Productivity Shocks and the Business Cycle: Reconciling Recent VAR Evidence

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Abstract

Galí (1999) used a VAR with productivity and hours worked to argue that technology shocks are negatively correlated with labor and are unimportant for the business cycle. More recently, Beaudry and Portier (2003) studied a VAR in productivity and stock prices. Remarkably, they found that the component which has a permanent impact on productivity is almost identical to that which has no immediate impact on productivity. Moreover, either of these components explains most business cycle variation. Like Galí's results, these observations are inconsistent with early RBC models, but on the other hand they contradict Gali's claim that technology shocks are unimportant for cycles.

In this paper, we study trivariate VARs in productivity, hours worked, and stock prices to see how these apparently contradictory results can be reconciled. We find one VAR specification that qualitatively and quantitatively matches the findings of Galí (so that long-run technology shocks drive hours down), and a second specification that matches the main findings of Beaudry and Portier (so that long-run technology shocks increase hours, are similar to the short-run shock to stock prices, and play a major role in generating business cycles). Surprisingly, the difference between these two specifications has nothing to do with estimating in levels or in differences, or with running VARs or VECMs, or with the ordering of variables. The only difference between the two specifications lies in which productivity variable is used: labor productivity (to generate results like Galí's) or TFP (to generate results like those of Beaudry and Portier). Both the original Beaudry and Portier estimations, as well as our findings on the productivity specification, add to the evidence that Galí's findings are not robust. Apparently the cyclical role of technology shocks is only picked up when a sufficiently cyclical productivity series is used in the estimation.

1 Introduction

A recent literature aims to test the basic real business cycle (RBCLike) theory of Kydland and Prescott (1982) and King, Plosser, and Rebelo (1988) by studying the effects of productivity shocks in the context of vector autoregressions (VARs). Just as Blanchard and Quah (1989) sorted shocks into "demand" and "supply" components, the more recent papers classify impulses into "technology" and "non-technology" components.

The influential paper of Galí (1999) constructs a VAR with productivity and hours worked. He separates the series into two components: the part that does not have any permanent effect on productivity, and that which does, which he interprets as a technology shock. He finds that the non-technology component is responsible for most variation at business cycle frequencies, and that the initial impact of a technology shock on labor is negative. Both these observations appear seriously inconsistent with the RBC theory that business cycles are due in large part to technological innovations.

More recently, Beaudry and Portier (2004) study a VAR in productivity and stock prices. Since different RBC papers have allowed for temporary or permanent productivity shocks as driving forces for business cycles, they consider two identification strategies for separating out the technological component of the data. Their "short-run" identification separates the component that has no immediate impact on productivity from that which does, while their "long-run" identification separates the component that has no permanent impact on productivity from that which does. Remarkably, they find that the component which has a permanent impact on productivity is almost identical to that which has no immediate impact on productivity. Moreover, either one of these components explains most business cycle variation.

Like Galí's results, these observations are inconsistent with the early RBC models in which booms are responses to increases in the current level of productivity. Nonetheless, Beaudry and Portier's results leave open the possibility of an alternative technology-based theory of the business cycle– they argue that technological changes are "news" which could stimulate the economy in the short run even if they do not immediately affect productivity. Thus, while both papers

could be interpreted as evidence against RBC theory, they appear to provide contradictory evidence on the sources of business cycles: Galí discards permanent shocks to productivity as a cause of business cycles, while Beaudry and Portier find them to be the main cause of cycles.

In this paper, we ask how these apparently contradictory results can be reconciled. If the results are robust, and are not due to subtle differences in data definitions (the measure of productivity used by Galí is output per hour worked, while Beaudry and Portier use TFP), then it must be the case that the permanent productivity component extracted from a VAR with hours worked is very different from that extracted from a VAR with stock prices. To explore this issue, we study a trivariate VAR with productivity, hours, and stock prices, and we ask what identification strategies give us results like those of Galí or like those of Beaudry and Portier.

2 Related literature

3 Econometric method

The first step of this paper is to reproduce Galí (1999) and Beaudry and Portier's (2004) results. To this end, first we estimate a bivariate VAR representation of the series considered by these authors. Once we have the VAR estimation, we can recover the Wold representation that takes the following form:

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\begin{bmatrix} \Delta x_t \\ \Delta y_t \end{bmatrix} = C(L) \begin{bmatrix} \mu_{1,t} \\ \mu_{2,t} \end{bmatrix},
$$

where $C(L) = I + \sum_{i=1}^{\infty} C_i L^i$, and the vector $\mu_t = [\mu_{1,t}, \mu_{2,t}]'$ is the vector of reduced form errors, correlated perturbations with zero mean and variance-covariance matrix equal to Ω. In the analysis below,

	Galí (1999)	Beaudry-Portier (2003)
Δx_t	labor productivity	TFP
Δy_t	hours	stock prices (S&P500)

Given this Wold representation the idea is to recover the structural representation, that is, the one with orthogonalized errors. While some identifications are more easily theoretically motivated than others, we mechanically explore a variety of specifications in order to understand the differences between Galí and BP results. In particular, we try imposing both short run and long run restrictions. Galí (1999) only considers a long run identification, whereas Beaudry and Portier (2004) analyze both short and long run identifications.

