Expansionary and Contractionary Technology Improvements*

Almut Balleer
IIES Stockholm

Zeno Enders
University of Bonn

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Abstract

This paper examines the effects of expansionary technology shocks (shocks that increase labor productivity and factor input) as opposed to contractionary technology shocks (shocks that increase labor productivity, but decrease factor input). We estimate these two shocks jointly based on a minimum set of identifying restrictions in a structural VAR. We show that most of the business cycle variation of key macroeconomic variables such as output and consumption is driven by expansionary technology shocks. However, contractionary technology shocks are important to understand the variation in labor productivity and production inputs. In addition, these shocks trigger different reactions of certain variables, which can help explain why existing evidence on technology shocks does not deliver clear results. In a simple DSGE model with managerial technology, which is consistent with our identifying restrictions, we interpret contractionary technology shocks as process innovations and motivate the difference to expansionary technology shocks.

Keywords: Technology shocks, business cycles, productivity
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*Please address correspondence to `almut.balleer@iies.su.se` or `zeno.enders@uni-bonn.de`

1 Introduction

What drives business cycles? Although disagreeing about their exact contribution, a large body of the macroeconomic literature assigns a substantial role to technology-induced changes in productivity for explaining economic fluctuations.[1] Related to the question of whether technology-shocks are the main driver of the business cycle, there is a considerable discord about their effects on key economic variables, at least in the short run. Specifically, there has been a recent fervid dispute around the issue whether technological improvements are contractionary or expansionary. Contradicting the results of the early real business cycle literature, Galí (1999) has argued on the basis of U.S. time series that after a positive improvement in aggregate technology, output changes little, while labor falls in the short run. This result has been attacked, among other reasons, on grounds of misspecification of hours, in levels rather than detrended, or problems with use of structural VARs per se.[2]

This paper does not ask 'Are technology shocks contractionary?', but 'Which technology improvements are contractionary?' Specifically, based on a minimum set of identifying restrictions in a structural VAR, we jointly estimate two different technology shocks: expansionary technology shocks, that from a Real-Business-Cycle point of view have the conventional positive effect on short-run labor input, and contractionary technology shocks, that affect labor input negatively. We show that most of the business cycle variation of key macroeconomic variables such as output and consumption is driven by conventional technology shocks. However, contractionary technology shocks are important to understand the variation in labor productivity and production inputs. In addition, these shocks trigger different reactions of certain variables, which can help explain why existing evidence on technology shocks does not deliver clear results. In a small theoretical model, which is consistent with our identifying restrictions, we argue that the contractionary technology shocks are different from existing technology or non-technology shocks in the literature. We also provide an economic interpretation of these shocks that is motivated by anecdotal evidence on process innovation and the effects of rationalization.

We present time-series evidence for expansionary and contractionary technology shocks that is estimated from a structural VAR with a combination of zero and sign restrictions in the short- and long-run. Our starting point is the original identification in Galí (1999) in which technology shocks are the only shocks that affect labor productivity in the long-run. Labor input is measured as total hours worked and incorporated in first differences into the VAR. This way, we are choosing a specification that has generated results in favor of contractionary technology shocks. Based on this, we then assess whether expansionary technology shocks play a role for aggregate dynamics in this setup. More precisely, we extend Galí's restriction by allowing two shocks, rather than one shock, to be technology shocks with a positive long-run effect on labor productivity. Out of these two shocks, we assume that expansionary technology shocks affect hours worked positively and contractionary shocks affect hours negatively in the short-run.

We find a sufficient number of responses that satisfy our identifying restrictions, indicating that what

[1] The early RBC literature argued for contributions of technology shocks to fluctuations in aggregate output as high as 70%, see Kydland and Prescott (1991). More recent studies, such as Altig et al. (2005) and Chari et al. (2008), found lower values, but typically not below 25%.

[2] This result was the starting point of the debate around the so called 'hours puzzle'. Since a negative response of hours worked to a positive technology shock runs contrary to the dynamics of a conventional shock to total factor productivity in a real-business-cycle model, Galí's empirical observation has been taken as evidence in favor of New Keynesian models in order to explain the aggregate dynamics in the data. Later studies that either support or challenge this result include Francis and Ramey (2005a), Francis and Ramey (2005b), Canova et al. (2008), and Chari et al. (2008) among many others. Based on alternative evidence, Basu et al. (2006) have answered the question 'Are technology shocks contractionary?' positively.

has been identified and interpreted as technology shocks in the existing literature can be described as an amalgum of two, orthogonal components with quite distinct business cycle properties. Expansionary technology shocks trigger the dynamics familiar in a RBC context: an increase in hours, output, investment and consumption. Contractionary technology shocks lead to a fall in hours worked, investment and output (the last insignificantly). Contractionary shocks further induce a strong increase in compensation, but a fall in the rental rate of capital.

Even though labeling them technology shocks in the empirical part, we are really agnostic about the interpretation of these shocks. Depending on the theoretical viewpoint, these shocks could equally be referred to as persistent preference or demand shocks for example. Moreover, they could be interpreted in a Real-Business-Cycle or New Keynesian framework respectively. In the RBC world, shocks to technology enhance productivity of inputs employed by raising the average and marginal product of labor and capital. As an optimal reaction, firms wish to employ more labor and capital. As Galí (1999) pointed out, nominal rigidities can limit the firm's ability to increase sales, such that factor inputs can fall in the short run. In the long run, however, optimal factor input will be unambiguously higher, which is not in line with our empirical results for contractionary technology shocks. We develop a simple dynamic general equilibrium model to argue why our evidence for contractionary technology shocks is not in line with the existing explanations and present an alternative view on these shocks which is quite distinct in nature and reduces the optimal factor input despite the firm's ability to freely set prices.

Our interpretation corresponds in broad terms to what is commonly understood as 'rationalization'. There is a lot of anecdotal evidence of firms or whole sectors enhancing efficiency by redesigning their business processes and cutting costs. Increased efficiency may stem from changes in managerial skill, but also from sources external to the firm, such as consultancy services.[3] Productivity is typically increased by these operations. It is not the case, however, that production is expanded given the existing resources. Instead of producing more with the same input factors, these improvements in organization and processes rather focus on producing at most the same amount with less inputs, i.e. at lower costs. In terms of economic language, the average product of labor and capital increases while their marginal product *decreases*, which implies that the marginal unit of capital or the marginal hour is made redundant. The workload previously done by this marginal worker can be reallocated to the remaining ones, due to their increased efficiency. The same is valid for capital goods. As a reaction, either these marginal workers are then dismissed, or average hours worked are reduced. Innovations to business organization and processes shift and rotate the labor and capital demand curves simultaneously. In our view, traditional TFP shocks are better suited to capture innovations to technologies, such as computers, which enhance general productivity and therefore shift the labor and capital demand curves upwards.

In order to model the process of rationalization, we introduce the concepts of managerial, or 'span-of-control' technology in our model. Relative to a textbook-style RBC model, only the production function is changed. Managerial technology acts as a new input factor to production, enhancing productivity of all employed factors, similar to TFP. Additionally, a supervision technology determines the intensity with which supervision can be conducted. An increase in this technology triggers a process restructuring, concentrating more efficient supervision on a smaller number of employees.

