessions for the two sub-periods. The threshold value does not change within the pre-Volcker period as to the whole sample, it is lower in the post eighties sample. Moreover, the estimated lag relevant for the regime switching increases from one to three in the second sub-period. We find 43 observations in expansion and 47 in recessions in the first sub-samples, while 50 and 62 observations in the latter one.

Let us now consider the GIRFs for the two sub-samples. The results of the pre-Volcker period are qualitatively similar to ones obtained with the whole sample (cf. Figure 5). More precisely, the negative effects of positive technology shocks on employment are abundantly stronger and negative in downturns. In fact, within this subperiod the effects appear even reinforced with respect to what observed for the whole sample. The point estimates of the response of GDP itself, although not significantly different from zero, turn negative after few quarters.

On the contrary, in the second sub-period, the generalized impulse response functions depict a different story. In this case, the responses in good times do not qualitatively change, but the ones in bad times are completely different (see Figure 6). Indeed, positive technology shocks appear to stimulate both GDP and hours during recessions. Our results are more *general* than those in Gali et al. (2003) and Galí and Gambetti (2009): the milder effects of TFP shocks since the mid eighties are due to the responses of hours and GDP in bad times.

What is the source of the different dynamics of employment in the two subperiods? We now study disaggregated employment series comparing the dynamics of number of employees (extensive margin) with average weekly hours per worker (intensive margin). The impulse response functions of average weekly hours show small differences in the dynamics of the series after a technology shock in the two sub-samples (Figures 7 and 8). In both regimes, the initial response is negative and the patterns of the GIRFs is substantially flat. However, in the second period the response over the intensive margin during recession is close to zero and never positive, whereas no similar shift characterizes the response in good times. On the contrary, the GIRFs of the number of employees closely tracks (again) the reaction of total hours. This implies that firms mostly adjust employment over the extensive margin (Figures 7 and 8). Such results cast further doubts on the real-business-cycle interpretation of technology shocks. Indeed, positive TFP shocks do not lead to more intense labor effort, but rather they appear to affect employment mostly via an aggregate demand channel. In Section 6 we elaborate more on this by enriching our analysis with further series.

Figure 7: Generalized impulse response functions. Cumulative response of average weekly hours (upper row) and of the number of employees (bottom row) with respect to a 1% standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs. expansions (right column). Sample: 1957-1979.
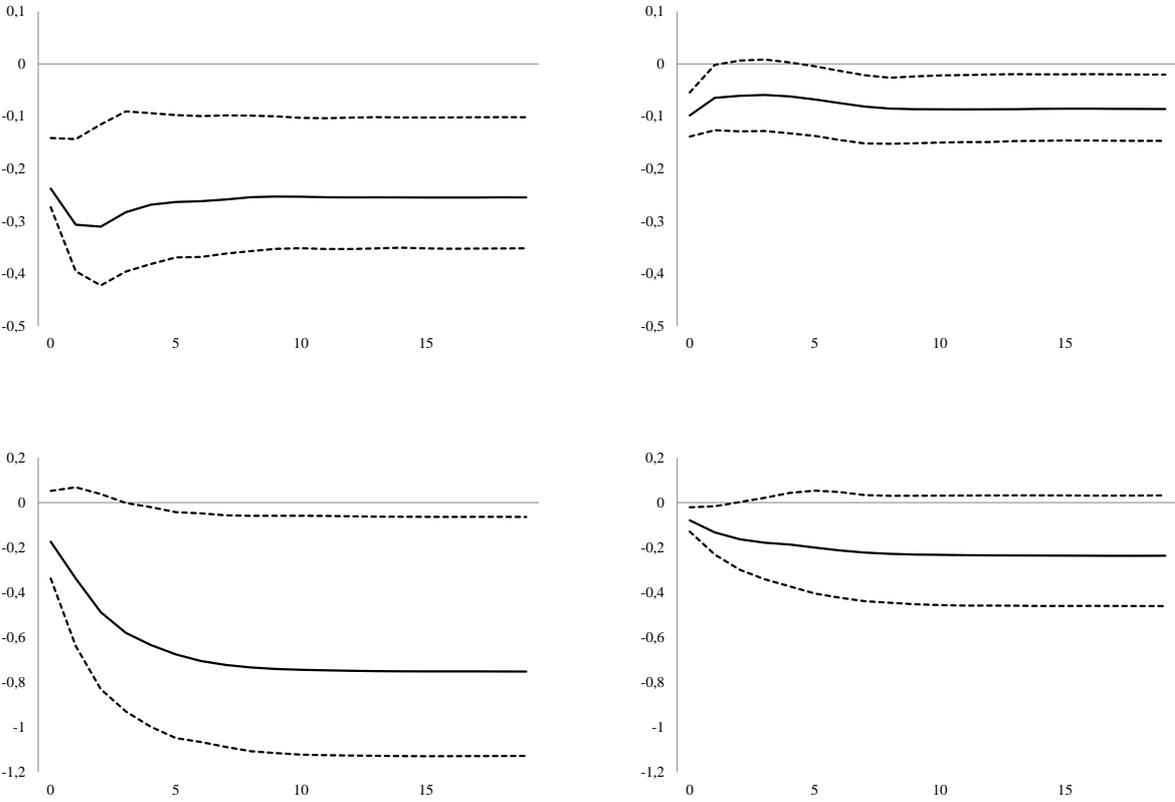
Figure 8: Generalized impulse response functions. Cumulative response of average weekly hours (upper row) and of the number of employees (bottom row) with respect to a 1% standard deviation positive shock to adjusted TFP shock. Recessions (left column) vs. expansions (right column). Sample: 1984-2011.
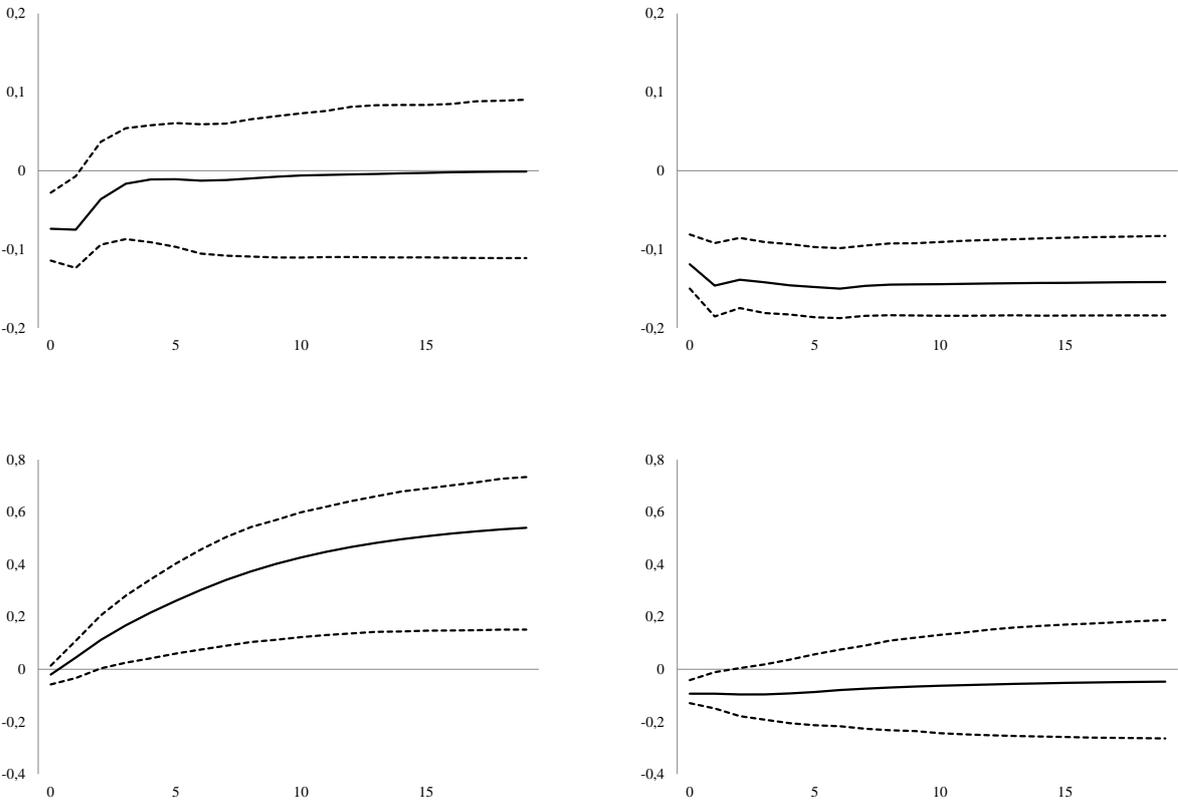
5.3 Robustness analysis

