

# The Labor Market Effects of Technology Shocks\*

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## Abstract

We analyze the labor market effects of neutral and investment-specific technology shocks along the intensive margin (hours worked) and the extensive margin (unemployment). We characterize the dynamic response of unemployment in terms of the job separation and the job finding rate. Labor market adjustments occur along the extensive margin in response to neutral shocks, along the intensive margin in response to investment specific shocks. The job separation rate accounts for a major portion of the impact response of unemployment. Neutral shocks prompt a contemporaneous increase in unemployment because of a sharp rise in the separation rate. This is prolonged by a persistent fall in the job finding rate. Investment specific shocks rise employment and hours worked. Neutral shocks explain a substantial portion of the volatility of unemployment and output; investment specific shocks mainly explain hours worked volatility. This suggests that neutral progress is consistent with Schumpeterian creative destruction, while investment-specific progress operates as in a neoclassical growth model.

JEL classification: E00, J60, O33.

Key words: Search frictions, technological progress, creative destruction.

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# 1 Introduction

There has been a renewed interest in the literature in examining how the labor market variables respond to technology shocks. However, except for Michelacci and Lopez-Salido (2005), the analysis has focused on the dynamics of total or per-capita hours worked—see, among others, Galí (1999), Francis and Ramey (2003), Fisher (2003), Uhlig (2004), Dedola and Neri (2004), Fernald (2004), Christiano et al. (2003, 2005), and Altig et al. (2005). This focus is partly motivated by the fact that the basic neoclassical growth model, where a representative household offers his labor services in a competitive labor market, is used as organizing principle to interpret results. However, such an approach obscures whether fluctuations in labor input reflect adjustment along the intensive margin (number of hours worked per employee) or along the extensive one (number of employed workers). In this paper we analyze labor market dynamics in response to technology shocks along both margins and characterize employment dynamics in terms of the job separation rate (the rate at which workers move from employment to unemployment) and the job finding rate (the rate at which unemployed workers find a job). There are several reasons why analyzing the labour market responses along different margins is important:

1. *The correlation between hours and employment is far from perfect.* During the post WW II period the correlation between the cyclical component of (log) per-capita hours and the unemployment rate in the US is around -0.8. This is similar to the correlation of the cyclical component of output and unemployment, which are usually regarded as two key cyclical variables of independent interest. Furthermore, such a correlation varies over the business cycle.
2. *Employment is more volatile than hours per employee.* It is well known that changes in the number of employed workers (rather than in the number of hours worked per employee) account for a major portion of the fluctuations in per-capita hours at business cycle frequencies—see Cooley (1995), Hansen (1985) and Rogerson (1988).
3. *Unemployment responses could shed light on the sources of cyclical fluctuations.* The empirical response of hours to technology shocks is often used to assess the

relative plausibility of sticky-price models. In such models, demand is sluggish to respond because prices cannot adjust. So, when technology improves, firms decide to use more advanced technologies that economize on the amount of labor input used. But, is this mechanism more likely to apply to the extensive or to the intensive margin? In principle, the costs of changing prices are small (see e.g. Mankiw (1985) and Ball and Romer (1999)) while the costs of adjusting the firm's work force, which include the direct cost of firing workers and the value of the investment in training and recruiting and in job specific human capital that is lost when a firm fires some of its workers, could be large (see Hamermesh (1993) for a review of the literature). Thus, it is reasonable to think that the mechanism emphasized by sticky price models applies to the intensive rather than to the extensive margin of labor market adjustment.

4. *Technological advancements may cause unemployment waves due to creative destruction.* This is the Schumpeterian view that the adoption of new technologies may require the destruction of obsolete productive units. Microeconomic evidence on productivity dynamics supports the view that creative destruction greatly contributes to aggregate productivity growth (see Foster et al. (2001)). Although this is a prominent paradigm in the growth literature, it has generally been overlooked as a possible explanation for the response of labor market variables to technology shocks - a notable exception is Michelacci and Lopez-Salido (2005).
5. *Worker flows explain employment movements.* The conventional wisdom has generally been that recessions—periods of sharply rising unemployment—are the result of higher job-loss rates. In this view, a recession begins with a wave of layoffs and it is prolonged over time because unemployed workers have hard time to find a new job. Shimer (2005) and Hall (2005) have recently argued instead that unemployment rises entirely because jobs become harder to find. Some recessions, in fact, involve no increases in the flow of workers out of jobs. But are all the recessions alike? Can we safely neglect the role of the separation rate in characterizing the labor market response to shocks? Which view better

characterizes recessions triggered by technology shocks?

Our analysis focuses on the response of unemployment, hours worked, the job separation rate and the job finding rate to investment-neutral and investment-specific technology shocks. To identify these two shocks, we rely on the properties of Solow (1960) growth model, which imply that investment-specific technological progress is the unique driving force for the secular trend in the relative price of investment goods, while neutral and investment specific technological progress explain long-run movement in labor productivity.

As first pointed by Blanchard and Quah (1989) and more recently by Fernald (2004), low frequency co-movements in the variables of the VAR could give a misleading representation of the effects of shocks. This is a relevant concern in our case since the growth rate of both labor productivity and the relative price of investment goods exhibit significant long run swings in the sample. These patterns have been greatly emphasized in the literature on growth and wage inequality. Violante (2002) and Greenwood and Yorokoglu (1997), among others, present the beginning of 1974 as a watershed for the evolution of technological progress, which caused a fundamental change in unemployment and wage inequality. The productivity revival of the late 90's has also been heralded as the beginning of a new era in productivity growth and it has been a matter of extensive independent research, see Gordon (2000), Jorgenson and Stiroh (2000). Once we efficiently take care of the low frequency movements in the variables of the system we find that:

1. Labor market adjustments mainly occurs along the extensive margin in response to neutral technology shocks and along the intensive margin in response to investment specific technology shocks.
2. The separation rate accounts for a major portion of the response of the unemployment rate to neutral shocks in the first quarters after the shocks. Three quarters after, however, unemployment is mainly explained by fluctuations in the job finding rate. Thus the economy response to a neutral technology shocks is in line with the conventional wisdom: unemployment initially rises because of

a wave of layoffs and remains high because the job finding rate takes time to recover.

3. Investment specific technology shocks expand aggregate hours worked. This arises mainly because hours worked per employee increases but also because the unemployment rate falls. On impact, unemployment falls because the separation rate falls. Over the adjustment path, the job finding rate remains above normal levels.
4. Neutral technology shocks explain a substantial proportion of the volatility of unemployment and output while investment specific technology shocks mainly account for the volatility of hours worked. Taken together, technology shocks explain a relevant proportion of the cyclical fluctuations of key variables such as output, unemployment, and hours worked—typically, around 30 per cent at time horizons between 2 and 8 years.