3.1 Short run identification

To recover the structural (uncorrelated) shocks,

$$\epsilon_t = \left[\begin{array}{c} \epsilon_{1,t} \\ \epsilon_{2,t} \end{array} \right]$$

from the empirical model

$$\left[\begin{array}{c} \Delta x_t \\ \Delta y_t \end{array} \right] = \Gamma(L) \left[\begin{array}{c} \epsilon_{1,t} \\ \epsilon_{2,t} \end{array} \right]$$

we need to compute the distributed lag $\Gamma(L) = \sum_{i=0}^{\infty} \Gamma_i L^i$. To this end we compute the transformation matrix Γ_0 such that

$$\Gamma_0^{-1} \Omega (\Gamma_0^{-1})' = I, \text{ or } \Gamma_0 \Gamma_0' = \Omega.$$

However, since the above system has one more variable than equations, it is necessary to add a restriction to pin down a particular solution. In the short run, this is done by computing the Cholesky decomposition of Ω, that is, a matrix Γ_0

$$\Gamma_0 = \left[\begin{array}{cc} a & b \\ c & d \end{array} \right],$$

in which $b = 0$, that is, we impose that the shock to the second variable not to have a short run effect on the first variable. From here, we can obtain $\Gamma_i = C_i \Gamma_0$, for $i > 0$.

3.2 Long run identification

The objective of this alternative restriction is the same, to recover structural errors from the Wold representation

$$\left[\begin{array}{c} \Delta x_t \\ \Delta y_t \end{array} \right] = \tilde{\Gamma}(L) \left[\begin{array}{c} \epsilon_{1,t} \\ \epsilon_{2,t} \end{array} \right],$$

however, the procedure now differs from the one above, and therefore, we have a different distributed lag $\tilde{\Gamma}(L)$. This time

$$\tilde{\Gamma}(L)\tilde{\Gamma}(L)' = C(L)\Omega C(L)',$$

we do not know Ω, that is why we need to estimate it, $\hat{\Omega}$, using this estimate we have,

$$\tilde{\Gamma}(L)\tilde{\Gamma}(L)' = C(L)\hat{\Omega} C(L)',$$

that is, in terms of matrices of long-run multipliers we have,

$$\tilde{\Gamma}(1)\tilde{\Gamma}(1)' = C(1)\hat{\Omega}C(1)',$$

where $\tilde{\Gamma}(1)$ is the (lower triangular) Cholesky decomposition of $C(1)\hat{\Omega}C(1)'$. Then recover the lag polynomial applying

$$\tilde{\Gamma}(L) = C(L)C(1)^{-1}\tilde{\Gamma}(1)$$

In the long run, the restriction we impose is $\tilde{\Gamma}^1_{12} = 0$, that is, we require the shock to the second variable not to have any long run effect on the first variable.

4   Data description

In this section we analyze the series to work with in the paper. Before putting together the two contrasting literatures, we attempt to reproduce independently the two main results reported in the literature. That is, we first reproduce Galí's 1999 results and then Beaudry and Portier's 2003 results. To this end, we collect data as close as possible to those employed by these authors. In both cases data correspond to postwar US.

To reproduce Galí's 1999 results we get data for labor productivity and hours worked. The sample considered is the same as in Galí and Rabanal (2004) and runs quarterly from 1948:1 to 2002:4. Labor productivity is computed as the ratio between the nonfarm business sector output, OUTNFB, and total hours in the nonfarm business sector, HOANBS.[1] The second variable in the VAR is nonfarm business sector: hours of all persons, that is HOANBS. (The VAR is setup in logs and first differences.)

For Beaudry and Portier's results we need data on total factor productivity (TFP) and stock prices. The sample runs from 1950:1 to 2004:1, also using quarterly data. Beaudry and Portier construct total factor productivity as follows:

$$TFP_t = \log\left(\frac{Y_t}{H_t^{\bar{s}_h}KS_t^{1-\bar{s}_h}}\right), \tag{1}$$

where Y denotes real GDP, H is total hours, and KS is capital services. As in Galí, we concentrate here on the nonfarm private business sector. The labor share, $\bar{s}_h$, is 67.66% which

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[1]Source: FREDII.

corresponds to the average value of the annual series reported by the BLS. Capital services measures the services derived from the stock of physical assets and software. This series is also annual so we need to interpolate to obtain a quarterly series. As Beaudry and Portier, we assume constant growth within the quarters of the same year. Output (Y) and hours (H) are quarterly seasonally adjusted nonfarm business measures, from 1947:1-2004:1 (also from the US BLS).

The second series refers to stock prices. Beaudry and Portier use the quarterly Standards & Poors 500 Composite Stock Prices Index (S&P500), deflated by the seasonally adjusted implicit prices deflator of GDP and transformed in per capita terms by dividing it by the population aged 15 to 64. As the population series is annual, it has been interpolated assuming constant growth within the quarters of the same year.

Next, the idea is to check for stationarity of the series in order to estimate the model in the most appropriate way. We performed unit root analysis on all the series. The results are reported in Table 1.

Table 1: Unit root tests

Series	$\hat{\tau}_\tau$	$Z[\hat{\tau}_\tau]$	Series	$\hat{\tau}_\tau$	$Z[\hat{\tau}_\tau]$
$\log(Y/H)$	-2.0974	-2.3727	$\Delta \log(Y/H)$	-7.4593	-16.8985
$\log(H)$	-3.4218	-3.1899	$\Delta \log(H)$	-6.8424	-7.6315
$\log(SP500)$	-1.4182	-1.5180	$\Delta \log(SP500)$	-6.5888	-9.8694
$\log(TFP)$	-2.5687	-3.2179	$\Delta \log(TFP)$	-8.9017	-9.4342

$t - statistic$ for the null hypothesis of a unit root in the level or the first difference of each time series, ADF and Phillips-Perron tests with 4 lags, trend and intercept. The 5 percent critical value for the tests is -3.43.

Following the literature, these tests are based on OLS regressions of the augmented Dickey-Fuller form

$$\Delta X_t = \alpha X_{t-1} + \delta + \beta t - \sum_{j=1}^{p-1} a_j^* \Delta X_{t-j} + \varepsilon_t.$$

The Table shows the statistics for the Augmented Dickey-Fuller (ADF) and Phillips-Perron analyses for unit root in time series, for the logs of each of the series considered below. From these tests, we cannot reject the null hypothesis that each of the series considered in the analysis are integrated of order one, neither in levels nor in differences at a 5% confidence level. Therefore, we setup our VARs in differences.