[3] Many consultant firms base their success on guiding firms in restructuring and cost cutting. McKinsey describes its activities in a case study on its homepage as "The strategy required that the company focus on core products, operate at 20 to 40 percent lower cost than competitors, and eliminate businesses that were inconsistent with the new direction." Another case study gives a similar description of its strategy: "...our team scrutinized the company's operations and identified multiple cost-reduction opportunities, which would involve consolidating plants..." Common to these examples is the focus on cutting costs, with a possible reduction of activity.

This restructuring implies that worker's labor input is reduced, leading to falling average hours and investment. Hence, an increase in this 'span-of-control' technology triggers a restructuring of business procedures that can be interpreted as rationalization. Increasing the intensity of supervision and a at the same time reducing worker's labor input enhances labor productivity. The theoretical model implies different reactions of macroeconomic aggregates to shocks to conventional expansionary technology on the one side and shocks to supervision technology (contractionary technology shocks) on the other. Most prominently, while both shocks increase labor productivity in the long run, the reaction of factor input is opposite after these two shocks, and are in line with the corresponding empirical responses.

The remainder of this paper is organized as follows. Section 2 explains the empirical identification strategy and documents business cycle dynamics of expansionary and contractionary technology shocks. Section 3 describes the theoretical model with a focus on our concept of contractionary technology shocks. Section 4 concludes.

2 Time-Series Evidence

2.1 Identification and Specification

Identification The evidence we provide on expansionary and contractionary technology shocks is based on a structural VAR with a combination of long-run zero and long-run and short-run sign restrictions. Generally, structural identification involves finding a mapping A of the residuals from a reduced form VAR into structural residuals such that these can be interpreted as structural shocks in (a class of) models. More precisely, the relationship between the structural and reduced form residuals is $e_t = Av_t$ which induces that $A\Sigma_e A' = \Omega$ is the reduced form variance-covariance matrix.

In order to pin down A uniquely, we assume that the structural shocks are orthogonal, normalize their variance to one, $\Sigma_e = I$, and impose our identifying restrictions:

1. Technology shocks are the only shocks that are allowed to affect labor productivity in the long-run.
2. Technology shocks affect labor productivity positively in the long-run.
   a. Out of these, expansionary technology shocks affect hours positively in the short-run.
   b. Out of these, contractionary technology shocks affect hours negatively in the short-run.

Note that restriction 1 corresponds to the long-run zero restrictions employed to separate technology and non-technology shocks as in Galí (1999). Note that Galí identifies two (groups of) shocks, while we seek to identify three (groups of) shocks, two with a long-run effect on labor productivity (the two technology shocks) and one with no long-run effect on labor productivity (the non-technology shock). In order to obtain two shocks with a long-run effect on labor productivity, we need to add at least a third variable to Galí's minimal bivariate VAR. That is, we use the additional degree of freedom of the extra variable to impose an additional sign restriction on top of the zero long-run restrictions in order to separate expansionary from contractionary technology shocks. Note that this also means that we can not exactly nest the Galí shocks in our framework, but that the sum of the two types of technology shocks should be a good approximation of the originally identified Galí shocks.

The restriction that technology shocks are the only shocks that affect labor productivity in the long-run holds in a large class of models and the resulting technology shocks are often interpreted as encompassing any effect that shows up as total factor productivity. There exists some doubt about the interpretation of these shocks as aggregate neutral technology shocks. Examples include technological shifts between sectors, identified as investment-specific technology shocks by Fisher (2006), or demand shifts in favor of more productive inputs such as skilled labor, identified as skill-biased technological change in Balleer and van Rens (2009). Further, preference shocks or, more generally, labor supply shocks that are permanent or at least very persistent can affect long-run labor productivity as well. Even though we label the estimated shocks technology shocks in the identification, following Galí's convention, we are agnostic about their interpretation at this point, and turn to this matter in the next section.

In order to implement our identifying restrictions, consider a VAR in which labor productivity and hours worked are ordered first. In the baseline specification, we estimate small VARs with three variables, adding different variables to labor productivity and hours worked in turn. Let

$$y_t = \sum_{i=0}^{\infty} \Phi_i v_{t-i}$$

be the moving average representation of these VARs in which the Φ_i are linear combinations of the estimated VAR coefficients for different lags. Then, we impose our identifying restrictions on two matrices, the short run matrix A and the long-run matrix L. These two matrices are linked via the infinite horizon forecast variance which is given by

$$LL' = \left(\sum_{i=0}^{\infty} \Phi_i\right) \Omega \left(\sum_{i=0}^{\infty} \Phi_i\right)' = \left(\sum_{i=0}^{\infty} \Phi_i\right) AA' \left(\sum_{i=0}^{\infty} \Phi_i\right)'.$$

For estimates of Ω and Φ_i, we now use a Cholesky decomposition of the infinite horizon forecast variance to obtain a candidate matrix for L and hence A. We can now rotate L and A around the unit ball using Givens rotations. In our three-dimensional system, there are three Givens rotations

$$Q_{12}(\theta) = \begin{pmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{pmatrix}, Q_{13}(\psi) = \begin{pmatrix} \cos(\psi) & 0 & -\sin(\psi) \\ 0 & 1 & 0 \\ \sin(\psi) & 0 & \cos(\psi) \end{pmatrix}, Q_{23} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi) & \cos(\phi) \end{pmatrix},$$

where θ, ψ and ϕ lie between 0 and 2π. Multiplying these three rotations $Q = Q_{12} \cdot Q_{13} \cdot Q_{23}$ one can describe any point on the unit ball such that any rotation of L satisfies that $LQQ'L'$ describes the long-run forecast variance and simultaneously rotating A gives $AQQ'A' = \Omega$.

Next, we want to impose our identifying restrictions. Imposing the long-run restrictions is equivalent to setting all but the first two elements of the first row in the matrix of long-run effects to zero. If L is given by a Cholesky decomposition of the long-run variance, the long-run restrictions are satisfied. We now want to rotate L such that these long-run restrictions remain valid. This can be achieved by setting $\psi = 0$, i.e. by rotating along two out of the three dimensions only. Rotating along these two dimensions, we then check whether our sign restrictions are satisfied.

As in Peersman (and similar to Uhlig (2005)), our VAR is estimated in a Bayesian framework. We estimate the reduced form VAR with a flat prior for which the median corresponds to the OLS estimate. For each of 100 draws of the posterior distribution of the reduced form VAR coefficients, we calculate the long-run forecast revision variance. From this variance, we obtain the Cholesky factor L as a starting point. Along a 20x20 point grid for θ and ϕ, we then rotate L and calculate the corresponding matrix A. We then check our sign restrictions and keep the draw if they are satisfied, we do not keep the draw in case our sign restrictions are not satisfied. We compute the impulse responses for all draws that satisfy the sign restriction and report the 16th and 84th percentile from the resulting distribution as confidence intervals. Our point estimate corresponds to the median of the posterior distribution of the impulse responses.[4]

Specification Estimating the reduced form VAR coefficients, we incorporate 4 lags of variables into the VAR as is usually done with quarterly data. We use quarterly U.S. time series data ranging from 1947:1 to 2004:4. Our baseline specification includes labor productivity and hours worked, taken from the nonfarm business measures from the BLS. We can then deduct the dynamics of output from the productivity and hours dynamics. We add a third variable to the VAR in turn. Fixed nonresidential investment and personal consumption expenditures are taken from the NIPA data provided by the BEA. We further include the relative price of investment as an additional control in our VAR. The price data is the quarterly series generated by Fisher (2006) that is based on the measure of Cummins and Violante (2002).[5] All series are seasonally adjusted. For all of the series included in our baseline VARs, we cannot reject the existence of a unit root in a standard ADF test. This is why we include all variables in first differences in our VAR. We can further statistically reject cointegration between these variables, specifically between consumption, investment and output as well as compensation and productivity.