We show that these findings are robust to the choice of the lag length of the VAR, to the presence of omitted variables, to the identification scheme used and to other auxiliary statistical assumptions one is forced to make in specifying the VAR. Hence, the dynamics produced by a neutral technological progress are consistent with the Schumpeterian creative destruction idea. Investment-specific technological progress instead operates essentially as predicted in the standard neoclassical growth model.

The rest of the paper is structured as follows. Section 2 briefly reviews the identification of technology shocks. Section 3 describes the data and offers some explanations for why low frequency movements could bias the conclusions one reaches in the full sample. Section 4 provides evidence after low frequency movements are properly accounted for. Section 5 examines the role of potentially omitted variables. Section 6 measures the role of the separation rate in determining unemployment dynamics. Section 7 quantifies the contribution of technology shocks to business cycle fluctuations. Section 8 shows that our results are robust to a number of changes in the auxiliary assumptions, both of statistical and of identification nature. Section 9 concludes

## 2 Identification of technology shocks

We use a version of Solow (1960) growth model to decompose aggregate productivity into the sum of a stationary component and a component driven by neutral and investment-specific technology shocks. Since this decomposition holds in several versions of the model, its robustness justifies our use for identification purposes.

**Solow model** Assume technological progress is exogenous and the rate of saving and capital depreciation are stationary. There are two inputs, capital,  $K$ , and labor,  $N$ , and the production function is:

$$Y = ZK^\alpha N^{1-\alpha}, \quad 0 < \alpha < 1,$$

where  $Y$  is final output and  $Z$  is the investment-neutral technology. Final output can be used for either consumption  $C$ , or investment  $I$ , i.e.  $Y = C + I$ . A constant (stationary) fraction of output  $s$  is invested,  $I = sY$ . Next period capital stock,  $K'$ , is

$$K' = (1 - \delta)K + QI,$$

where  $0 < \delta < 1$  is the depreciation rate which is assumed to be stationary. The variable  $Q$  formalizes the notion of investment-specific technological change. A higher  $Q$  implies a fall in the cost of producing a new unit of capital in terms of output. It may also represent an improvement in the quality of new capital produced with a given amount of resources. If the sector producing new units of capital is competitive, the inverse of its relative price (i.e. relative to output) is an exact measure of  $Q$ .<sup>1</sup>

One can check that this economy evolves around the (stochastic) trend given by

$$X \equiv Z^{\frac{1}{1-\alpha}} Q^{\frac{\alpha}{1-\alpha}}$$

and that the quantities  $\tilde{Y} \equiv Y/(XL)$ , and  $\tilde{K} \equiv K/(XQL)$  converge to  $\tilde{Y}^* = (s/\delta)^{\frac{\alpha}{1-\alpha}}$  and  $\tilde{K}^* = (s/\delta)^{\frac{1}{1-\alpha}}$ , respectively. Furthermore, the model predicts that the logged level of aggregate productivity,  $y_n \equiv \ln Y/L$ , evolves according to

$$y_n = \tilde{y}^* + v + x = \tilde{y}^* + v + \frac{1}{1-\alpha}z + \frac{\alpha}{1-\alpha}q \quad (1)$$

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<sup>1</sup>For simplicity, we do not distinguish between capital equipment and capital structure. Empirically, the price of structures has remained approximately constant while that of equipment is downward trended, so investment-specific technology progress mainly pertains to equipment goods.

where small letters denote the log of the corresponding quantities in capital letters and  $v$  is a stationary term which accounts for transitional dynamics in the convergence to the steady state. Equation (1) decomposes aggregate productivity into the sum of a stationary term plus a trend induced by the evolution of the neutral and the investment-specific technology. Hence, such an equation can be used to identify technology shocks from VAR residuals using long run restrictions. Specifically, we identify a neutral technology shock (a  $z$ -shock) as the disturbance having zero long-run effects on the level of  $q$  and non-negligible long-run effects on labor productivity, while an investment specific technology shock (a  $q$ -shock) affects the long-run level of both labor productivity and  $q$ . Implicit in this formulation is the assumption that no other shock has long-run effects on  $q$  and labor productivity.

**Choice of deflator** There is some controversy on how the price of investment and GDP should be deflated. In this paper we work with a specification where both are deflated by using the output deflator. Fisher (2005) and Michelacci and Lopez-Salido (2005) instead deflate them both by using the CPI index. Christiano et al. (2005) appear to deflate the relative price of investment with the CPI index, and output with the output deflator (although they are not entirely clear about the issue). In a closed economy the consumer price index and the output deflator are the same (with the possible exception due to the wedge introduced by indirect taxes), but in an open economy they are not. In the appendix we show that our approach is consistent with the balanced growth conditions of a well defined *open* economy, while the approach employed by either Fisher (2005) or Christiano et al. (2005) would imply that decomposition (1) no longer hold exactly. Using the GDP deflator is in fact equivalent to use as a numeraire *domestic* consumption—i.e. the consumption goods produced in the US. The Consumer Price Index,  $P_c$ , instead also includes consumption goods produced abroad in its basket, so that

$$P_c = \left( \frac{P_c^H}{a} \right)^a \left( \frac{P_c^F}{1-a} \right)^{1-a}$$

where  $P_c^H$  and  $P_c^F$  is the price of consumption goods produced in the US and abroad, respectively; and  $a$  represents the share of domestic consumption goods. Let  $q_c$  and  $y_c$

denote the inverse of the relative price of investment and labor productivity (both in logs), when deflated with CPI index. In the appendix we show that

$$y^c = cte + \frac{1}{1 - \alpha - \beta} z + \frac{\alpha + \beta}{1 - \alpha - \beta} q^c + \frac{1}{1 - \alpha - \beta} (1 - a) (p_c^H - p_c^F) \quad (2)$$

where  $\alpha$  and  $\beta$  correspond to the output elasticities to domestic and foreign capital, respectively (see the appendix for details on the form of the production function). Equation (2) highlights that, with this choice of numeraire, a permanent change in the logged price of domestic consumption relative to foreign consumption affects the long run level of labour productivity measured in CPI units—i.e. a change in the terms of trade affects  $y^c$  in the long run. This means that  $z$  and  $q^c$  are not the only long run determinants of labour productivity measured in consumption units. When we consider a VAR with the first difference of  $y^c$  and  $q^c$ , as in Fisher (2003), permanent changes in the relative price of consumption goods could be identified as “neutral” technology shocks.