6

In spite of these tests we will run VARs both in levels and in differences, since there is currently a big debate in the literature on the presence of a unit root in the hours series. Interestingly, in contrast to the claims of recent papers we find that using DVARs or LVARs is not crucial for our results.

5   Reproducing Galí's results

In this section we perform the same analysis as in Galí (1999) and Galí and Rabanal (2004). That is, we estimate a bivariate VAR in labor productivity and hours. In order to compare the results of the two papers objective of this paper, we perform both short and long run restrictions on the VARs in order to identify technology and nontechnology shocks. In all the figures, we refer to labor productivity as PTY.

Figure 1 reports the impulse response functions for a 1% shock to labor productivity (top row), and to hours (bottom row) for the short run identification. The two left panels show the impulse responses to short run technology shocks.

Productivity jumps to plateau at 7e-3. Hours converge to plateau at 5e-3. Slight overshooting in both cases. That is, a short run shock to PTY has a permanent effect on it, and also on hours.

The right panels report the impulse responses to short run nontechnology shocks. After very small rise, productivity converges DOWN to permanently lower level at -3e-3. Hours converge up to plateau at 11e-3. Slight overshooting in both cases.

Figure 2 reports the same for the long run identification, which corresponds to the exercise done by Galí (1999). As before, to the left we have the impulse responses to long run technology shocks. As it can be seen, these figures reproduce Galí-Rabanal Fig. 2 almost exactly. Productivity jumps to plateau at 7e-3. This positive technology shock causes persistent fall in hours (hitting -2.5e-3 at t=2, negative until t=5), which then overshoots slightly and dies out. That is, the long run technology shock drives labor down while having a permanent impact on labor productivity. Notice that the magnitude of the change in PTY is almost the same as in the short run technology shock.

To the right, the impulse responses to long run nontechnology shocks show how productivity jumps up in first year to around 4e-3 to substantially overshooting down in second year to -1e-3, and finally, converges back to zero. Hours jump to 7e-3, overshoot to 15e-3, and then plateau to 12e-3. This last impulse response function is very close to that after a short run nontechnology shock.

Right now the analysis has focused mainly on the unconditional comovement of labor productivity and hours after the shock. Contrary to RBC theory, Galí finds a negative correlation between labor productivity and hours after a technology shock. So the immediate question arises: what is driving business cycles, then? To answer this question, we compute the business cycle series for labor productivity and hours implied by this VAR specification conditional on long run technology and nontechnology shocks.[2] This is displayed in Figures 3 and 4.

First, in Figure 3 we show the behavior of labor productivity and hours conditional on short run technology shocks (top panel) and nontechnology shocks (bottom panel). For the technology shock, we can see that there is a strong positive correlation of productivity and hours resulting from short run technology shocks, with productivity substantially leading. Regarding short run nontechnology shocks, there is a mildly negative correlation between productivity and hours, strongly so after 1990. (These shocks clearly play an important role in the short run identification of the fall in hours during the 1991 and 2001 recessions, where productivity appears countercyclical). Interestingly, under the short run identification, technology shocks appear to explain most of the cycle, though nontechnology shocks become important after 1990.

Figure 4 is parallel to the previous one but for the long run identified shocks. More concretely, for the long run technology shock (top), there is a strong NEGATIVE correlation between growth rates of productivity and hours, as Galí claims. In levels, this shock appears to pick up much of the "productivity slowdown", but only causes small acyclical fluctuations in hours. That is, consistently with Galí's results, we obtain that long run technology shocks are not relevant for business cycles. The predicted series for hours is quite stable, and the labor productivity

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[2]Notice that at this point our analysis differs from Galí's. This author reports the business cycle frequency data for GDP and hours, HP detrended and in logs, whereas we report the conditional cycle implied by the two shocks for the variables we are considering: labor productivity and hours. With these two series at hand, it would be very easy to recover the GDP cycle.

hours shows the productivity slowdown of the 80s. However, there is a remarkably part of the variations of both series that cannot be explained by technology shocks.

For the long run nontechnology shock (bottom), we find a clear positive correlation between productivity and hours, with hours lagging. The business cycle fluctuation in hours is attributed to this shock, as Galí claims. That is, we obtain that both series, labor productivity and hours, go together for most of the sample considered. Moreover, the predicted series capture the main recessions in the US, mainly the 1973 recession and the 1982 recession.

Summarizing, using this VAR specification, we can reproduce Gali-Rabanal results quite exactly using their data. Besides, Galí's results seem to be quite robust in the sense that technology shocks seem to be unrelated to the business cycle.

Conclusions from 19 Oct 2005 (especially b and d):

1. Qualitative results are relatively robust, but there are nontrivial quantitative changes even from small changes in the sample.

2. As Gali-Rabanal claim, under LONG RUN identification, nontechnology shocks are clearly responsible for the recognized (NBER etc.) business cycles.

Further results:

3. Results from series with nonzero mean (191005a and c) are always more or less qualitatively consistent with results found from demeaned series (191005b and d). But quantitative differences are quite large. In particular, hours do NOT initially fall due to LR tech shock here in 19100a, whereas they do initially fall strongly in 191005b.

4. Interesting observation: productivity appears countercyclical after 1990. Nonetheless, restricting the sample to 1947-89 does not appear to have any major qualitative effects on the results (output not saved here, but easy to reproduce with the program).