In Section 3, we develop a model with expansionary and contractionary technology shocks, where we interpret the latter shocks as the theoretical counterparts to our estimated shocks in this section. We argue in favor of our interpretation and against interpreting the contractionary shocks as, e.g., technology shocks under nominal rigidities or permanent preference shocks. In order to back this interpretation, we consider two additional variables and compare the effects of the two shocks from the model and the data. More precisely, we add wages and the real interest rate to our baseline VAR, one at a time. Wages correspond to the BLS nonfarm business measure for compensation. The real interest rate is calculated from the nominal (3MTB) interest rate and the inflation rate (based on CPI data from NIPA).

2.2 Evidence

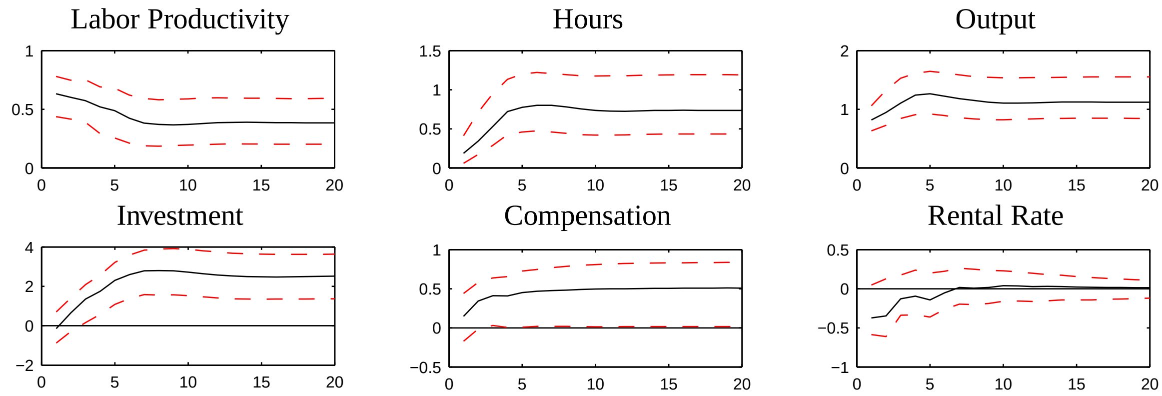
Impulse-responses Figure 1 shows estimated impulse-responses to the identified expansionary and contractionary technology shocks. The responses of labor productivity and hours worked to both shocks exhibit the identifying assumptions. The responses of labor productivity, hours and output in this figure correspond to the ones from the estimation with the relative price of investment as a third variable. The responses remain very similar if other third variables are added to the VAR. After a expansionary technology shock labor productivity, hours worked, output, and investment all increase significantly. After a contractionary technology shock, labor productivity increases and hours worked fall. Investment falls and output does not react significantly. After a expansionary shock, compensation increases, while the rental rate does not react significantly. Compensation also increases after a contractionary shock, while the rental rate falls substantially and persistently. The results have been checked for robustness along a number of dimensions. Note that summing up the responses of these two orthogonal shocks delivers similar results to the technology shocks identified with the

[4] Addressing concerns by Fry and Pagan (2007), the results for the point estimate are very similar if we compare them to a measure that uses the OLS estimate of the VAR coefficients, calculates and rotates the corresponding impulse responses and reports the median of the draws that satisfy the sign restrictions.

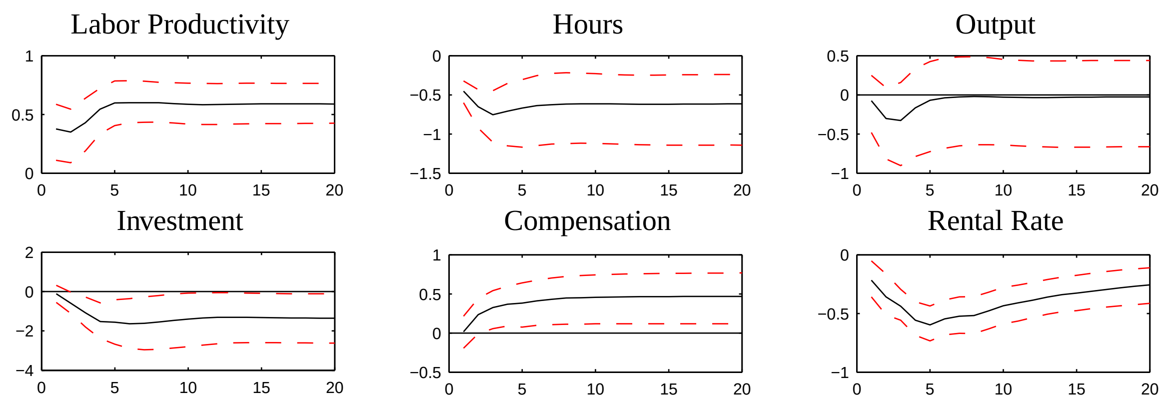
[5] The series by Jonas Fisher was extended by Ricardo DiCecio. We thank both for making their data available.

Figure 1: Impulse-responses to expansionary and contractionary technology shocks

A. Expansionary Technology Shocks



B. Contractionary Technology Shocks



Notes: Quarterly responses in percent to a positive one-standard-deviation shock. Confidence intervals are 68% Bayesian bands.

original Galí identification[6]. Figure A-2 in the Appendix further provides additional responses of the relative price of investment and consumption to the two technology shocks. The relative price of investment does not react significantly to either of the two shocks indicating that these shocks should not be interpreted as investment-specific technology shocks as in Fisher (2006). Consumption increases strongly and significantly after an expansionary shock and does not react to a contractionary technology shock. The Appendix further discusses robustness with respect to the specification such as omitted variables, structural breaks, etc.

Variance decomposition How important are these shocks over the cycle? Table 1 shows the variance decomposition of the variables in the VAR to the two identified shocks. Both shocks explain a large amount of the business cycle fluctuations in productivity and hours. The expansionary shock

[6]See Figure A-1 in the Appendix

is more important for productivity in the short run, the contractionary one in the long run. The contractionary shock explains about 50% of the impact response of hours worked, while both shocks are about equally important for hours in the medium and long-run. As already indicated by the impulse-responses, the expansionary technology shock explains the largest part of investment, consumption and output fluctuations. Still, the contractionary shock explains just above 10% of investment fluctuations. Not shown in the table, neither the expansionary shock nor the contractionart shock are very important for the cyclical fluctuations of the relative price of investment, indicating that this decomposition is not closely related to previously identified investment-specific and neutral technology shocks.