Similarly when we deflate the relative price of investment with the CPI index and output using the GDP deflator, as in Christiano et al (2005), we obtain that

$$y = cte + \frac{1}{1 - \alpha - \beta} z + \frac{\alpha + \beta}{1 - \alpha - \beta} q^c + \frac{\alpha + \beta}{1 - \alpha - \beta} (1 - a) (p_c^H - p_c^F)$$

which also implies, that a permanent change in  $p_c^H - p_c^F$  has long run effects on productivity. This means that  $z$  and  $q^c$  are not the only long run determinants of labour productivity measured by using the output deflator and that, potentially, permanent changes in the relative price of consumption goods will be identified as “neutral” technology shocks in a VAR with  $y$  and  $q^c$ .

In a general equilibrium setup, the price of domestic consumption relative to foreign consumption is determined by the level of the neutral technology of the US economy relative to the rest of the world. Thus, relative changes in the neutral technology of the world economy could potentially be identified as neutral technology shocks when either the price of investment or GDP are deflated by the CPI index.

**Empirical implementation** Let  $X_t$  be a  $n \times 1$  vector of variables and let  $X_{1t}$  and  $X_{2t}$  be the first difference of  $q_t$  and  $y_{nt}$ , respectively. Let  $\Gamma(L)X_t = \eta_t$  denote a VAR



model where  $\Gamma(L)$  is a  $p$ th-order matrix of polynomials in the lag operator  $L$ , with all roots outside the unit circle and  $\eta_t$  is a vector of zero-mean iid innovations with covariance matrix  $\Sigma_\eta$ . The Wold representation is  $X_t = D(L)\eta_t$ , where  $D(L) = \Gamma(L)^{-1}$ . In general,  $\eta_t$  is a combination of several structural shocks  $\epsilon_t$ . We assume a linear relationship between  $\eta_t$  and  $\epsilon_t$  such that  $\Sigma_\eta = S\Sigma_\epsilon S'$  where  $\Sigma_\epsilon$  is diagonal and where, by convention, the first element of  $\epsilon_t$  is taken to be the  $q$ -shock and the second the  $z$ -shock. Our identifying restrictions that the nonstationarities in  $q_t$  and  $y_{nt}$  originate exclusively from technology shocks amounts to the requirement that the first row of  $G = D(1)S$  is a zero vector except in the first position, while the second row is a vector of zeros except in the first and second position. With the assumed orthogonality of structural shocks, these restrictions are sufficient to identify the two technology shocks and to analyze the response of the variables in the VAR to each disturbance. Note also that equation (1) implies that  $G_{12}$ , the long run effect of a  $q$ -shock on labor productivity, is  $\frac{\alpha}{1-\alpha}$ , we will leave this coefficient unrestricted as the exact magnitude of this response depends on the specification of the model, in particular, on the production function used and the exact details of the law of motion of the capital stock.

### 3 Effects of low frequency comovements on the VAR

Our benchmark model includes six variables and  $X = (\Delta q, \Delta y_n, h, u, s, f)'$ , where  $\Delta$  denotes the first difference operator. All variables are in logs:  $q$  is equal to minus the relative price of a quality-adjusted unit of new equipment,  $y_n$  is labor productivity,  $h$  is the number of hours worked per capita and  $u$  is the unemployment rate;  $s$  and  $f$  are the job separation rate and the job finding rate, respectively. We estimate the VAR using 8 lags of each variable and stochastically restrict their decay toward zero. The specification we use allows us to recover the effects of a shock on hours per employees, provided that labor force participation is unaffected by the shocks.

The series for labor productivity, unemployment, and hours worked are obtained from the USECON database commercialized by Estima and are all seasonally adjusted. The data on  $q$  are taken from Cummins and Violante (2002) which extend the Gordon (1990) measure of the quality of new equipment till 2000:4. This restricts the sample period to 1955:1-2000:4. The original series for  $q$  is annual and it is converted into

quarters as in Fisher (2003).<sup>2</sup> As previously discussed, the relative price of investment is measured in output units, for consistency with the Solow model.<sup>3</sup>

The series for the job separation and the job finding rate are from Shimer (2005). They are quarterly averages of monthly rates. Shimer calculates two different series for the job separation and job finding rate. The first two series are available from 1948 up to 2004. Their construction uses easily available data from the Bureau of Labor Statistics for employment, unemployment, and unemployment duration to calculate the *instantaneous* (continuous time) rate at which workers move from employment to unemployment and viceversa. The two rates are calculated under the assumption that workers move between employment to unemployment and viceversa, that is it abstracts from workers' labor force participation decisions. Hence, they are an approximation to the true underlying labor market rates. Starting from 1967:2, Shimer also uses the monthly Current Population Survey public microdata to directly calculate the flow of workers that move in and out of the three possible labor market states (employment, unemployment, and out of the labor force). With this information he calculates the instantaneous rates at which workers move in and out each state. This yields an exact instantaneous rate at which workers move from employment to unemployment and from unemployment to employment.<sup>4</sup> Below we analyze the labor market responses to technology shocks using both measures. We refer to the first series as to the *approximated* rates, to the second as to the *exact* rates.

The first graph in the first row of Figure 1 plots hours worked and the unemployment rate together with the NBER recession dates (corresponding to the grey areas in the figure). Hours worked display a clear U-shaped pattern. Unemployment and hours

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<sup>2</sup>Our series for  $q$  coincides with that used in Galí and Rabanal (2004). We thank Pau Rabanal for making it available to us.

<sup>3</sup>Specifically, real output (LXNFO), the output deflator (LXNFI) and the aggregate number of hours worked (LXNFH) correspond to the non-farm business sector. Nominal consumption is calculated as the sum of the nominal consumption of non-durable (CN) and nominal consumption in services (CS). Real consumption is calculated analogously, the mnemonics for the corresponding real variables are CNH and CSH, respectively. The consumption deflator is simply equal to  $(CN+CS)/(CNH+CSH)$ . The relative price of investment by subtracting to the (log of the ) original Cummings and Violante series the (log of) the output deflator and then adding the log of the consumption deflator  $\ln((CN+CS)/(CNH+CSH))$ . The aggregate number of hours worked per capita is calculated as the ratio of LXNFH to the working age population (P16), i.e.  $h \equiv \ln(LXNFH/P16)$ .

<sup>4</sup>See Shimer (2005) and his webpage <http://home.uchicago.edu/~shimer/data/flows/> for further details.

exhibit a strong negative correlation of around minus 0.8. Whether the two series are stationary or exhibit very persistent low frequency movements, is matter of great controversy in the literature, see for example Fernald (2005) and Francis and Ramey (2003) . The second graph plots hours worked per employee. Clearly the series exhibit some low frequency changes over the sample period, primarily at the beginning of the 1970s.