6 Reproducing Beaudry and Portier's results

In this section we turn to the results reported by Beaudry and Portier (2003). We estimate a bivariate VAR in levels for the log of TFP and stock prices for the US during 1950:1-2002:1. Following Beaudry and Portier we consider two alternative identifications. Figures 5 and 6 report the impulse response functions corresponding to short run and long run shocks, respectively. In each figure, the left column refers to technology shocks and the right column to nontechnology shocks, and the top panel to TFP and bottom panel to stock prices.

The following results stand out. As Beaudry and Portier obtain, a short run shock to stock prices has a permanent effect on productivity measured as TFP. However, it's also true that all four VAR specifications yield SR NONTECH IRFs very similar to those of BP. That is, initial impact on productivity is zero (by construction), converging in about a year to plateau around 5e-3; stock prices jump to 50e-3, then converge to a plateau around 90e-3, except in 211005c, where they thereafter appear to tend slowly back towards zero. Interestingly, a long run shock to TFP reflects almost the same effect on TFP as the shock run shock to stock prices. In both cases, productivity and stock prices go up. Our estimation is successful therefore in replicating the shape of the impulse response functions, however, we cannot account for the magnitude of the changes as reported by Beaudry and Portier.

Main difference between SR NONTECH IRFs and LR TECH IRFs is one of relative magnitude. Shape of IRFs is usually similar, but productivity rises more (relative to SP500) in case of LR tech than in case of SR nontech.

If we complete the analysis in parallel to Galí's results, and compute the business cycle implied by this estimation we obtain the following. Figures 7 and 8 shows the predicted series for TFP and stock prices conditional on short run and long run technology (top) and nontechnology (bottom) shocks. First, we observe that stock prices are much more volatile than TFP as expected. The predicted series for stock prices captures the main recessions of the 70s and the 80s. Figure 8 shows the same series conditional on the long run nontechnology shock. This time this component cannot explain the business cycle. We can only observe in the 2000 the bubble.

As a conclusion, according to this specification and identification, technology shocks are important for the cycle, in contradiction with Galí's results. However, we cannot reject the fact that nontechnology shocks also play a role in the business cycle.

Conclusions:

1. Both in differences and in levels, LR TECH picks up most business cycle variation

2. But SR TECH often picks up business cycles too

3. In fact, unlike B-P, we consistently find much higher correlation of the SR tech shock (instead of the SR nontech shock) with the LR tech shock!!

7 Comparing short-run and long-run specifications

GALÍ (19 Oct 05)

B-P and Alternative shock series comparison: Strong negative correlation between eps2sr and eps1lr (-0.43). Less strong positive correlation between eps1sr and eps1lr (0.90).

B-P impulse response comparison: Completely different responses: SR nontech makes productivity and hours go permanently in opposite directions; LR tech makes productivity go up but hours go temporarily down.

SR-LR tech impulse response comparison: Shape of impulse responses is similar. Productivity jumps up permanently by same amount in both cases. For SR tech, hours are initially unchanged, then converge up to plateau; for LR tech, hours initially fall, then converge up to their starting point. responses: SR nontech makes productivity and hours go permanently in opposite directions; LR tech makes productivity go up but hours go temporarily down.

BEAUDRY AND PORTIER (21 Oct 05)

B-P estimated structural shock series comparison: strong positive correlation between eps2sr and eps1lr: 0.56962. Much higher positive correlation between eps1sr and eps1lr: 0.81654. This points towards the direction that both shocks matter: technology and nontechnology shocks.

B-P impulse response comparison: this replicates BP result that a shock to stock prices in the short run has a long term impact on productivity. And so does the long run technology shock.

Regarding SR-LR technology impulse response comparison: again the shapes are very similar to those impulse response functions in B-P comparison. That is, there is not such a big difference between short run shocks or long run shocks with respect to the effects on productivity in the long run.

7.1 Alternative specifications

Before turning to the 3x3 VAR results, we check for robustness on the use of alternative variables for productivity. First, we reproduced the same exercise as Galí but using TFP instead of labor productivity. We find that using BP-TFP makes technology shocks more important for the business cycle, both for SR identification and for LR identification. A possible explanation is that since BP-TFP follows the cycle more closely, it is easier for the component which drives productivity improvements also to pick up business cycle fluctuations.

Next, we do the opposite with Beaudry and Portier's specification, that is, we run their VAR using labor productivity instead of TFP. The results show that the long run tech shock always picks up most of the business cycle. Also, long run nontech always picks up a lot of stock market variation, which is negatively correlated with the small movements in productivity. Using labor productivity in place of TFP makes the SR tech shock more similar to the long run tech shock, and makes the SR nontech shock less similar. That is, using labor productivity in place of TFP weakens the B-P claim that LR tech is positively correlated with SR nontech. B-P estimated structural shock series and SR-LR estimated structural tech shock series correlations 0.37554 and 0.92893, respectively. That is, using labor productivity makes SR and LR tech shocks very strongly correlated, a lot more than with TFP. Therefore the correlation of the LR tech shock with the SR nontech shock (the B-P correlation) falls.

8   Estimating the 3x3 VAR

Given these apparently contradicting results, the immediate next step is to put together both points of view and estimate a trivariate VAR in productivity, hours and stock prices. Our hypothesis to test is that if both identifications are correct, then they should capture different

types of shocks. If not, then we should check whether the differences are due to the alternative variables included (hours or stock prices), the definition for productivity (TFP or labor productivity) or the model estimated (VAR versus VECM).