To summarize, what has been identified and interpreted as technology shocks in the existing literature can in our view be described as a mixture of two, orthogonal components with quite distinct business cycle properties. Next, we develop a small-scale RBC model, giving an interpretation of the two different technology shocks.

Table 1: Variance Decomposition for expansionary and contractionary shocks

Variable	Horizon				Horizon			
	1	8	16	32	1	8	16	32
	Expansionary shock				Contractionary shock			
Productivity	65.09	45.28	39.05	35.53	23.64	49.23	57.97	63.02
	(29.2,92.6)	(18.7,77.3)	(14.0,71.9)	(11.2,69.1)	(2.3,53.1)	(19.7,73.9)	(26.2,82.3)	(29.8,87.0)
Hours	10.31	27.13	28.46	29.16	49.64	27.92	25.93	25.24
	(0.8,39.3)	(7.9,60.6)	(8.0,63.4)	(7.9,65.0)	(22.7, 81.9)	(6.9,62.9)	(5.6,61.1)	(4.8,60.9)
Output	62.57	58.97	60.65	61.61	5.07	6.44	6.31	6.17
	(32.6,88.8)	(29.0,86.5)	(29.2,87.6)	(29.3,88.4)	(0.5,21.4)	(1.3,24.3)	(1.1,23.7)	(0.9,23.6)
Investment	16.35	37.06	40.78	41.53	5.23	15.94	13.84	13.20
	(1.5,58.7)	(11.0,68.1)	(12.9,73.0)	(13.0,74.6)	(0.5,20.8)	(2.4, 45.1)	(1.9,43.2)	(1.6,42.7)
Consumption	24.17	62.82	62.84	62.78	6.59	7.35	7.72	7.81
	(2.7,71.6)	(14.8,87.0)	(14.1,87.9)	(13.7,88.1)	(0.6,24.7)	(1.3,22.5)	(1.3,24.0)	(1.1,24.8)
Compensation	17.93	29.95	30.78	30.84	6.23	21.31	23.82	24.67
	(1.6,64.0)	(4.5,73.6)	(4.0,73.4)	(3.7,73.8)	(0.5,25.7)	(3.9,53.7)	(3.6,57.0)	(3.5,58.9)

Notes: The values for the displayed shocks and the (omitted) residual disturbances add up to 100 for each variable at each time horizon. The point estimate is the median, the confidence intervals are 68% Bayesian bands from the posterior distribution. All numbers are percent.

3 Model

3.1 A Model with rationalization

In order to interpret our empirical findings, we use a textbook-type small RBC model, with a modification of the production function. The closed economy is inhabited by a representative household and a representative firm. The household consumes, supplies two types of labor, and accumulates capital, which it rents to the firm. The firm uses a production technology with the input factors capital, labor, and management to produce a final good, which can be used for consumption or investment.

Firms The only innovation of the model lies in the production function. Additional to the standard input factors capital and labor, we assume that management is needed for the organization of input factors. The task of this new input factor is to design operational schedules and to structure business processes, thereby avoiding idle resources, overlapping responsibilities and similar inefficiencies. This production function is related to what Lucas (1978) has referred to as "span-of-control" production. We share the idea that managerial technology is a production input additional to a conventionally modeled production technology, here the usual Cobb-Douglas relationship between capital and labor input.[7] Different from Lucas, and in a quite different framework, we plan to assert the role of management for the business cycle. The production function is given by

$$Y_t = \left(\frac{A_t^M M_t}{K_t^\alpha (A_t L_t)^{1-\alpha}}\right)^{\eta_t} \left[K_t^\alpha (A_t L_t)^{1-\alpha}\right], \qquad 0 < \eta < 1 \tag{1}$$

where L is worker's labor input. The ratio $M_t/K_t^\alpha(A_t L_t)^{1-\alpha}$ determines how many capital-labor units one manger has to supervise. We assume that the management layer M has to grow with the other input factors in order to maintain constant returns to scale, such that coefficients of all input factors sum up to one.[8] Two parameters determine the efficiency of management. On the one hand the multiplicative managerial technology $A_{M,t}$ states how many labor-capital units $K^\alpha L^{1-\alpha}$ a single manager can supervise without reducing efficiency. With a fixed number of managers, increasing capital and labor yields decreasing returns to scale because each manager has to supervise more units. By how much efficiency is reduced, i.e. the degree of the decreasing returns to scale w.r.t. L and K, depends on the intensity of supervision and is measured by η. This parameter hence represents 'span-of-control' technology, that determines the intensity with which supervision can be conducted. A innovation to η therefore allows to focus on supervising a smaller number of employees more efficiently, allowing the firm to reduce factor input without reducing total output (see below in the impulse-response functions). This 'span-of-control' technology can thus also be understood as labor- and capital-saving technology. For a given set of technologies, consisting of standard TFP, managerial technology $A_{M,t}$, and 'span-of-control technology' η, the firm employs the optimal amount of capital, labor, and management. The first-order conditions of the firm are

$$W_t = (1-\alpha)(1-\eta_t)\frac{Y_t}{L_t}, \tag{2}$$

$$W_t^M = \eta_t \frac{Y_t}{M_t}, \tag{3}$$

$$r_t = \alpha(1-\eta_t)\frac{Y_t}{K_t} - \delta, \tag{4}$$

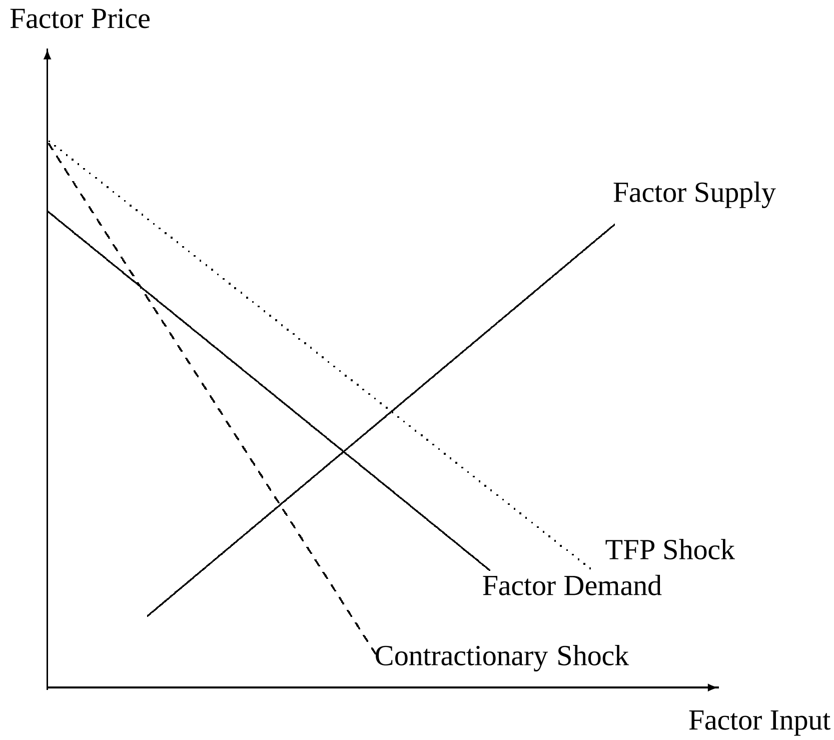
with r_t being the real interest rate, W_t worker's wage, W_t^M the managerial wage, and δ the depreciation rate. The firm takes factor prices as given. Figure 2 visualizes these first-order conditions for worker's labor (or capital) input for a given number of managers. On the axis are log factor input and the log factor price. A standard TFP shock pushes Y_t upwards, thereby increasing factor demand

[7] The concept of managerial skill as production input has also caught large attention in the international economics literature, e.g. Burstein and Monge-Naranjo (2009).