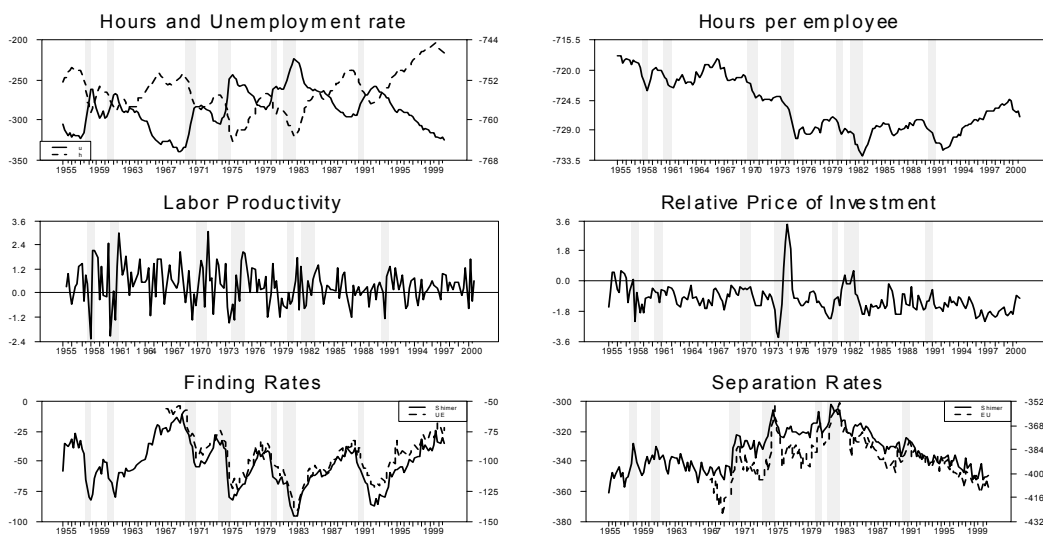


Figure 1: First graph: the dashed line is the aggregate number of hours worked per capita; the continuous line is civilian unemployment both series in logs. Second graph: (logged) hours per employee. Third graph: rate of growth of labor productivity in the non-farm business sector. Fourth graph: growth rate of the relative price of investment goods (multiplied by 100). Fifth and sixth graph: job finding rate and the job separation rate (both in logs), respectively. The solid line corresponds to the approximated rate, the dashed to the exact rate. The areas in grey correspond to the NBER recessions.

The two graphs in the second row of Figure 1 plot the first difference of  $y_n$  and of the relative price of investment (equal to minus  $q$ ), respectively. One can also notice the existence of a dramatic fall in the value of  $q$  in 1975 and its immediate recovery in the following years. Cummins and Violante (2002) attribute this to the introduction of price controls during the Nixon era. Since price controls were transitory, they do not affect the identification of investment specific technology shocks, provided that the

sample period includes both the initial fall in  $q$  and its subsequent recovery. The two panels in the third row of Figure 1 display the job finding rate (first graph) and the job separation rate (second graph). Each graph plots approximated and exact rates. The two series move quite closely, are roughly the same for the job finding rate, while the exact job separation rate has a lower mean in the 1968-1980 period but overall tracks the approximate job separation series reasonably well.

Recessions are typically associated with a persistent fall in the job finding rate. This has motivated Shimer (2005) and Hall (2005) to claim that cyclical fluctuations in the unemployment rate are driven mainly by fluctuations in the job finding rate. The job finding rate is relatively more persistent than the separation rate (AR1 coefficient is 0.86 vs. 0.73) and appears to be reasonably stationary over the full sample.

The low frequency co-movements of the series entering in the VAR are highlighted in figure 2. We follow the growth literature and choose 1973:2 and 1997:1 as a break

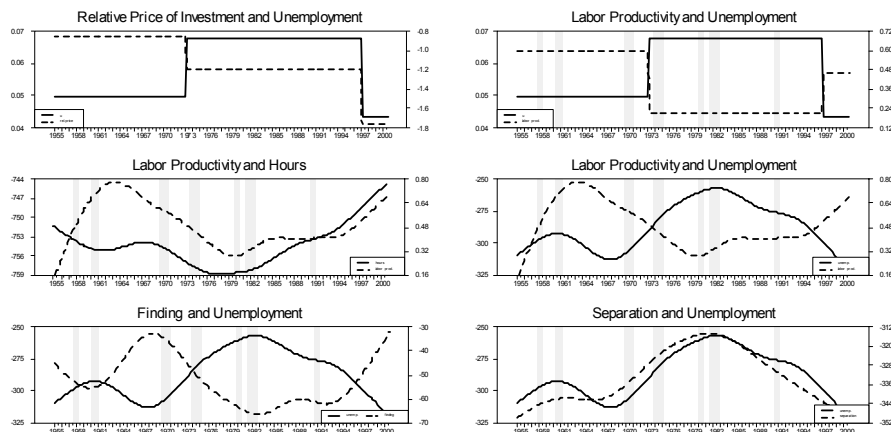


Figure 2: First graph: average quarterly growth rate of the relative price of investment (dotted line) and unemployment rate (solid line). Second graph: average quarterly growth rate of labour productivity (dotted line) and unemployment rate (solid line). Third graph: Hodrick Prescott trend of labor productivity growth (dotted line) and hours per capita (solid line). Fifth graph: Hodrick Prescott trend of labor productivity growth (dotted line) and unemployment rate (solid line). Sixth and seventh graphs: Hodrick Prescott trend of finding and separation rates (dotted lines) and unemployment rate (solid line). The smoothing coefficient  $\lambda = 12800$ .

points, two dates that many consider critical to understand the dynamics of techno-

logical progress and of the US labor market (see Greenwood and Yorokoglu, 1997, Violante, 2002, Hornstein et al. 2004, and Fernald, 2004). The rate of growth of the relative price of investment goods was minus 0.8 per cent per quarter over the period 55:1 to 73:1 and moved to minus 1.2 per cent per quarter in the period 73:2-97:1. This difference is statistically significant. During the productivity revival of the late 90's the price of investment goods was falling at even a faster rate. The rate of growth of labor productivity exhibits an opposite trend. It was higher in the 55:1 to 73:1 period than in the 73:2-97:1 period, and recovered in the late 90's. Also in this case differences are statistically significant. Shifts in technological progress occurred together with changes in the average value of the unemployment rate, see the graphs in the first row of Figure 2.

The graphs in the second row of Figure 2 plot the trend component of labor productivity growth, hours worked and unemployment obtained by using a Hodrick Prescott filter with smoothing coefficient equal to 12800. The trends of the three series are related: there appears to be negative comovement between productivity growth and the unemployment rate and positive comovements between productivity growth and hours. The graphs in the third row of Figure 2 also show that the separation rate exhibits low frequency movements that closely mimic those present in the unemployment rate. The opposite is true for the finding rate. We now show that these low frequency comovements are problematic: if not appropriately taken care they may strongly bias the estimated responses to technology shocks.