The procedure is to estimate the following structural 3x3 VAR:

$$\begin{bmatrix} \Delta x_t \\ \Delta y_t \\ \Delta z_t \end{bmatrix} = \Gamma(L) \begin{bmatrix} \epsilon_{1,t} \\ \epsilon_{2,t} \\ \epsilon_{3,t} \end{bmatrix},$$

where now we add a new variable (stock prices for the case of Galí, or hours for the case of Beaudry and Portier), and in addition we obtain a new shock, $\epsilon_{3,t}$ we need to identify. As in the sections above, we proceed with the two alternative identification methods: short run and long run. The short run identification will yield three shocks that we denote $[\epsilon_{1,t}, \epsilon_{2,t}, \epsilon_{3,t}]'$ and the long run identification will be $[\tilde{\epsilon}_{1,t}, \tilde{\epsilon}_{2,t}, \tilde{\epsilon}_{3,t}]'$.

Figure 9 shows the impulse response functions to a shock to productivity and a shock to hours for the long run identification, which we will call Galí's specification. The panels report the effects on productivity, hours and stock prices. These IRFs are obtained using $[\Delta \log(labprod), \Delta \log(hours), \Delta \log(SP500)]$, that is, Galí's specification adding stock prices.

From the left panels (a long run shock to productivity), it is clear that both results (Galí's and BP's) are reproduced. That is, a long run shock to productivity drives hours down and stock prices go up. As Galí claims, long run technology shock implies a decrease in hours in the baseline Galí specification. The right panels show what Galí would call a nontechnology shock, in this case, a long run shock to hours. Again, we obtain Galí's results that productivity goes up to converge immediately to zero.

As a conclusion, the inclusion of an additional explanatory variable in the VAR does not alter Galí's results. Figure 10 reports the implied cumulated series for labor productivity, hours and stock prices. In the baseline Galí specification, the long run technology shock yields recognizable business cycle movements in productivity and SP500, but these are associated with COUNTERCYCLICAL hours movements. Also, the long run shock is responsible for a positive comovement between the three variables near business cycle dates.

An immediate question is to check whether these results are changed if we use TFP as a measure of productivity instead of labor productivity, as Galí does. Figure 11 reports the same analysis but using the baseline Beaudry and Portier's specification, that is, $[\Delta \log(TFP), \Delta \log(hours),$

$\Delta \log(SP500)]$, and comparing short run shock to stock prices versus the long run shock to productivity. Beaudry and Portier results are reproduced here, that is in both cases a permanent effect on productivity.

As Beaudry and Portier claim, the long run technology shock implies an increase in all three series, and picks up an important business cycle component. Furthermore, this long run technology shock is strongly positively correlated with the short run shock to stock prices (though it is even more strongly positively correlated with the short run technology shock). However, the long run shock to productivity does not show the fall in hours reported by Galí. That is, surprisingly, when we consider TFP as a measure of productivity instead of labor productivity, hours do not fall after a long run shock to TFP. That is, when running the 3x3 Beaudry and Portier VAR with labor productivity instead of TFP, it is difficult to pick up any component that is strongly correlated with the business cycle (probably because labor productivity is less cyclical).

Summarizing, both 3x3 Galí and 3x3 Beaudry and Portier baselines do a fairly good job of reproducing the results of the corresponding 2x2 baselines!! So arguably, the inclusion of these three variables is LESS IMPORTANT than the choice of TFP or labor productivity.

8.1 Robustness

The 3x3 VAR analysis done above intends to compare Galí with Beaudry and Portier by including all three variables. But in addition to the change in the second variable, there are three other differences between the two papers:

- Run in differences versus run in levels (or VECM)

- Express last variables in per capita terms (BP) versus in aggregate terms (Galí)

- Alternative ordering of variables in VAR

[VAR in LEVELS versus DIFFERENCES]

To check whether this failure was only due to the definition of productivity and not to other specification in the estimation we compared the output of a VAR in differences and in levels. If we estimate a VAR in levels, we obtain the same result as in Christiano et al., that is, hours

jump up slightly after an increase in productivity. Under this specification, technology shocks matter a lot for the cycle (both in the short and long run), whereas nontechnology shocks are also important, although they report a negative correlation between productivity and hours. For the Galí's specification, either using TFP in place of labor productivity, or running in levels instead of differences, suffices to eliminate Gali's result of a significant fall in labor after a positive technology shock. Also, either using TFP in place of labor productivity, or running in levels instead of differences, makes long run technology shocks important for business cycles.

For the Beaudry and Portier specification (already mentioned) As BP claim, the long run technology shock implies an increase in all three series, and picks up an important business cycle component. (already mentioned) As BP claim, LR tech is strongly positively correlated with last SR shock (though it is even more strongly positively correlated with the SR tech shock). The two previous results hold both for LVAR and DVAR, if TFP is used. So arguably, the inclusion of these three variables is LESS IMPORTANT than the choice of TFP or LP, and the choice of DVAR or LVAR.

Surprising degree of similarity between BP comparison graphs in Galí 021105Gb (Galí DVAR using TFP) and BP 011105BPa (BP LVAR using TFP). In other words, just using TFP in a 3x3 VAR based on Galí brings us closer to BP results than to Galí results.

In all of the runs based on TFP (and also when we run Galí VAR in levels), long run technology shocks explain much of the business cycle.

[TOTAL vs PER CAPITA data]

We also compared the estimation for alternative scales of the data, total versus per capita data. The differences are nil.

Finally, it is using Beaudry and Portier's TFP instead of Galí's labor productivity what makes technology shocks more important for the business cycle. The reason is that BP's measure follows the cycle more closely.

[ALTERNATIVE ORDERING OF THE VARIABLES]

If we run the 3x3 VAR from above but using an alternative ordering of the variables, in particular $[\Delta \log(TFP), \Delta \log(SP500), \Delta \log(hours)]$, we obtain that using labor productivity, Galí's results are robust to any alternative ordering of these three variables. However, this

result is lost when we use TFP instead of labor productivity, independently of the ordering of the variables. At the same time, this ordering with TFP and using Beaudry and Portier's specification also maintains the same results, that is a short run shock to stock prices has the same permanent effects on productivity as the long run shock to productivity. So both results are robust to the ordering of variables, and independently of the variables we include in the VAR.