Let us assess the robustness of our results as to modifications in the setup of our exercise. First, we normalize GDP and hours by dividing the series by the US civilian population. Second, we change the threshold values in the different samples. Finally, we control for the timing of the break. Indeed, in addition to the pre and post Volcker sub-periods, we also consider the dates for possible structural breaks in U.S. labor productivity (i.e., 1973:2; 1995:4; 2003:4) proposed by Fernald (2007, 2014). We accordingly obtain three different sub-periods: 1957:1-1973:2, 1984:1-1995:4 and 1996:1-2003:4.

Normalized GDP and hours. In the benchmark model, GDP and worked hours are expressed in aggregate terms. We test the robustness of our result by normalizing the series by the civilian population as in Gali (1999). Again, both GDP and hours are held in first differences. The results are qualitatively similar. First, the Tsay tests reject linearity in all the samples (cf. Table 2). Second, we obtain the same results reported above for the i) full sample; ii) pre-Volcker period; iii) Great Moderation cum Great Recession period. Moreover, the results are confirmed for the pre-Volcker vs. post mid 80s period even when we consider normalized hours in levels as suggested by Christiano et al. (2003).

Different threshold values. Since our results may be sensitive to the value and the number of lags of the estimated threshold, we check whether they are robust to changes in the estimation procedure. First, we employ the median value of the threshold variable at each lag. Second, we perform estimation searching for the model minimizing the sum of squared residuals at all lags. Again, the results do not qualitatively change.

Different sub-samples. With respect to our sub-sampling strategy, another possible source of breaks stems from the rate of growth of labor productivity. Indeed, according to Fernald (2007, 2014), labor productivity growth has been characterized by major changes over the post WWII periods, with high growth periods (1957-1973 and 1996-2003) being followed by low growth years (1974-1995 and 2004-2011). Starting from our sub-samples (1957-1979 and 1984-2011), we narrow our analysis controlling whether our results change if we concentrate upon shorter time periods, namely, the pre-Volcker high productivity growth periods (1957-1973); the Great Moderation low productivity growth era (1984-1995), and the Great Moderation high productivity growth sample (1996-2003).[13] We find that the results do not qualitatively differ from those obtained from our main sub-samples.

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[13]We excluded from our analysis the pre-Volcker low productivity growth sample (1974-1979), given the extremely limited amount of observations. We also did not considered the last low productivity growth period (2004-2011), as the last results would be strongly affected by the Great Recession.

6 Transmission mechanisms

The previous results showed that the relationship between technology shocks, GDP and employment changed over time in the two regimes. There are several possible explanations of such variations. Broken trends in productivity dynamics (e.g., Fernald, 2007, 2014) can be responsible for significant changes occurred to the correlations among productivity, hours and output. Moreover, the literature on the Great Moderation (e.g., Gali et al., 2003; Galí and Gambetti, 2009) has already shown that the effects of technology shocks on employment become milder the last thirty years.

During the Great Moderation, not only the U.S. output volatility considerably fell, but the very characteristics of the business cycles changed deeply (Ng and Wright, 2013, i.e., long but weak expansions; vanishing pro-cyclicality of labor productivity; pronounced leverage cycle; jobless recoveries; tight availability of credit creating headwinds to the recovery). If the long-run relationship between productivity and unemployment is influenced by the volatility of the former one (Benigno et al., 2015), the Great Moderation can be a source of regime change in the relation between the two. More specifically, if the benefits of a reduced GDP volatility are greater in recessions than in expansions, the relationship among technology, employment and output can change.

Competing explanations have been advanced to explain the Great Moderation, namely good luck and smaller shocks (Stock and Watson, 2003); better monetary policy (Clarida et al., 2000); better fiscal policy (Gordon, 2005); falling private investment volatility (Justiniano and Primiceri, 2008); ICT revolution and improved inventories management (Kahn et al., 2002); skill-biased technical change (Cantore et al., 2012a); labor market reforms, deunionization and performance pay (Nucci and Riggi, 2011); financial innovations (Dynan et al., 2006).

By augmenting our benchmark TVAR model with a variable each time capturing a possible source of the Great Moderation, we try to shed more light on how GDP and hours react to technology shocks before and after the mid 80s.[14] Our results should be considered with the caveat that we are not likely to find a clear cut cause for such a shift, but an "impressionistic" picture of the possible channel of variations. The battery of the impulse response functions (in Appendix D) associated to the possible explanatory mechanisms document several interesting shifts in the two periods.[15]

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[14]Note that we do not exclude the Great Recession from the sample, as it shares many characteristics with the post eighty recessions Ng and Wright (2013). Nevertheless, our results are robust to the sample choice.