[8] The standard case without managerial input is nested by setting $\eta = 0$. Note that one can also rewrite this production function as a general constant returns to scale production function with capital and two types of labor input $Y_t = M_t^\eta \left(K_t^\alpha (A_t L_t)^{1-\alpha}\right)^{1-\eta}$. We argue that two types of labor input are necessary to explain the estimated responses in the data, in contrast to Ríos-Rull and Santaeulàlia-Llopis (2010) as discussed below. One could also think of different ways to combine the three production inputs, e.g. $Y_t = K_t^\alpha \left(M_t^\eta (A_t L_t)^{1-\eta}\right)^{1-\alpha}$ as in Balleer and van Rens (2009). One can show that in this case, investment does not fall after a shock to η contrary to our estimated responses.

on all levels. A positive shock to 'span-of-control' technology potentially also increases Y_t if good supervision is in place, but rotates the demand curve.[9] If the impact on Y_t is not too large, optimal factor input of worker's labor and capital is actually reduced. Demand for managerial input typically increases. However, given that management's hours are few relative to worker's hours, this effect is dominated by the decrease in worker's labor.

Figure 2: Factor demand before and after a standard and a contractionary technology shock.



Households The representative household maximizes lifetime utility

$$E_t \sum_{\tau=t}^{\infty} \beta^{\tau} \frac{C_t^{1-\sigma}}{1-\sigma} - b_L \frac{L_t^{1+\Psi}}{1+\Psi} - b_M \frac{M_t^{1+\Psi}}{1+\Psi},$$

where C_t is consumption, respectively. In doing so, it has to obey a series of period budget constraints

$$C_t + K_{t+1} = (1 + r_t) K_t + W_t L_t + W_t^M M_t + \Pi_t, \tag{5}$$

with Π_t representing potential profits of the firms, which are owned by the household. The resulting first-order conditions are the familiar Euler equation

$$C_t^{-\sigma} = \beta E_t (1 + r_{t+1}) C_{t+1}^{-\sigma}, \tag{6}$$

[9] Increasing the intensity if bad supervision prevails (too low a value of $M_t / K_t^{\alpha} (A_t L_t)^{1-\alpha}$) can of course decrease performance.

and a labor-leisure trade off

$$C_t^{-\sigma} W_t = b_L L_t^{\Psi}, C_t^{-\sigma} W_t^M = b_M M_t^{\Psi}. \tag{7}$$

Equilibrium In equilibrium, all markets clear. Hence, labor supply (for worker's labor and management), defined in (7), equals labor demand in (2) and the goods market clears

$$Y_t = C_t + K_{t+1} - (1-\delta)K_t. \tag{8}$$

We focus on the effects of a changing η by assuming that the factor-saving technology evolves in logs exogenously according to a simple AR(1) process

$$\eta_{t+1} = \eta_t^{\rho_\eta} \varepsilon_t,$$

with ε_t being a i.i.d. shock with mean one. Also conventional TFP technology in logs follows an AR(1) process

$$A_{t+1} = A_t^{\rho_A} \nu_t.$$

Note that in the model and the empirical estimation we remain agnostic about the occurrence of shocks to conventional TFP A. Moreover, we could also allow for investment-specific technology and other shocks as discussed below. All of these shocks satisfy the identifying assumptions of expansionary technology shocks, but are distinct to the contractionary technology shock, the focus of this paper.

Calibration The baseline parameters used for the simulation of the model are summarized in Table 2. The parameter σ is set to unity to guarantee balanced growth (note that we are simulating extremely long-lasting impulse-responses). The Frisch elasticity of labor supply was estimated between 1/3 and 1/2 by Domeij and Flodén (2006). We use $\Psi = 1/2$. The parameters b_L is chosen such that steady-state hours are one third of total time endowment. The discount factor implies an annual interest rate of four per cent. We set α such that the capital share $(1-\eta)\alpha = 1/3$ in steady state. Using information about hours worked and wages from managers and non-managers from the Current Population Survey, b_M is chosen such that the total hours of managers are 17% of worker's hours, as found in the data.[10] Regarding the steady-state value of managerial technology A^M, there is no clear correspondence in the data.[11] We therefore normalize $\bar{A}^M \bar{M}$ to unity. The steady state value of η is set such the relative wage of managers is 1.5 times the worker's wage, as observed in the CPS data. The autocorrelation of shocks to η is set to 0.999, since we are interested in the long-run effects of a change in η. Steady-state TFP is normalized to unity.

Impulse-Response Functions to Shocks to Factor-saving technology Figure 3 shows the responses of several variables to a unanticipated, one-time shock to η of 3.5 percent, such that the impact response of total hours worked is the same as in our VAR exercise. A higher intensity of supervision lead to enhanced efficiency of capital-labor units already in place. At the same time, managers have less capacities to supervise new employees. Put differently, the efficiency of supervision can be enhanced by reducing factor input and concentrating supervision on a smaller number of employees. Hence, labor and investment fall after such a shock, as they are substituted by re-organizing production. While the real interest rate falls, however, the wage increases. Both reactions correspond to the estimated responses. This due to the pre-determinedness of capital. Its marginal product cannot

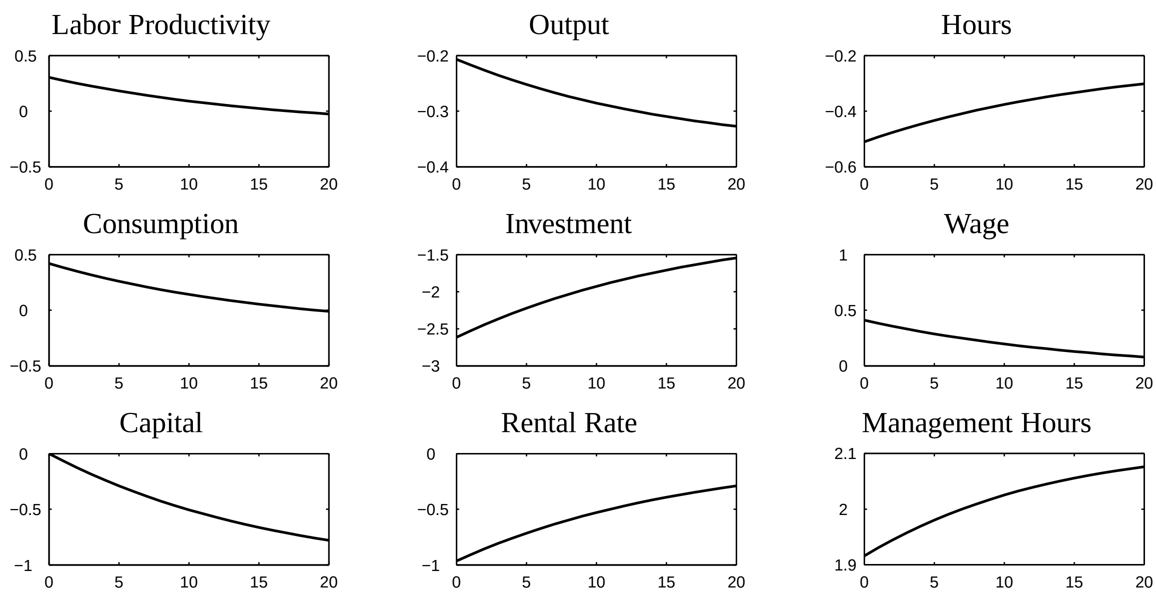
[10] [Data description still missing.]
[11] We seek to further explore the microdata to calibrate this parameter in the future.