### **The effects of low-frequencies comovements on VAR impulse responses**

Figure 3 displays the responses of labor productivity, the relative price of investment goods, unemployment, hours worked, hours worked per employee, the separation rate, and the finding rate to a neutral shock. We plot together the point estimates obtained in three different sample periods: the full sample 1955:I-2000:IV, the 1955:I-1973:I period, and the 1973:II-1997:I period. Yet they look quite different from the responses estimated using the full sample. In the full sample, the relative price of investment and the separation rate fall, while they increase in the two subsamples. Moreover the fall in hours and the job finding rate and the increase in unemployment are much less

## Neutral Shock

55:I-00:IV (continuous), 55:I-73:I (dotted), 73:II-97:I (dash-dotted)

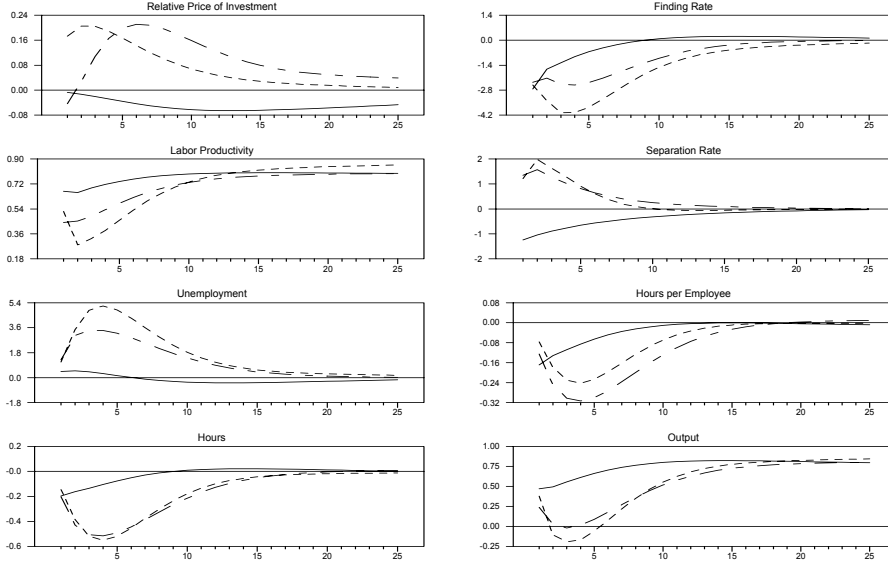


Figure 3: Each line corresponds to a VAR estimated over a different sample period. Each VAR has 8 lags and six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) unemployment rate, and the (logged) aggregate number of hours worked per capita, the log of separation and finding rates.

pronounced in the full sample than in each sub-sample. Finally, both output and labor productivity respond faster in the full sample than in each subsample.

The potential bias present in the estimated responses for the full sample can be related to the low frequency correlations previously discussed. In fact when the full sample is used, a permanent change in the rate of productivity growth is at least partly identified as a neutral technology shock. Thus, over the period 1973:II-1997:I when productivity growth is on average lower, the full sample specification finds a series of negative shocks. Since in this period the unemployment rate and the separation rate are also higher than their average value over the full sample, while hours worked and the finding rate are lower, biases in the estimates of the effects of a positive neutral technology shock emerge implying, for example, a lower response of the unemployment rate and of the separation rate, and a higher response of hours worked and the job

finding rate.

Figure 4 presents responses for the full sample and for the same two subsamples previously discussed to an investment specific shock. In comparing the results across samples, one should bear in mind two important facts: i) the estimated responses in the first subsample are almost never significant (with the exception of the response of the relative price of investment) and ii) investment specific technology shocks contribute little to the volatility of all variables in the first subsample (again leaving aside the price of investment)—for example, at horizons less than eight years they never explain more than five per cent of the volatility of all variables. In the second sub-period the contribution of investment-specific shocks becomes important. Hence, it is probably more appropriate to compare estimates obtained for the full sample and those obtained for the 1973:2-1997:1 sub-period.

Also in this case, low frequency comovements tend to bias the responses. In the full sample output increases very little while it increases substantial in the relevant sub-period, both in the short and in the long run. The two specifications agree in characterizing the response of hours and the job finding rate although both variables increase more in the 1973-1997 sub-sample. The unemployment rate rises on impact in the full sample while it falls in the relevant sub-sample. The separation rate falls in the relevant subperiod while it increases on impact when considering the full sample.

Again, the bias in the estimated responses for the full sample, is in line with the low frequency correlations previously discussed. In fact, in the full sample, a permanent change in the rate of growth of the relative price of investment is at least partly identified as a series of investment specific technology shocks. Thus, over the period 1973:II-1997:I when the price of investment falls at a faster rate on average, the full sample specification tends to identify a series of positive investment specific technology shocks. Since, over the period, the unemployment rate and the separation rate are also higher than their average value over the full sample, while hours worked, the job finding rate, and productivity growth are lower, the full sample specification biases estimates of the effects of a positive investment specific technology shock towards a higher response of the unemployment rate and of the separation rate, and a lower response of hours worked, the job finding rate, and productivity.

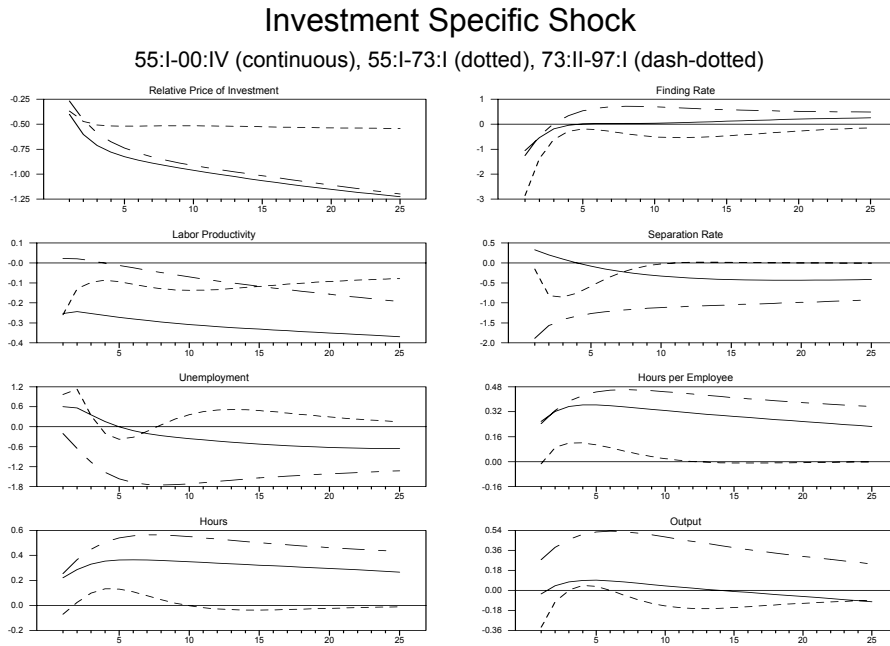


Figure 4: Each line corresponds to a VAR estimated over a different sample period. Each VAR has 8 lags and six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) unemployment rate, and the (logged) aggregate number of hours worked per capita, the log of separation and finding rates.