[15]As to the Cholesky order of the variables in the four dimensional TVAR, we adopt different choices depending on the characteristic of the each additional series. More precisely, we reserve the first position for TFP and we order second aggregate demand components (i.e., private investment and its components; government spending; private consumption and its components; private inventories). We place inflation as third variable, assuming that it responds immediately to GDP shocks but only with a lag to fundamental shocks to hours worked. Finally, we order credit spreads and wages as last. Robustness checks in which we have switched the order of the variable show that our results do not qualitatively change.

Monetary policy. Although the role of better monetary policy as a source of the Great Moderation is not undisputed (Clarida et al., 2000; Stock and Watson, 2003), we know from Gali et al. (2003) and Galí and Gambetti (2009) that an accommodative monetary policy is crucial in affecting the response of employment to technology shocks (see also Inoue and Rossi, 2011). We add inflation to our TVAR model[16] and we compute the generalized impulse response function as to TFP shocks. The GIRFs show that the behavior of inflation in the aftermath of a technology shock is rather different within the two sub-samples under examination (Figure 10). In particular, the response of inflation is abundantly negative in recessions within the pre-Volcker era. The opposite holds in the post mid 80s sample. Thus, a change in the policy rule may have contributed to generate the observed results.

Fiscal policies. According to Gordon (2005), the reduction in volatility of government spending is one of the main sources of the Great Moderation. In our framework, fiscal policy may dampen the impact of technology shocks. We then add to our TVAR model government consumption expenditures or gross investment, and finally take into account the dynamics of public deficit. Let us start from government gross investment. There is a striking difference between its response in bad times during the two time periods (Figure 11). Indeed, technology shocks depress government gross investment in the pre-Volcker period, but they strongly and positively impact it in the post mid 80s sub-sample. Moreover, there is a change in the composition of government spending in recessions with a greater weight attached to investment vs. consumption within the second sub-sample.[17] Indeed, government consumption remains rather low in recessions within the post mid 80s period (Figure 12). Finally, government deficit shows an improvement in fiscal balance in the aftermath of TFP shocks in recessions (Figure 13).

Private investment. Here we consider ICT investment, fixed nonresidential investment and fixed residential investment. Investment may have had a major role in explaining the different emerging patterns in the two sub-samples. for instance, the rise of ICT investment and the computer revolution may have contributed to skill-biased technical change (Acemoglu, 2002; Cantore et al., 2012a,b). Moreover, falling investment adjusting costs may be at the roots of the Great Moderation (Justiniano and Primiceri, 2008; Inoue and Rossi, 2011). Let us start from ICT investment, whose share in nonresidential investment changed from 5% in the 50s to more than 20% in the late 90s. The pattern of its response to positive technology shocks in bad times closely tracks that of government gross investment. As shown in Figure 14, tech shocks strongly depress it in the first subperiod, whereas exactly the opposite holds within the Volcker-Greenspan-Bernanke era. Not much happens in good times: the reaction is positive in both period but weaker

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[16]This is line with Gali et al. (2003). A TVAR including real interest rates as an additional control variable returns qualitatively similar results.

[17]The role of government gross investment in affecting consumers and producers expectations in recessions is emphasized by Bachmann and Sims (2012).

in the second one. Private nonresidential fixed investment tracks the response of ICT investment and does not need further discussion (Figure 15). Residential investment behaves very differently as it positively reacts to technology shocks in recessions in both samples, as displayed in Figure 16.

Inventories. One of the main sources of the Great Moderation is constituted by the improvements in the inventory management due to the ICT revolution (see Kahn et al., 2002; Davis and Kahn, 2008, among others). In our framework, we would expect a much less volatile response after the mid 80s. Moreover, inventories dynamics could provide an explanation for our state dependent results, if the responses in recessions are relatively smaller. However, as documented by Figure 17, this is not the case. In particular, the response of inventories is mute in good times, whereas the same does not hold in recessions. Such results suggest that inventories management does not constitute a relevant explanation of the time-dependent patterns of the interrelations between technology and employment.

Private consumption. During the Great Moderation the volatility of private investment, but also of consumption fell considerably (see e.g. Canova, 2009). The responses of the three components of consumption (e.g. durable, nondurable and service consumption) are quite close within the pre-Volcker era, especially on impact (Figures from 18 to 20). At the same time, they are characterized by similar, an abundantly higher responses in recessions during the second sub-samples. Technology shocks, either because of the changing nature of technological change or because of a shift in accomodative policies, appear to act like a broad stimulus for the entire economy.

Financial frictions. For Dynan et al. (2006) and Cecchetti et al. (2006), the Great Moderation is strictly linked to financial development. Moreover, pronounced leverage (ex ante) and tight credit in recoveries are one of the qualifying characteristics of the post mid 80s recessions (Ng and Wright, 2013). We now study the possible change in the reaction of credit markets after a technology shock since the mid 80s, by assessing the response of the spread between the BAA-rated corporate bonds and the 10-year constant maturity Treasury rate (Figure 23). Moreover we do also check for the response of the BAA-AAA rated corporate bonds spread (Figure 24). We find that the reaction of credit markets in the face of technology shocks is much more accommodating in recessions within the second sub-sample.

Labor market. Labor market reforms may have contributed to the Great Moderation (Stiroh, 2009) and provide an explanation of milder effects of technology shocks on employment (Nucci and Riggi, 2011). We start analyzing the behavior of nominal and real wages in relation to technology shocks. The response of nominal wage is rather similar in the two states within different regimes (Figure 21), but we find a shift (in both states) from the first to the second sub-sample. Indeed, the GIRFs identify a negative response within the pre-Volcker era, but a rather positive one in the second period. The responses

of real wage are positive in both states and regimes (Figure 22). In this case a relevant role is played by inflation dynamics. Again however, the difference between the two regimes does not seem to be so relevant. We then consider the share of part time employment. Indeed, the rising share of part time employment vis-à-vis total one could explain the positive response of hours in bad times. However, such conjecture is not supported by the impulse response functions, which shows a rise of non part time workers in the aftermath of a technology shock since the mid eighties.[18]

Taking stock. The foregoing results appear to show that monetary and fiscal policies, private investment dynamics, and financial frictions have had a major role in switching the response of employment from negative to positive after a technology shock during recessions since the beginning of the Great Moderation. In particular, the big shift in the responses of public as well as private nonresidential investment and ICT in the low growth periods since the mid 80s seems to suggest the importance of aggregate demand transmission mechanisms during downturns. Finally, the responses of wage and inventories dynamics do not seem to add a convincing alternative channel working either throughout the functioning of the labor market or through a more efficient firms' management of the supply chain.[19]

7   Concluding remarks

In the current work, we contribute to the literature about the short-run effects of technology shocks on employment and output by showing that there are diverse effects arising from different states of th economy. Indeed, the impulse response functions resulting from our TVAR model show that positive technology shocks spur GDP in expansions, while their impact is not significantly different from zero in downturns. On the contrary, TFP shocks have contractionary effects on hours in recessions, but they are not significantly different from zero in good times. Our results generalize the work of Gali (1999) and Basu et al. (2006). We also find that the response of aggregate hours to TFP shocks is mainly driven by the reaction of the number of employees (extensive margin) rather than hours per worker (intensive margin).