Table 2: Baseline calibration of the model

Parameter		Value	Calibration Target	
Coefficient of rel. risk aversion	σ	1	Intertemp. elasticity of subst.	1
Labor supply coefficient	Ψ	1/2	Frisch Elasticity	1/2
Parameter in UF	b_L	5.18	Labor supply in SS	1/3
Discount factor	β	0.99	SS interest rate	4%
Parameter in PF	α	0.38	Capital share	0.33
Parameter in UF	b_M	18.82	M/L	0.17
Span of control technology SS	$\bar{\eta}$	0.136	W^M/W	1.5
Autocorrelation of A	ρ_A	.999	Close to unit root	
Autocorrelation of A^M	ρ_M	.999	Close to unit root	

adjust as quickly as the one of labor. According to equation (4), a fixed capital stock with a hardly changing output reduces the rental rate after an increase in η. On the other hand, labor adjusts quickly, with hours falling. The raises the marginal product of labor, such that we can observe an increase in the wage, see equation (2). Output falls mildly, since more can be produced with an higher intensity of supervision, but input factors fall at the same time.

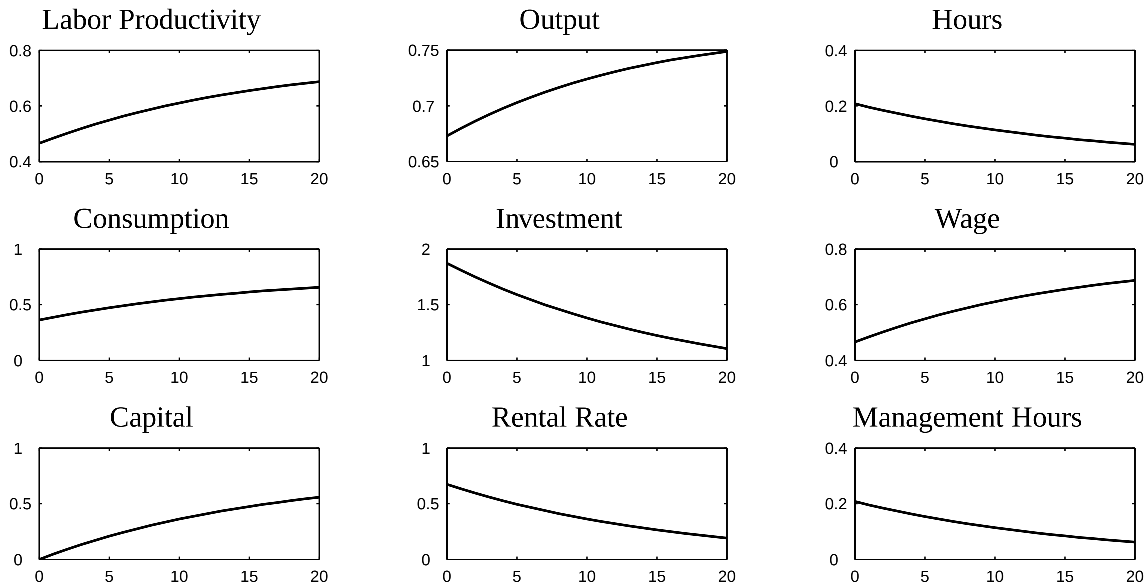
Figure 3: Impulse-responses to a contractionary technology shock



Notes: Horizontal axis denotes quarters, vertical axis shows log deviations from steady state.

Impulse-Response Functions to Shocks to Total-Factor Productivity In order to compare the effects of factor-saving technology shock to standard TFP shocks, Figure 4 plots the responses of the same variables as in Figure 3 after an unanticipated 1% shock to A_t in period 1 ($\nu_1 = 1\%$). We assume an AR(1) process for TFP with an autocorrelation coefficient of 0.999 as well. The resulting impulse-response functions are well-known from frictionless RBC models. The most prominent difference to the contractionary shock is the reaction of hours worked (and the real interest rate). While the contractionary shock reduces employment, a positive TFP innovation triggers a surge. Consumption increases after both shocks due to the increased efficiency. Output clearly rises after TFP shocks, while it does not react very much after contractionary shocks.

Figure 4: Impulse-responses to a TFP shock



Notes: Horizontal axis denotes quarters, vertical axis shows log deviations from steady state.

3.2 Discussion

The above newly introduced contractionary technology shocks increase labor productivity in the long run and lower hours worked in the short run. However, possible shocks which induce the same dynamics are technology shocks under sticky prices, preference shocks, investment-specific technology shocks, labor-share shocks, and shocks to the income tax. Here, long-run labor productivity depends only on $\alpha, \sigma, \Psi, \beta, \delta, b, M, A, \eta$, the price of investment goods, and the income tax (the latter two variables are introduced below). Permanent TFP shocks move A in the long run (which has the same effect as permanently shocking M), contractionary technology shocks affect η, investment-specific technology shocks change the price of investment goods, income-tax shocks affect the income tax rate, while permanent preference shocks can be interpreted as a change in b. All shocks can lower hours worked in the short run, as will be shown below. In the following, we ensure that our estimated shocks can be interpreted as documented in the model, by looking at the predictions of these shocks for other macroeconomic variables and comparing these to the empirical responses to contractionary shocks. We thereby argue that the contractionary technology shocks dominate the dynamics of our empirically identified shocks.

Technology shocks under nominal rigidities Galí (1999) identifies technology shocks via an long-run restriction on labor productivity and shows that hours worked fall in response to the identified shocks. He interprets these results in favor of a New Keynesian model. In order to simulate the effects of technology shocks under nominal rigidities, we introduce monopolistic competition and sticky prices in our model. In doing so, we follow Galí (2008) but keep capital in the model. To close the model, we assume a standard Taylor rule of the type

$$\hat{i}_t = \phi_\pi \pi_t + \phi_y \hat{y}_t,$$

with π denoting inflation and i the nominal interest rate. Hats represent log deviations from steady state. We use the following values for parameterizing the monetary policy rule, $\phi_\pi = 1.5, \phi_y = 2.5/4$, and an autocorrelation for the monetary policy shock of 0.9. We furthermore assume that each period 80% of firms cannot reset their prices. This parameterization is chosen such that hours falls after a conventional TFP shock. If hours increase, there would be no possibility to confuse this shock with the contractionary shock. The reaction of the variables of interest to a positive 1 % shock to TFP is plotted in Figure 5 with red dashed dotted lines. Focusing on the differences to the reactions to a contractionary technology shock, depicted by black solid lines, output increases much more and hours react little. Most importantly, investment and the rental rate rise. This is not the case for our identified contractionary technology shocks, showing that these are distinct shocks.