9   Conclusions

References

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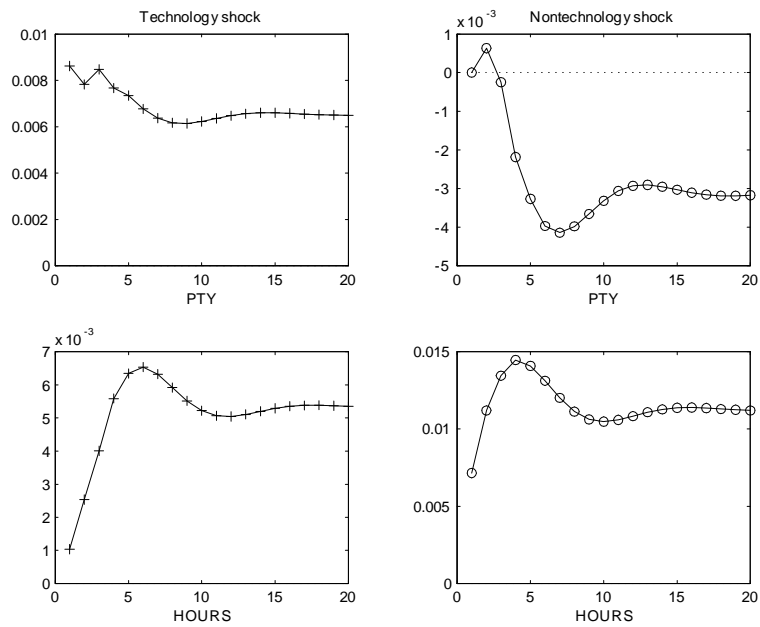
A   Galí's identification

Figure 1: Impulse response functions: technology and nontechnology shocks, short run identification
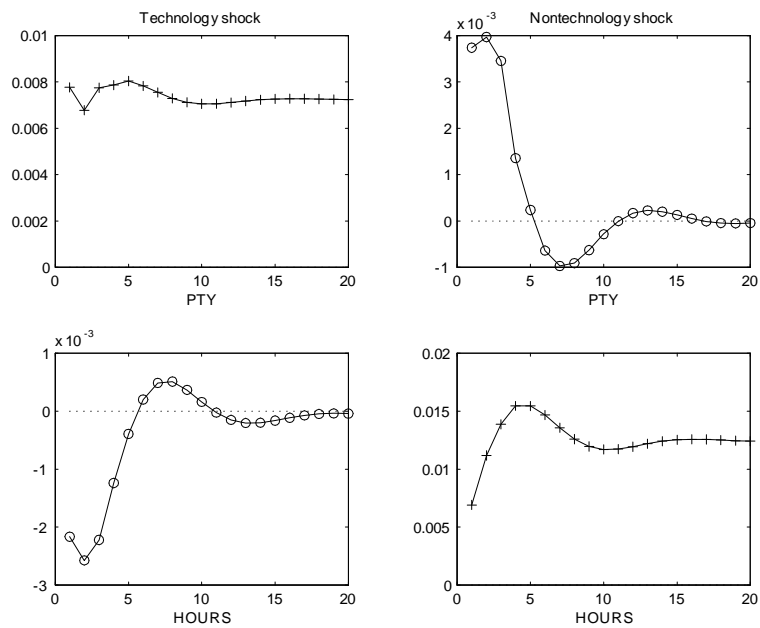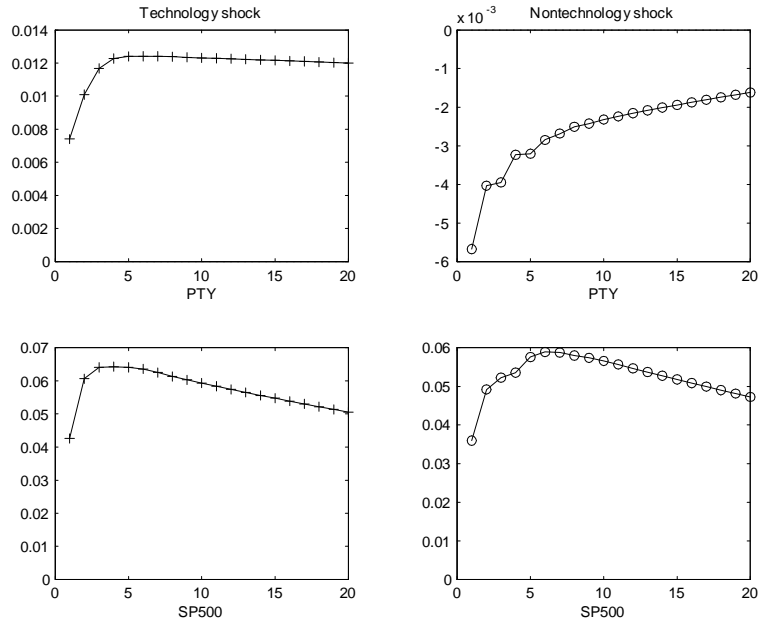