Beyond state depend effects, in line with the prevailing literature (e.g., Gali et al., 2003; Galí and Gambetti, 2009), we also uncover structural breaks in the reaction of GDP and employment to technology shocks. Indeed, during the Great Moderation, TFP shocks stimulate both hours and output in recessions. We then study possible transmission

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[18]The impulse response functions are not reported. They are available from the authors upon request.

[19]A not formally tested alternative explanation resides in the response of the real exchange rate in the two sub-periods. Unfortunately the length of the series (1964:1–) does not allow us to follow the same approach applied here in the pre-Volcker era. Nevertheless, results for the after mid eighties sample show that the US real exchange rate does not rise in recession in the aftermath of a technology shock, contrary to what happens in good times. Whereas a persistent fall follows tech shocks in both states in the pre-Volcker era. We thank Katarina Juselius for this suggestion.

channels that could contribute to explain the different patterns observed in the two sub-samples. We find that better stabilization policies, enhanced ICT investment, and lower financial frictions could be responsible for the different responses of GDP and hours before and after the mid eighties.

Our research can be expanded in at least three directions. First, we can further study the transmission channels responsible for the different patterns observed in the Great Moderation employing e.g. alternative identification schemes such as the one proposed in Moneta et al. (2012). Second, we could employ wavelet analysis (Gallegati et al., 2014) to uncover possible changing patterns in the relation between employment and productivity at different time scales. Finally, nonlinear cointegration analysis (Enders, 2008; Candelon and Lieb, 2013) could be applied to assess whether the long- and short-run relations among technology, GDP and employment are affected by regime dependent dynamics as well as the by the structural change observed in the mid eighties.

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Acknowledgements

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Appendices

A Data

Data on adjusted TFP and aggregate hours worked are recovered from Fernald (2012)'s database (`http://www.frbsf.org/economic-research/economists/john-fernald/#`). Both series are in annualized rates of growth but transformed in quarterly rates of change for the analysis.

Further data are from the FRED database (`http://research.stlouisfed.org/fred2/`) provided by the Federal Reserve Bank of St. Louis and transformed in order to get real values through the most appropriate deflator. The series employed in the empirical analysis are:

- Gross Domestic Product (GDP);

- GDP Implicit Deflator (GDPDEF);

- Nonfarm Business Sector: Hours of All Persons (HOANBS);

- Nonfarm Business Sector: Employment (PRS85006013);

- Nonfarm Business Sector: Average Weekly Hours (PRS85006023);

- Employment Level: Nonagricultural Industries (LNS12035019);

- Employment Level: Part-Time for Economic Reasons, Nonagricultural Industries (LNS12032197);

- Employment Level: Part-Time for Noneconomic Reasons, Nonagricultural Industries (LNS12032200);

- Federal Government Consumption Expenditures (A957RC1Q027SBEA);

- Government Consumption Expenditures: State and Local (A991RC1Q027SBEA);

- Government Consumption Expenditures and Gross Investment Implicit Price Deflator (A822RD3Q086SBEA);

- Government Gross Investment: Federal National Defense Gross Investment (DGI) + Federal Nondefense Gross Investment (NDGI) + State and Local Government Gross Investment (SLINV);

- Gross Government Saving (GGSAVE);

- Private Fixed Investment in Information Processing Equipment and Software (ICT) (A679RC1Q027SBEA);

- Private Nonresidential Fixed Investment (PNFI);

- Gross Private Domestic Investment: Fixed Investment: Nonresidential Implicit Price Deflator (A008RD3Q086SBEA);

- Private Residential Fixed Investment (PRFI);

- Gross Private Domestic Investment: Fixed Investment: Residential Implicit Price Deflator (A011RD3Q086SBEA);

- Personal Consumption Expenditures: Nondurable Goods (PCND);

- Private Consumption Expenditures: Nondurable Goods Implicit Price Deflator (DNDGRD3Q086SBEA);

- Personal Consumption Expenditures: Durable Goods (PCDG);

- Private Consumption Expenditures: Durable Goods Implicit Price Deflator (DDURRD3Q086SBEA);

- Personal Consumption Expenditures: Services (PCESV);

- Private Consumption Expenditures: Services Implicit Price Deflator (DSERRD3Q086SBEA);

- Change in Private Inventories (CBI);

- Nonfarm Business Sector: Compensation Per Hour (COMPNFB);

- Nonfarm Business Sector: Real Compensation Per Hour (COMPRNFB);

- Moody's Seasoned BAA Corporate Bond Yield (BAA);

- Moody's Seasoned AAA Corporate Bond Yield (AAA);

- 10-Year Treasury Constant Maturity Rate (GS10);

- Civilian Noninstitutional Population (CNP16OV).

B   Generalized Impulse Response Functions

The algorithm to get the generalized impulse response function (GIRF) specific to each regime with R observations works as follows (see Baum and Koester, 2011):

1. pick a history Ω_{t-1}^r;

2. pick a sequence of shocks by bootstrapping the residuals of the TVAR taking into account the different variance-covariance matrix characterizing each regime;

3. given the history Ω_{t-1}^r, the estimated TVAR coefficients and bootstrapped residuals, simulate the evolution of the model over the period of interest;

4. repeat the previous exercise by adding a new shock at time 0;

5. repeat B times the steps from 2 to 4;

6. compute the average difference between the shocked path on the non-shocked one;

7. repeat steps from 1 to 6 over all the possible starting points;

8. compute the average GIRF associated with a particular regime with R observations as:

$$y_{t+m}(\varepsilon_0) = \frac{1}{R} \sum_{r=1}^{R} \frac{y_{t+m}(\Omega_{t-1}^r | \varepsilon_0, \varepsilon_{t+m}^*) - y_{t+m}(\Omega_{t-1}^r | \varepsilon_{t+m}^*)}{B}$$

Once GIRFs are obtained, we apply the algorithm in Schmidt (2013) to compute the related confidence bands:

1. artificial data are generated recursively using the estimated coefficients and errors from the TVAR structure;

2. using the recursive dataset, the TVAR regression coefficients and the error terms are calculated assuming that the threshold corresponds to the estimated value;

3. employing the original dataset and the newly computed coefficients and errors, GIRFs are computed following the steps described above;

4. steps 1-3 are repeated $S = 500$ times to generate a sample distribution of the GIRFs from which confidence bands are drawn at the respective significance level.