Preference shocks In order to include preference shocks into the model, discussed for example in Uhlig (2004), we change equation (7) to

$$C_t^{-\sigma} W_t = e^{\upsilon_t} b L_t^{\Psi},$$

such that a preference shock υ_t reduces labor supply. We assume that υ follows an AR(1) process with an autocorrelation coefficient of 0.99, since we are interested in the long-run effects of (almost) permanent shocks. The response of the usual variables to a 1% innovation to υ_1 is shown in Figure 5 by blue dashed line. Comparing again with the responses to a contractionary technology shock, labor productivity turns negative in the long-run (not shown in the graph). This is in contrast to our empirical findings for the contractionary technology shock.

Investment-specific shocks Fisher (2006) finds that also an investment-specific shock triggers a fall in hours. To ensure that we do not confuse this kind of shocks with our contractionary shocks, we introduce the relative price p_t of investment goods into the setup of the above described RBC model via the budget constraint (5) in the following way

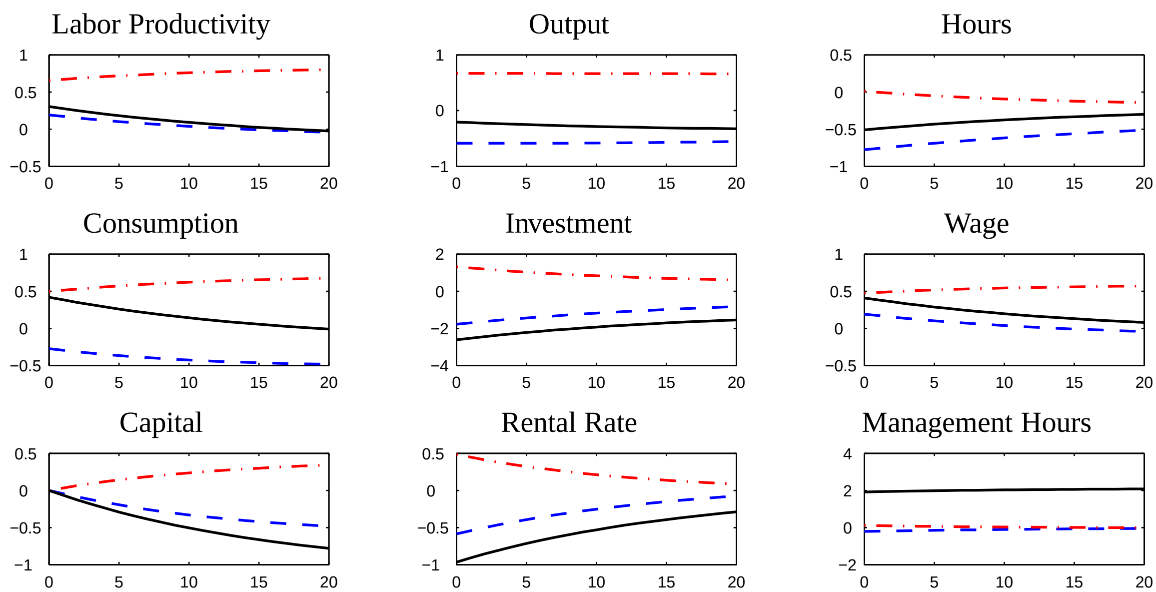
$$C_t + p_t K_{t+1} = (1-\delta) p_t K_t + (1-\tau_t)[r_t K_t + W_t L_t + W_t^M M_t + \Pi_t], \tag{9}$$

where the income-tax τ_t will be discussed below. The capital-Euler equation changes correspondingly, and the goods-market equilibrium (8) becomes

$$Y_t = C_t + p_t K_{t+1} - (1-\delta) p_t K_t.$$

Figure 6 plots the reaction of the economy to a unexpected, highly autocorrelated (coefficient of 0.999) decrease in p_t. The lower relative investment price increases hours, investment, and the real interest rate, in contrast to our empirical finding for the contractionary shock. We therefore argue that investment-specific shocks are different in nature compared to the contractionary shock.

Figure 5: Impulse-responses to different shocks



Notes: Horizontal axis denotes quarters, vertical axis shows log deviations from steady state. Black lines: contractionary technology shock. Red dashed-dotted lines: conventional TFP shock under sticky prices. Blue dashed lines: preference shock.

Labor-share shocks Ríos-Rull and Santaeulàlia-Llopis (2010) propose a different shock: changes in the steady-state labor share. We incorporate this shock in our model by extending the production function (1) as follows

$$Y_t = K_t^{\alpha_t}(A_t L_t)^{1-\alpha_t},$$

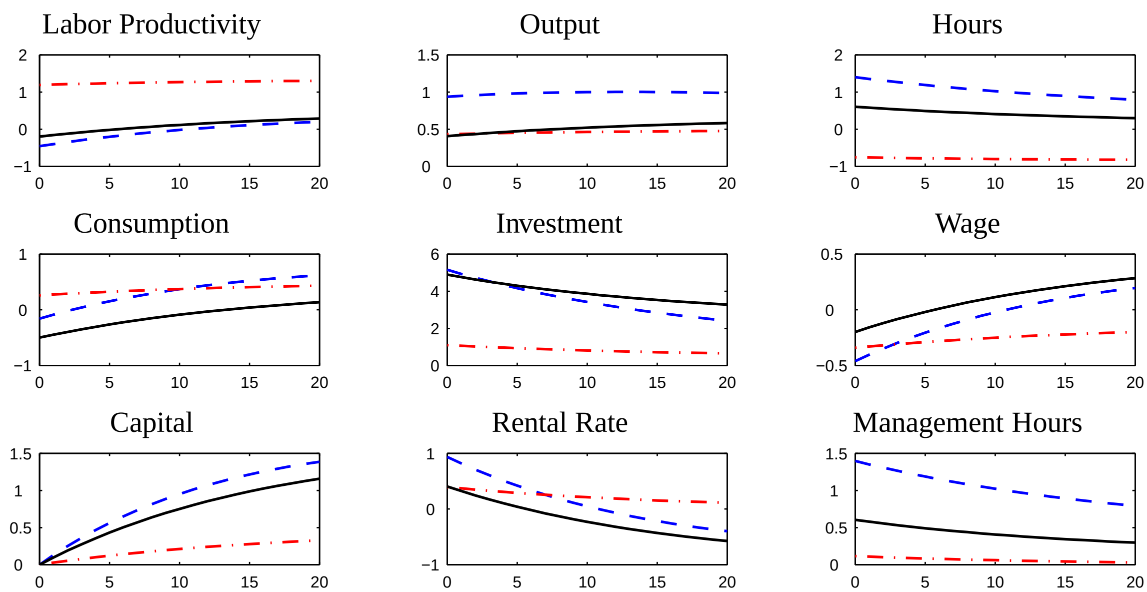
i.e. we allow the labor share α_t to be time varying. Figure 6 plots a highly autocorrelated positive shock to α_t. Because after the contractionary shock, hours worked fall and labor productivity rises. Investment, however, increases because of the higher marginal product of capital. This stands in contrast to the theoretical prediction of contractionary shocks and our corresponding empirical findings.