Figure 2: Impulse response functions: technology and nontechnology shocks, long run identification
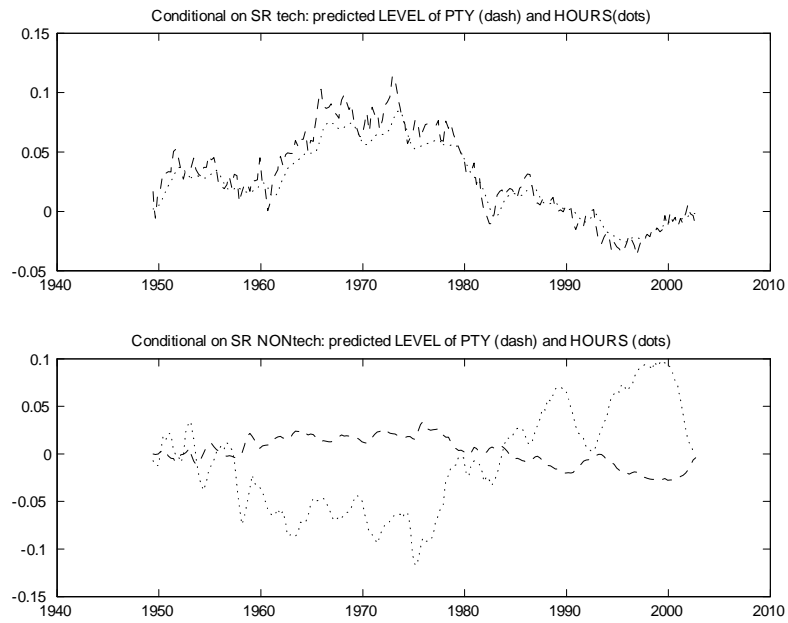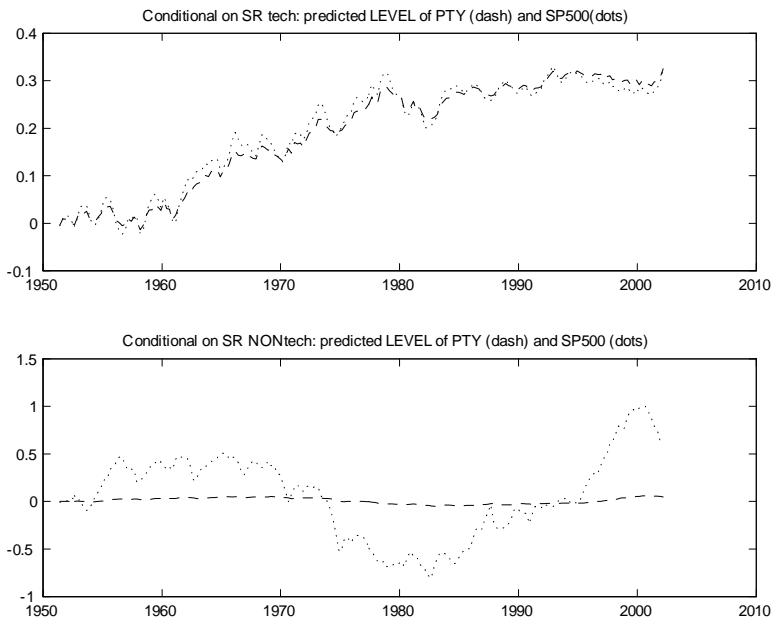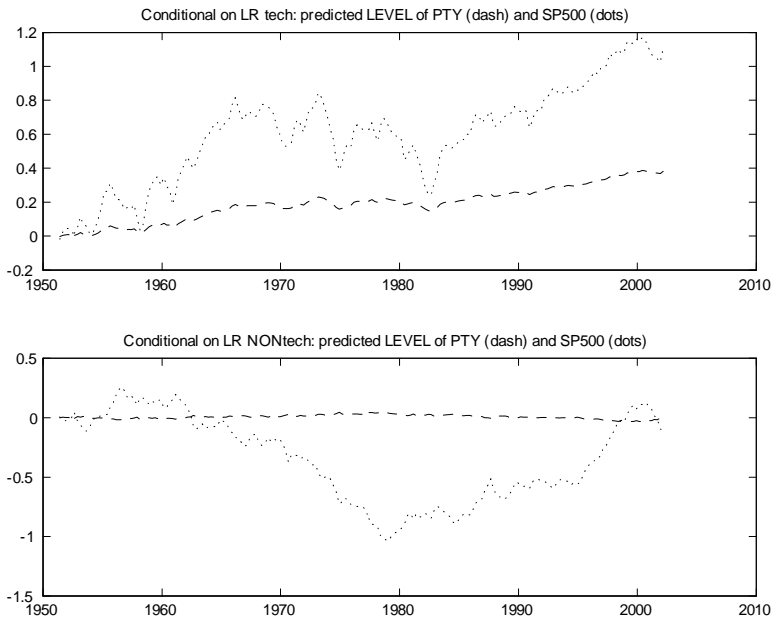
Figure 3: Cummulative series, short run identification.
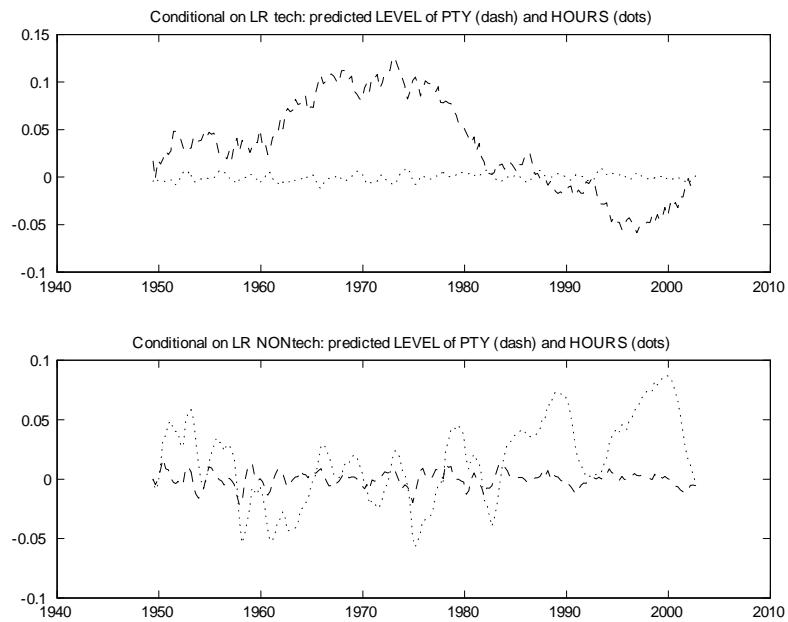
Figure 4: Cummulative series, long run identification.