C Series

Figure 9: Series (first difference of natural logarithm). NBER recessions in parenthesis

(a) Utilization adjusted TFP
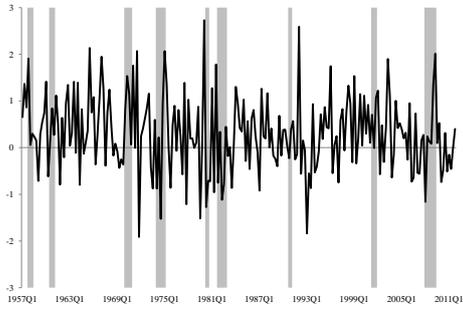
(b) GDP
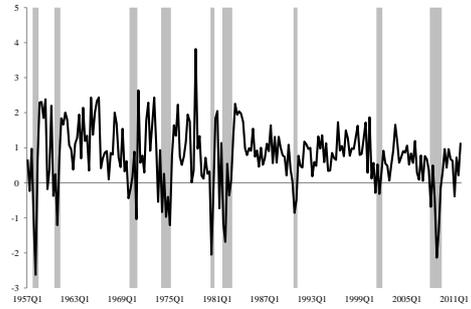
(c) Aggregate hours worked
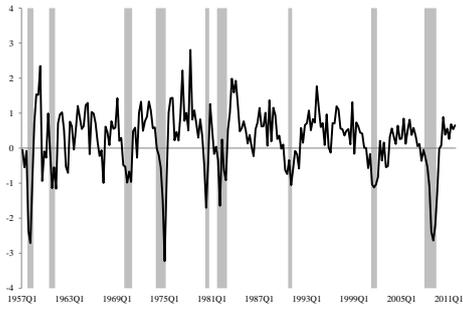
(d) Average weekly hours
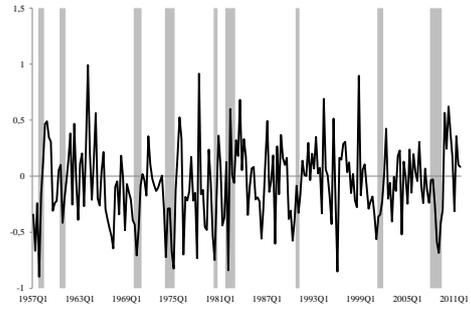
(e) Employees
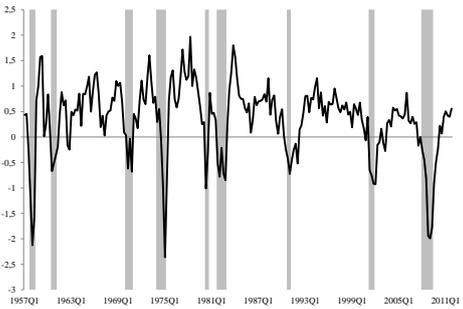
(f) Threshold variable
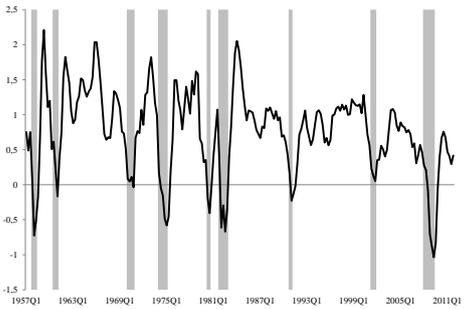
D Generalized Impulse Response Functions: Transmission Channels

Figure 10: Response of inflation with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
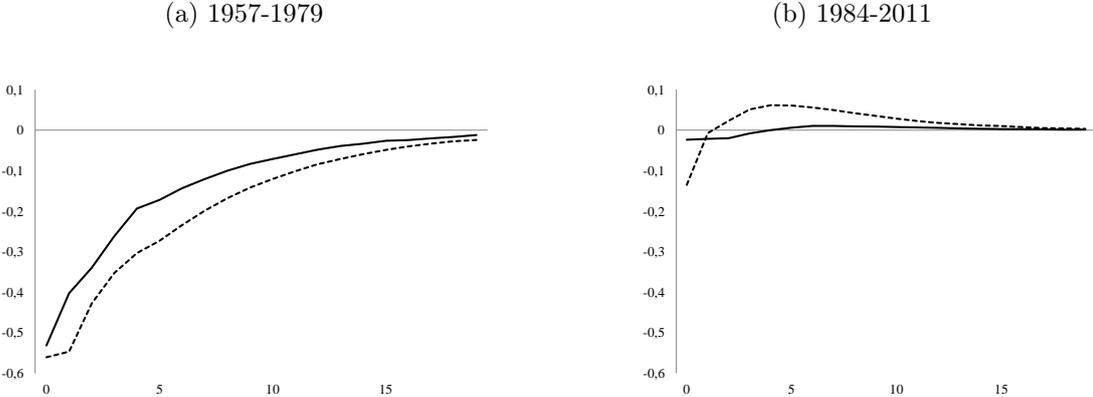
(b) 1984-2011

Figure 11: Response of government gross investment with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
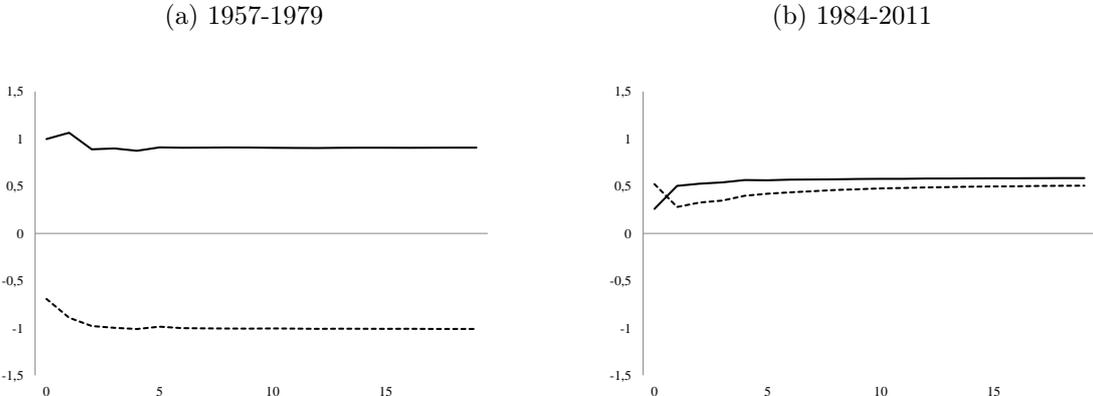
(b) 1984-2011