We have checked that these results are robust to a number of modifications. In particular, they are not affected if the second subsample we use is 1973:II-2000:IV (see figures 18 and 19 in Appendix B) or if we use the population-adjusted hours produced by Francis and Ramey (2004). In fact, as shown in Canova, Lopez-Salido and Michelacci (2006), the adjusted hours series exhibits the same low frequency variations as the one used here. In sum, figures 3 and 4 suggest that there are little sub-sample instabilities and that the difference between the estimates in the full sample and in each sub-sample could be partially due to the low frequency comovements exhibited by the variables of the VAR.



## 4 The full sample results after dealing with trends

To tackle the issue of the low frequency comovements one could estimate the VAR in each sub-sample. Splitting the sample as we have done in section 3 and tracing out the dynamics separately in each of them is however inefficient, since the dynamics of the data are roughly unchanged over the sub-samples. Moreover, imposing as identifying long run restrictions in a system estimated over a small sample is likely to induce serious biases in the structural estimates (see Erceg et al. 2005). As an alternative, we allow the intercept of all the equations in the VAR to vary over time but restrict the slopes to be time invariant. We have considered several modelling options: in the baseline specification we assume that the intercept is deterministically broken at 1973:2 and 1997:1. We refer to this as the dummy specification. We show below that conclusions are robust to alternative low frequency removal approaches.

### 4.1 Evidence using the approximated rates

Figure 5 plots the response of the eight variables of interest to a neutral technology shock for the full sample using the approximate job finding and job separation rates. The reported bands correspond to the 90 percent confidence interval (obtained from 500 bootstraps replications). A neutral shock leads to an increase in unemployment and to a fall in the aggregate number of hours worked. The effects on hours worked per employee are small and generally statistically insignificant. The impact rise in unemployment is the result of a sharp rise in the separation rate and of a significant fall in the job finding rate. In the quarters following the shock the separation rate returns to normal levels while the job finding rate takes up to fifteen quarters to recover. Hence, the dynamics of the job finding rate explains why unemployment responses are persistent. Output takes about 5 quarters to significantly respond. In the first year after the shock output is almost unchanged and then gradually increases until it reaches its new higher long-run value. Interestingly, once low frequency movements are taken into account, the dynamic responses for the full sample look like those of the two subsamples.

Figure 6 plots responses to an investment specific shock. The estimated responses are very similar to those obtained when considering the 1973:2-1997:1 sub-sample. An

### Neutral Shock

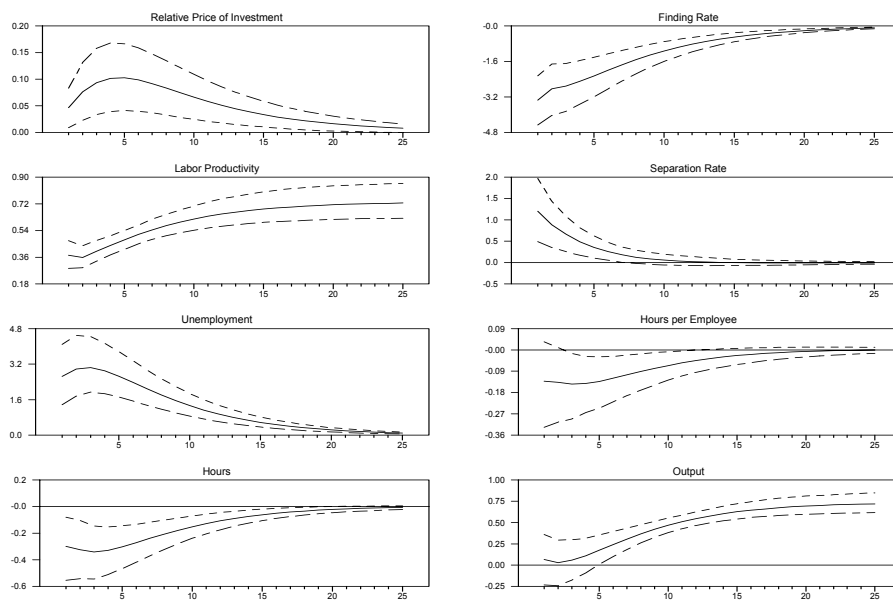


Figure 5: Full sample with intercept deterministically broken at 1973:II and 1997:I. Six variables VAR. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to the median estimate.

investment specific technology shocks makes the price of investment fall permanently,

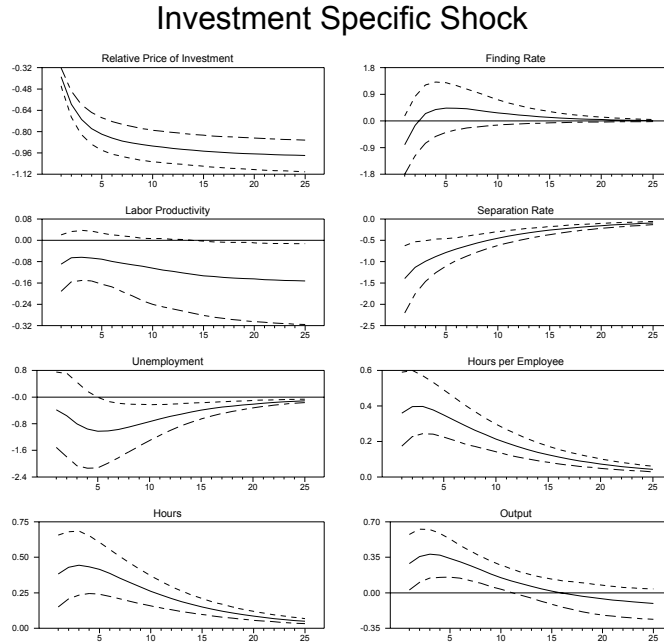


Figure 6: Full sample with intercept deterministically broken at 1973:II and 1997:I. Six variables VAR. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to the median estimate.

leads to a short run increase in output and hours worked per capita and a fall in unemployment. The fall of unemployment on impact is due to a sharp drop in the separation rate. This effect is however partly compensated by a fall in the job finding rate. As a result, the initial fall in unemployment rate is small in absolute terms and statistically insignificant. Hence, most of the increase in the number of hours worked is explained by the sharp and persistent rise in the number of hours worked per employee. Thus labor market adjustment to an investment specific technology shock mainly occur along the intensive margin.