B   Beaudry and Portier's identification
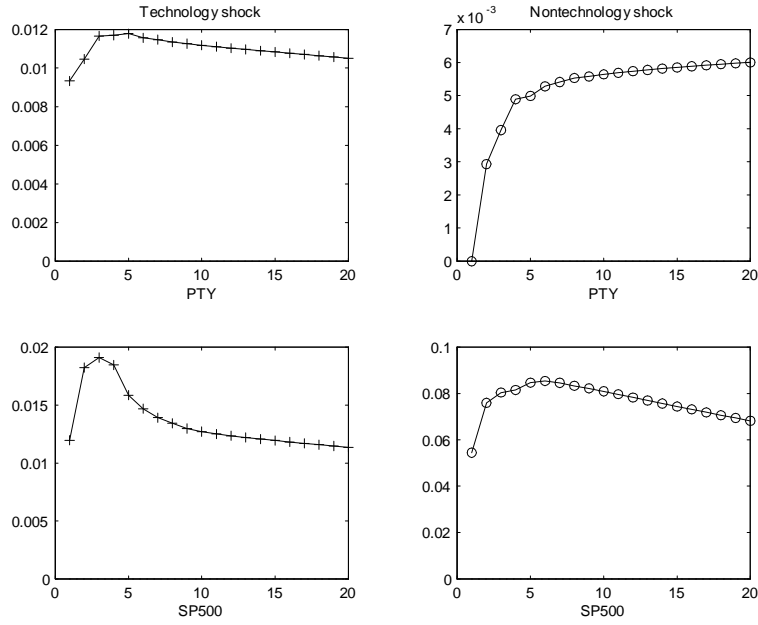
Figure 5: Impulse response functions: technology and nontechnology shocks, short run identification

Figure 6: Impulse response functions: technology and nontechnology shocks, long run identification

Figure 7: Cummulative series, short run identification.

Figure 8: Cummulative series, long run identification.
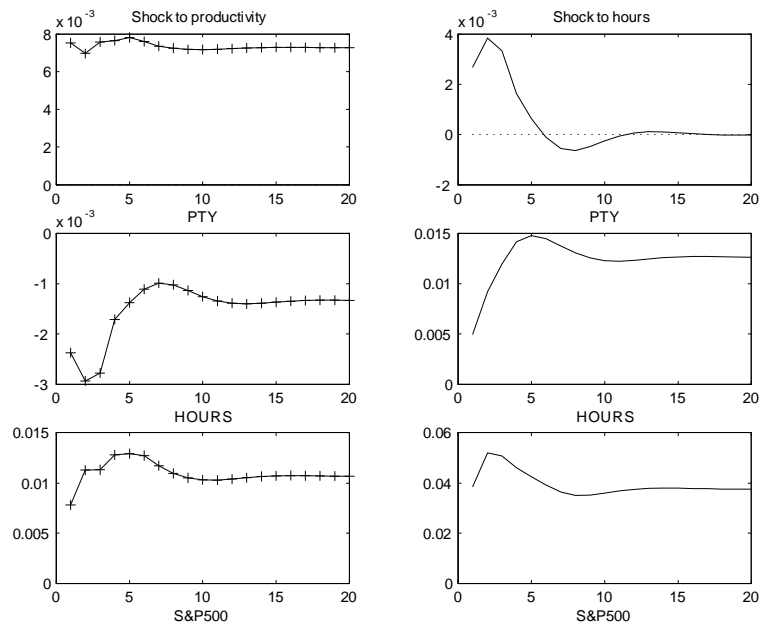
22

C   3x3 VAR

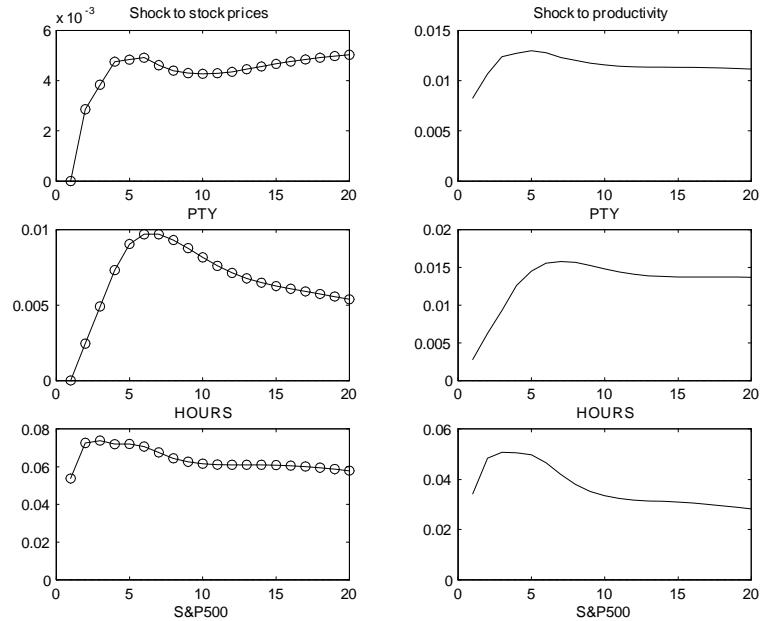Figure 9: Galí's specification, 3x3 VAR.

Figure 10: Beaudry and Portier's specification: 3x3 VAR.
Left panel: short run identification. Right panel: long run identification.