Figure 12: Response of government consumption expenditures with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
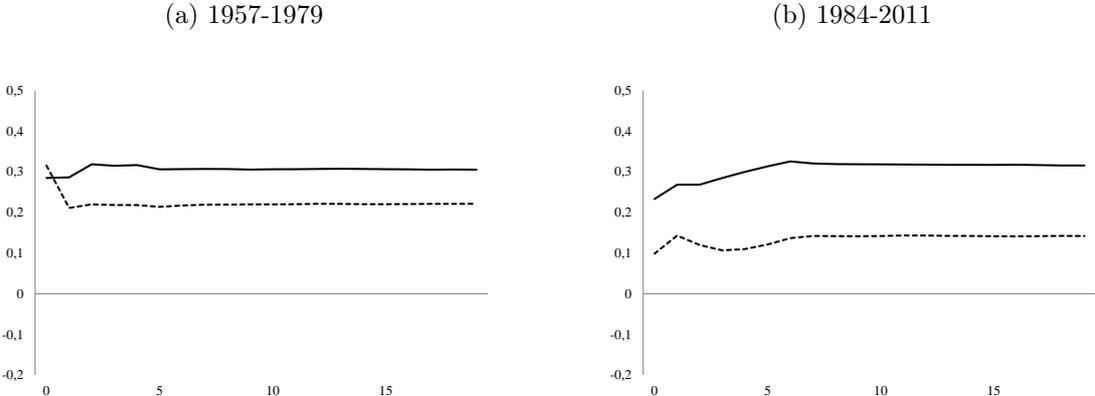
(b) 1984-2011

Figure 13: Response of public deficit with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
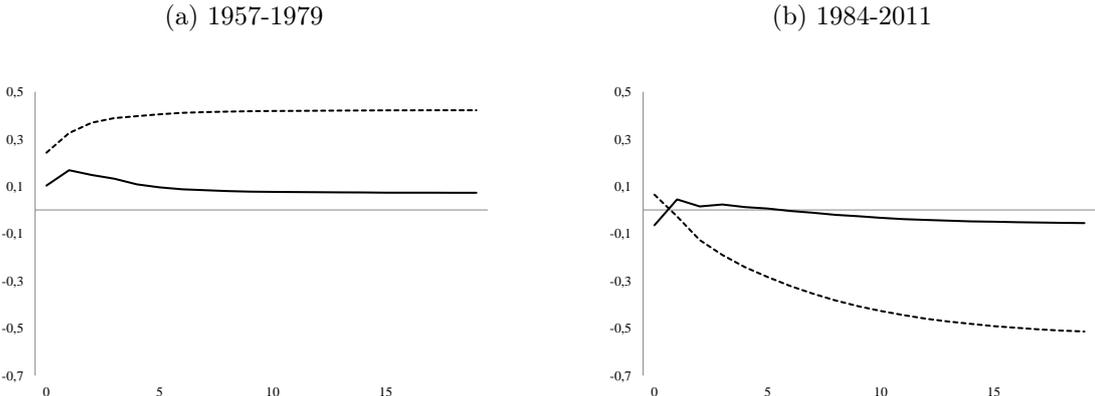
(b) 1984-2011

Figure 14: Response of ICT investment with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
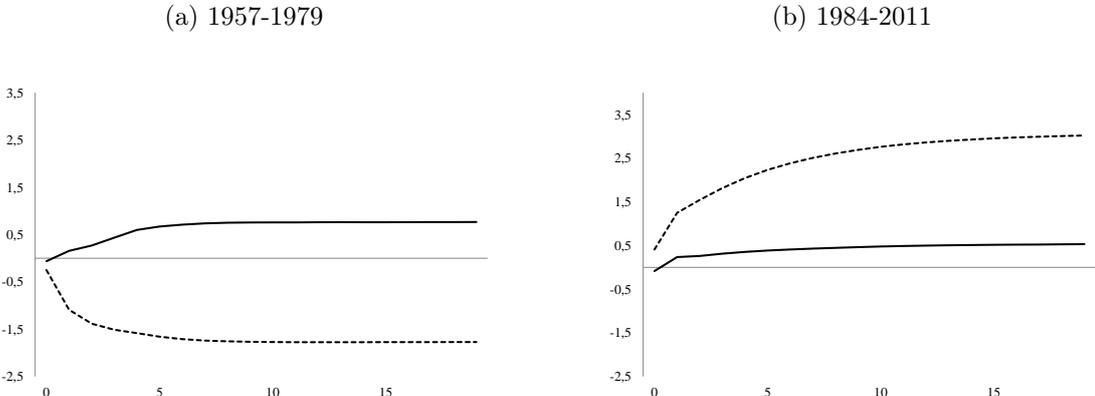
(b) 1984-2011

Figure 15: Response of non residential fixed investment with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
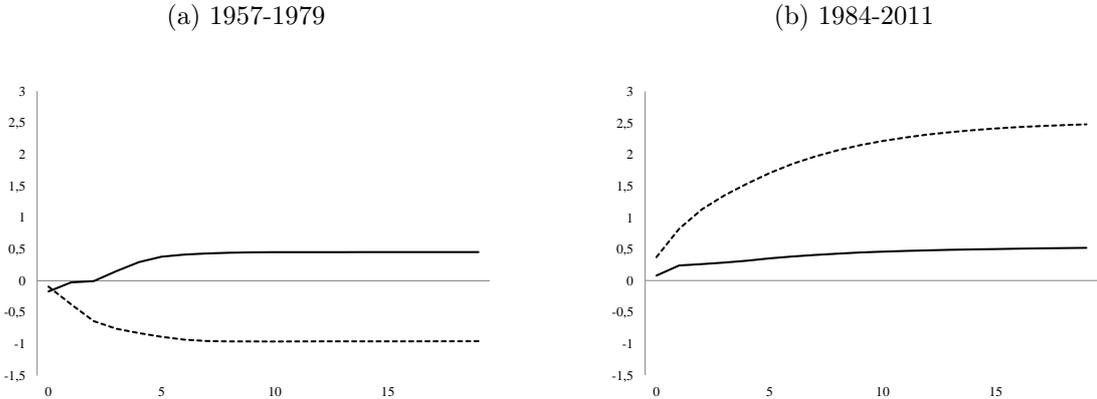
(b) 1984-2011