## 4.2 Evidence using the exact rates

We next analyze the effects of technology shocks when considering exact job finding and separation rates calculated using information on worker flows from the CPS. Again, we report results obtained with the dummy specification. Figure 7 presents the responses to a neutral technology shock. We plot the response obtained with the exact

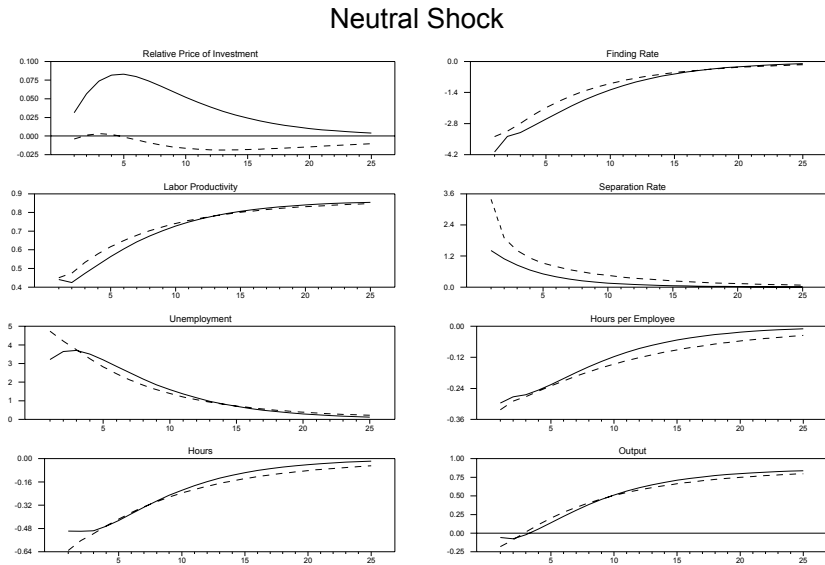


Figure 7: Exact rates (dotted lines) and approximated rates (solid lines). Both VAR includes dummies corresponding to the breaks in technology growth. Each VAR has 8 lags and six variables. Reported are point estimates of the responses.

rate (dotted line) together with the previously discussed responses obtained with the approximated rates (solid line). Both specifications agree on the sign and shape of the responses for all variables. There are however two important quantitative differences. When considering the true rates, the separation rate rises on impact twice as much, while the finding rate falls significantly less, especially on impact. Furthermore, over the adjustment path the separation rate exhibits more persistence when exact rates are used.

Figure 8 reports responses to an investment specific technology shock when exact and approximate rates are used. Also in this case, the two specification generally agree

on the sign and shape of the responses, but there are again two significant quantitative

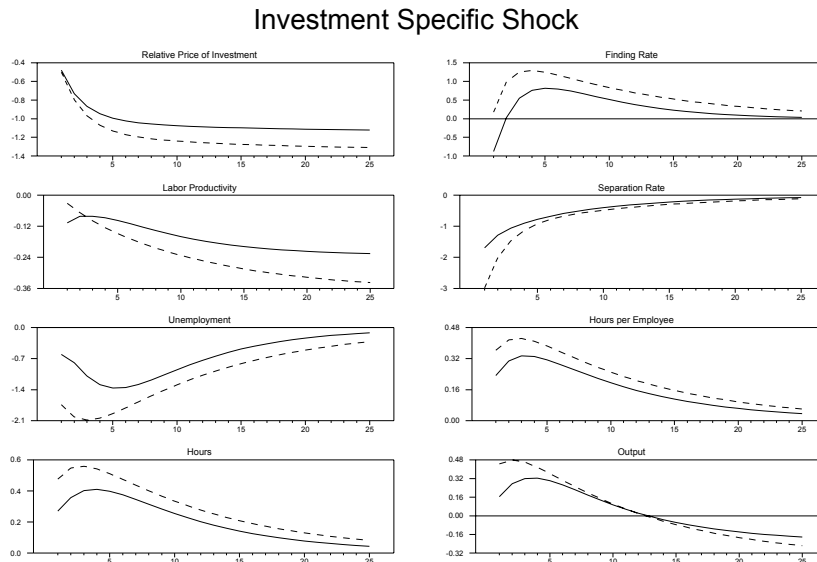


Figure 8: Exact rates (dotted lines) and approximated rates (solid lines). Both VAR includes dummies corresponding to the breaks in technology growth. Each VAR has 8 lags and six variables. Reported are point estimates of the responses.

differences. When the true rates are used, the response of the separation rate is more pronounced and falls on impact twice as much. Instead, the job finding rate is now unaffected on impact and remains above normal levels during all the adjustment path. As a result the fall in the unemployment rate is more pronounced both on impact and during the transition. This implies that the extensive margin plays a more important role in accounting for the rise in hours worked when exact rates are used. Nevertheless, in both cases, the role played by the increase in hours per employee remains predominant.

## 5 Adding variables to the VAR

Our specification has allowed for enough lags, so that the residuals are clearly white noise processes. Yet it is possible that omitted variables play a role in the results. For example, Evans (1992) showed that Solow residuals are correlated with a number of

policy variables, therefore making responses to Solow residuals shocks uninterpretable.

**Consumption, investment and inflation** To check for this possibility we have correlated our two estimated technology shocks with variables which a large class of general equilibrium models suggests as being jointly generated with neutral and investment specific shocks. In particular, we compute correlations up to 6 leads and lags between each of our technology shocks and consumption to output ratio, investment to output ratio, and the inflation rate. The point estimates of these correlations together with an asymptotic 95 percent confidence tunnel around zero are reported in Figure 9. The technology shocks are obtained from the VAR in the dummy specification with the approximated rates (similar results are obtained with the exact rates). There is

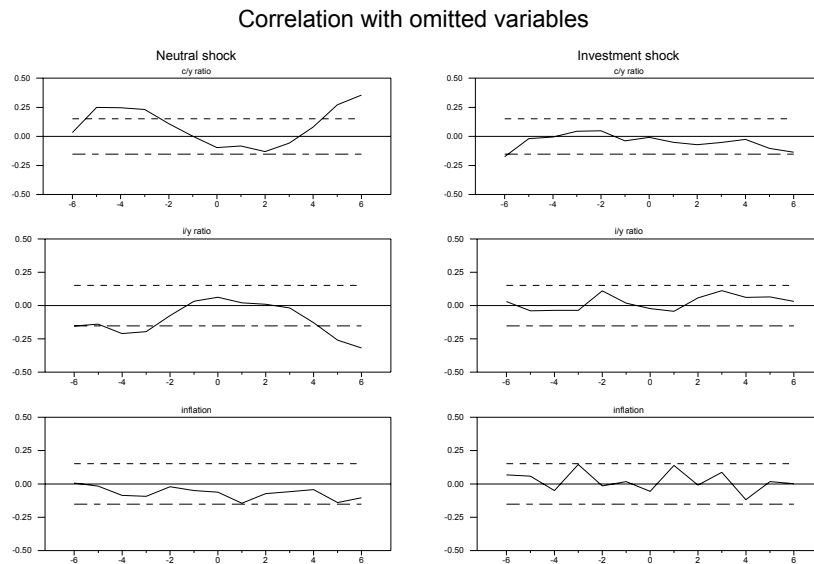


Figure 9: Left column corresponds to neutral technology shocks; right column to investment specific technology shocks. The first row plots the correlation of the corresponding technology shock with the consumption-output ratio, the second with the investment-output ratio, the third with the inflation rate. The shocks are estimated from the six variables VAR with approximated rates in the dummy specification. The horizontal lines correspond to an asymptotic 95 percent confidence interval centered around zero.