Income-tax shocks Mertens and Ravn (2010) argue that permanent income-tax shocks can be confused with technology shocks, as they also impact on labor-productivity in the long run. Again, Figure 6 plots the reaction of our model to a highly autocorrelated shock to the income tax τ_t, in the above budget constraint (9). In order to increase labor productivity in the long run, we have to consider a negative income shock. By this, the capital stock increases over time, thereby enhancing labor productivity. A negative income-tax shock, however, leads to an increase in hours worked in the short run, in contrast to our identifying assumption and findings for the contractionary technology shock.

4 Conclusion

[STILL TO BE DONE]

Figure 6: Impulse-responses to different shocks



Notes: Horizontal axis denotes quarters, vertical axis shows log deviations from steady state. Black solid lines: investment-specific shock. Red dashed-dotted lines: labor-share shock. Blue dashed lines: negative income-tax shock.

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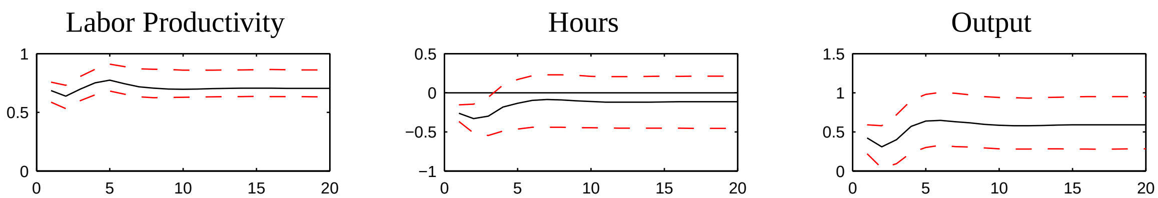
A Robustness and Additional Evidence

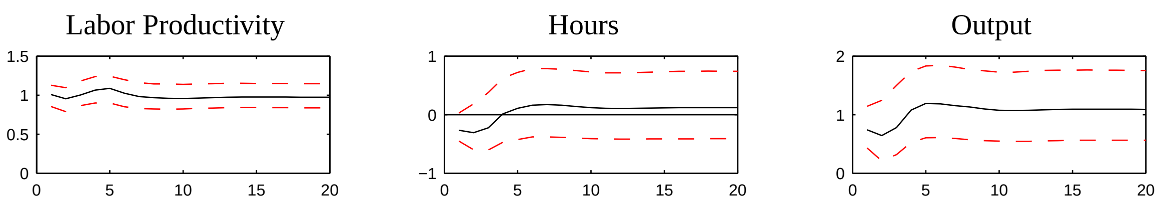
Comparison to Galí identification Figure A-1 compares the responses to a technology shock that is identified with the standard Galí assumption on the long-run effect of labor productivity only with the sum of conventional and contractionary technology shocks. The graph depicts the fall in hours worked after a Galí-type shock that has triggered a lively debate in the macroeconomic literature. Galí-type shocks have important effects on output and consumption and have hence been interpreted to matter a lot for macroeconomic fluctuations over the business cycle. While the sum of our two shocks delivers a higher response of all three variables to the two technology shocks, it still serves as a good approximation of the original Galí shocks.

Figure A-1: Comparing responses from Galí and sign identification

A. Galí Technology Shocks



B. Sum of Conventional and Contractionary Technology Shocks



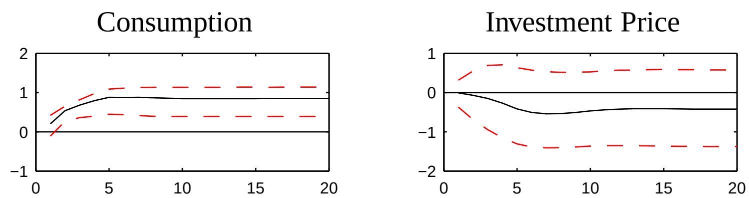
Notes: Quarterly responses in percent to a positive one-standard-deviation shock.
Confidence intervals are 68% Bayesian bands.

Robustness of the results to the specification We have checked the robustness of the results to various specifications. Addressing the discussion about the hours puzzle, we can show that our results are robust if we include hours in levels in the specification. We have also checked that our shocks look alike if different third variables are added to the specification. Most of the responses stay significant if we consider 90% instead of 68% error bands; the exception is that the fall in investment after contractionary technology shocks is no longer significant in the long run, but still significant in the medium run. We further added more potentially omitted variables to the VAR such as profits, inflation, the real interest rate and variables assessing reallocation such as worker and job flows. Finally, we can show robustness if we specify a larger VAR with more than three variables. The difficulty in this case is that we need to add more restrictions for a meaningful identification of shocks, we do so by adding more long-run zero restrictions. [ADD A FIGURE TO ILLUSTRATE ROBUSTNESS]

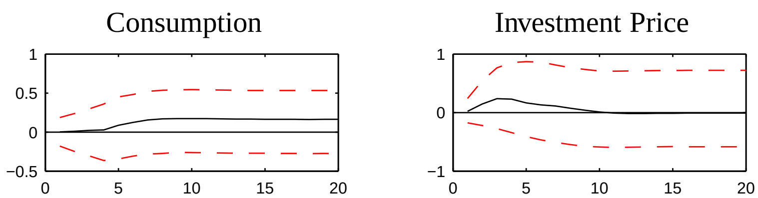
Additional variables Figure A-2 shows additional responses of consumption and the relative price of investment to expansionary and contractionary technology shocks.

Figure A-2: Additional responses to expansionary and contractionary technology shocks

A. Expansionary Technology Shocks



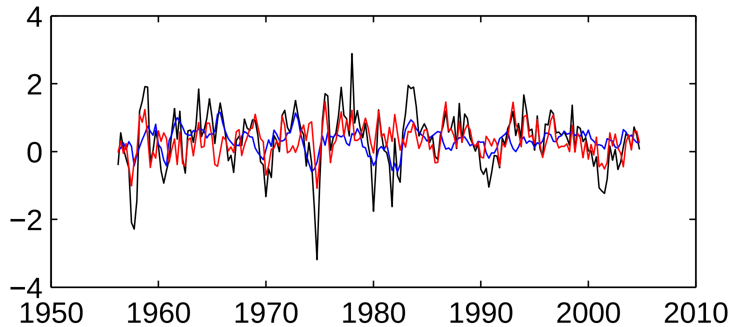
B. Contractionary Technology Shocks



Notes: Quarterly responses in percent to a positive one-standard-deviation shock. Confidence intervals are 68% Bayesian bands.

Historical decomposition Figure A-3 plots hours worked in first differences over time. Here, the black line shows the actual hours series, while the blue line plots hours worked that are driven by expansionary shocks only and the red line plots hours worked that are driven by contractionary shocks only. One can see that different booms and recessions are driven by different shocks. In particular, expansionary shocks become less important for hours worked after 1980, i.e. the Great Moderation.

Figure A-3: Historical decomposition of hours



Notes: Hours worked in first differences: Black line, hours driven by expansionary shock: blue line, hours driven by contractionary shock: red line