Figure 16: Response of residential fixed investment with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
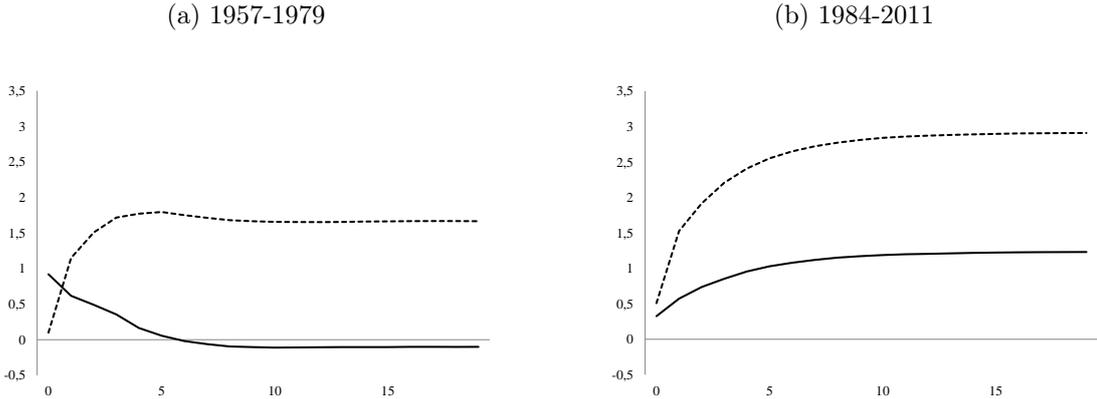
(b) 1984-2011

Figure 17: Response of inventories with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
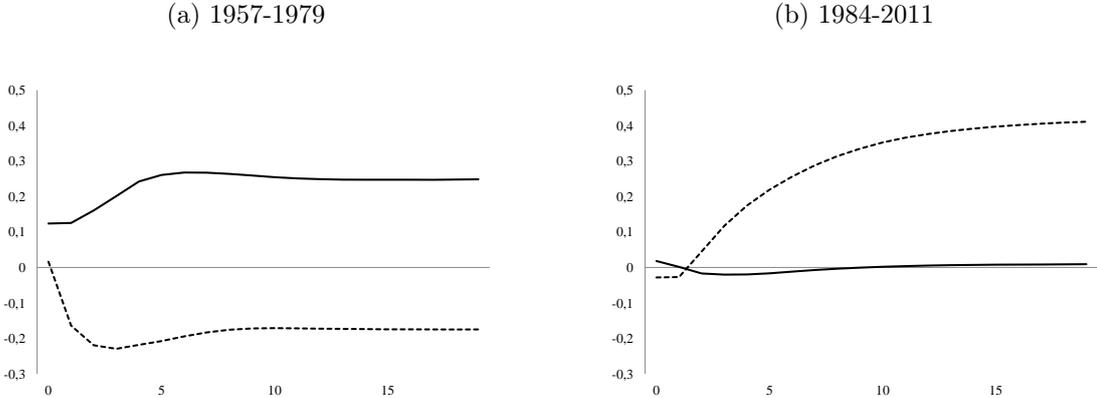
(b) 1984-2011

Figure 18: Response of private nondurable goods consumption with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011


(a) 1957-1979
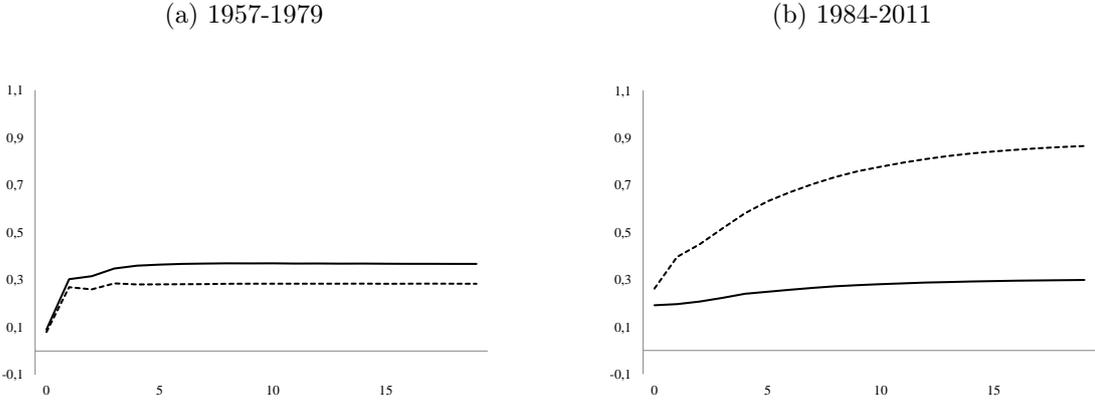
(b) 1984-2011

Figure 19: Response of private durable goods consumption with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
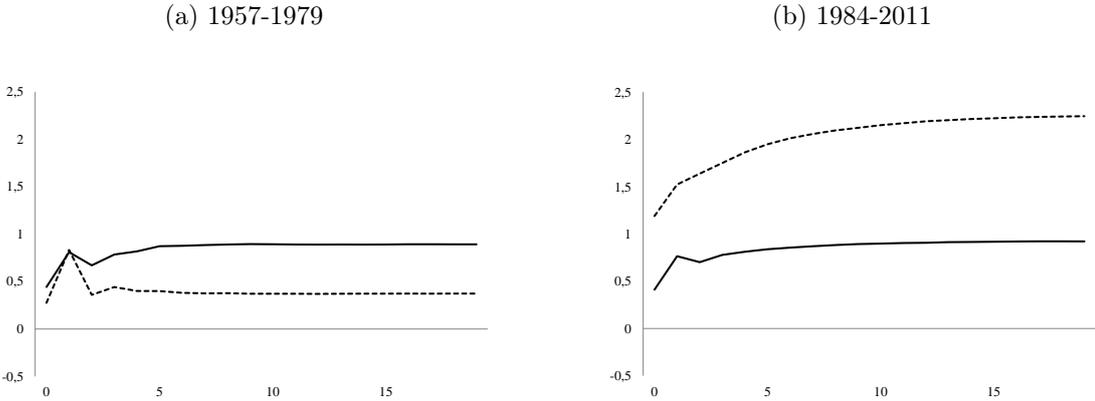
(b) 1984-2011

Figure 20: Response of private services consumption with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
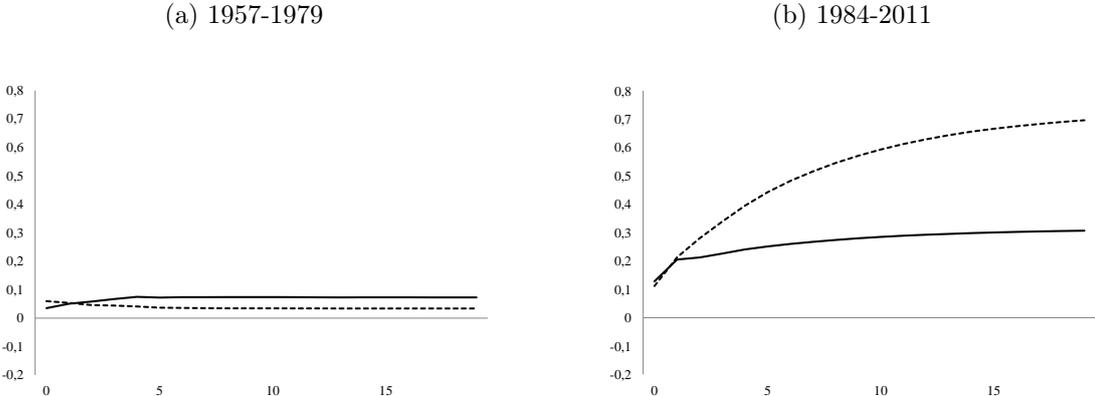
(b) 1984-2011

Figure 21: Response of nominal wage with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
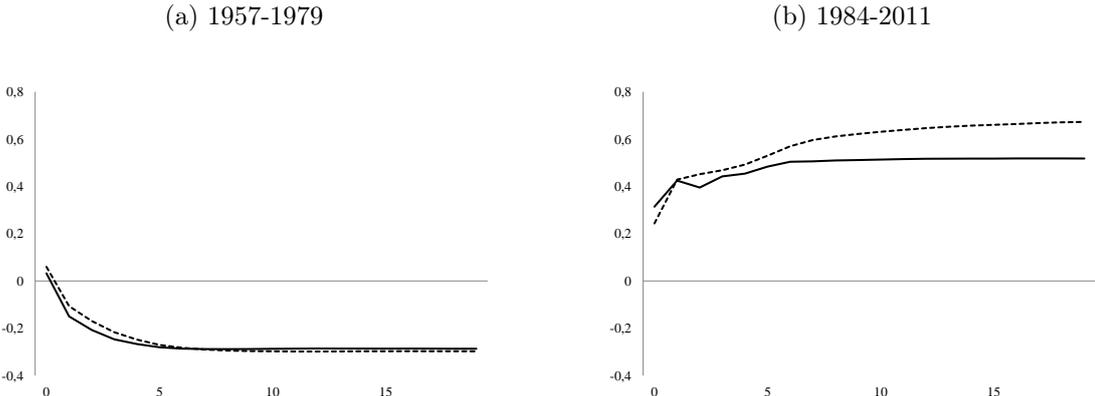
(b) 1984-2011

Figure 22: Response of real wage with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
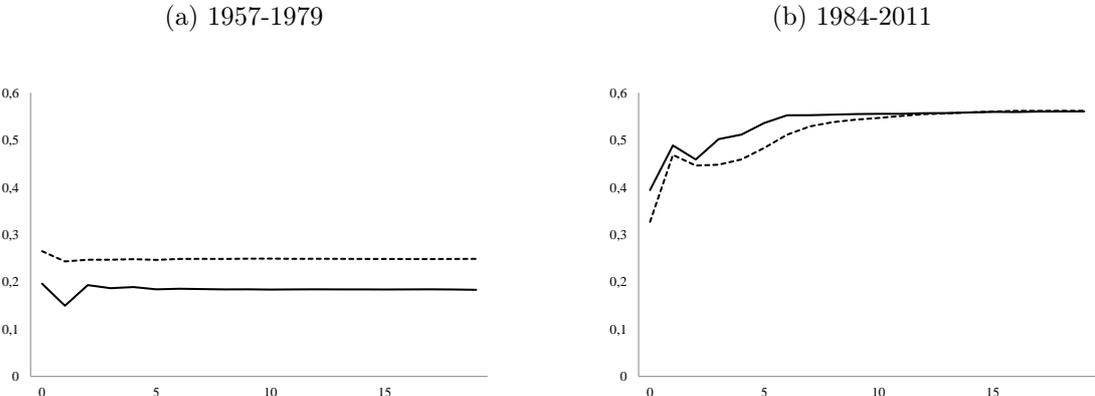
(b) 1984-2011

Figure 23: Response of BAA spread with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979
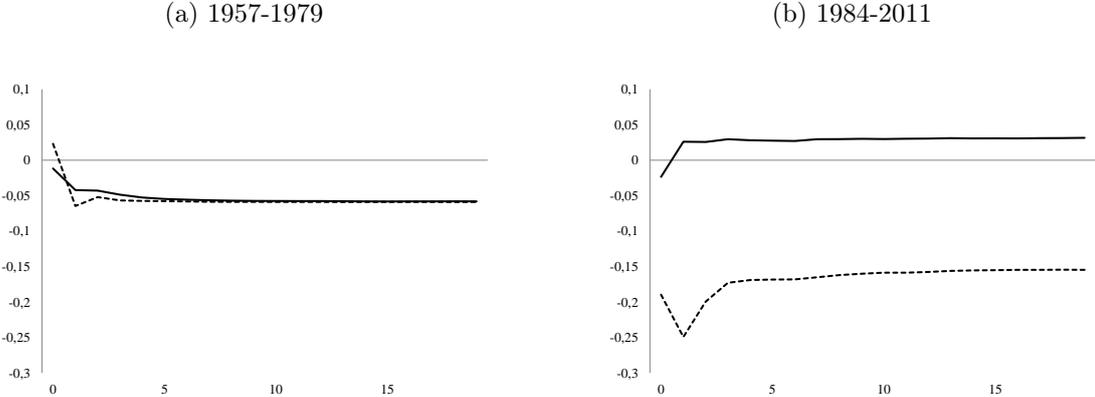
(b) 1984-2011

Figure 24: Response of AAA spread with respect to a 1% sd positive shock to adjusted TFP in recessions (dashed lines) and expansions (solid line). 1957-1979 vs. 1984-2011

(a) 1957-1979

(b) 1984-2011