some evidence that the consumption output ratio and the investment output ratio help to predict neutral technology shocks, while none of the three potentially omitted

### Neutral Shock

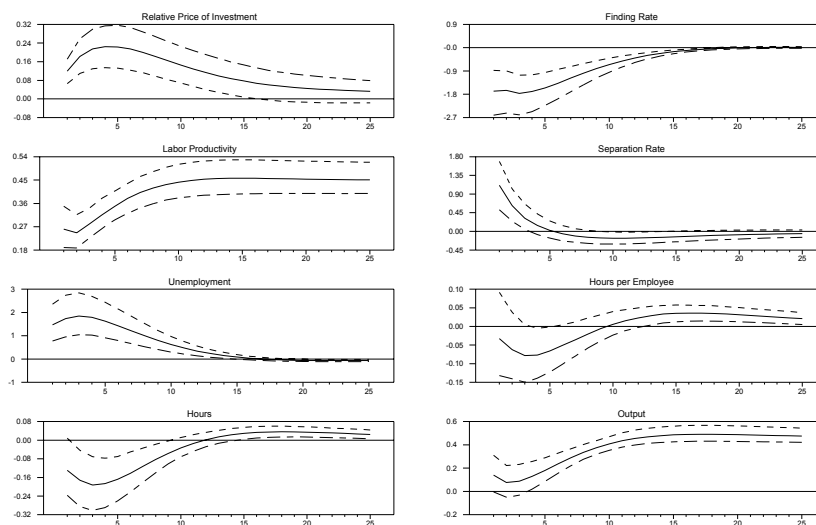


Figure 10: Nine variables VAR. 1955:I-2000:IV sample with intercept deterministically broken at 1973:II and 1997:I. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate.

variables significantly correlate with investment specific shocks. Hence, we investigate what happens when we enlarge the system to include these three new variables. Figures 10 and 11 present the responses of the eight variables of interest when considering a VAR which includes the original size variables plus the consumption to output, the investment to output ratios and the inflation rate in the dummy specification, when approximated rates are used. It is apparent that none of conclusions are affected and this is still the case when exact rates are used.

**Unemployment flows** As previously discussed, starting from 1967:2, Shimer also calculates the flow of workers that move in and out-of-the labor force. With this information he produces an exact instantaneous rate at which workers move from unemployment to out-of-the labor force and from out-of-the labor force to unemployment. This allows us to characterize the response of the participation rate to each technology shock. We consider now a VAR with eleven variables (the previous nine variable plus

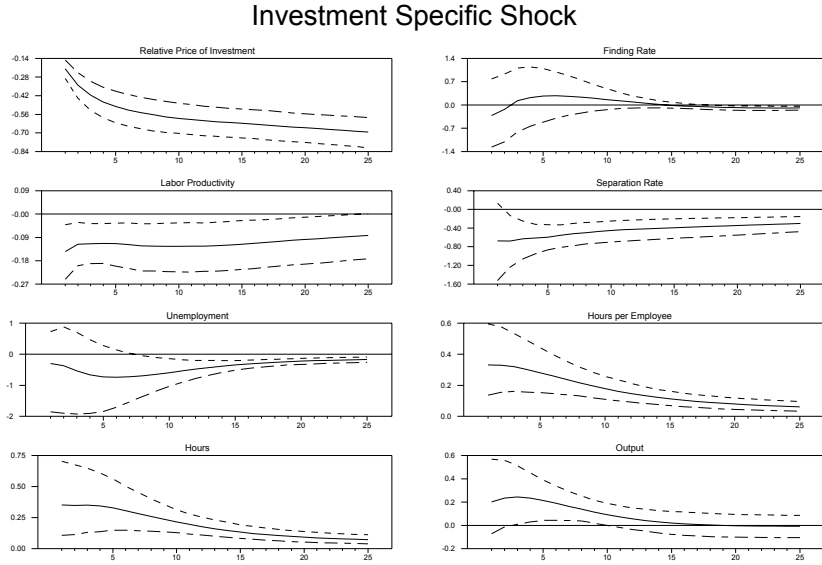


Figure 11: Nine variables VAR. 1955:I-2000:IV sample with intercept deterministically broken at 1973:II and 1997:I. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate.

the two new rates in logs). Figure 12 and 13 report the results for the neutral and the investment specific technology shock, respectively in the dummy specification. In response to a neutral technology shocks, the participation rate falls, mainly because more unemployed workers exit the labor force but the effect is insignificant. Interestingly, and in agreement with the results in Michelacci and López-Salido (2005), after taking into account changes in the participation rate, hours per employee increase in response to a neutral technology shock . In response to an investment specific technology shock, the participation rate increases both because less unemployed workers become inactive and because more inactive individuals participate in the labor market.

## 6 The dynamics of fictional unemployment rates

Shimer (2005) and Hall (2005) have challenged the conventional view that recessions—defined as periods of sharply rising unemployment—are the results of higher job-loss



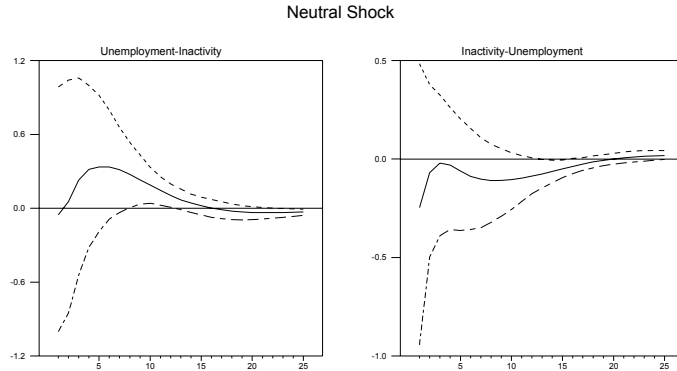


Figure 12: Responses of the rate from unemployment to inactivity and viceversa. Sample period 1967:I-2000:IV, VAR with 11 variables in the dummy specification. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to the median estimate.

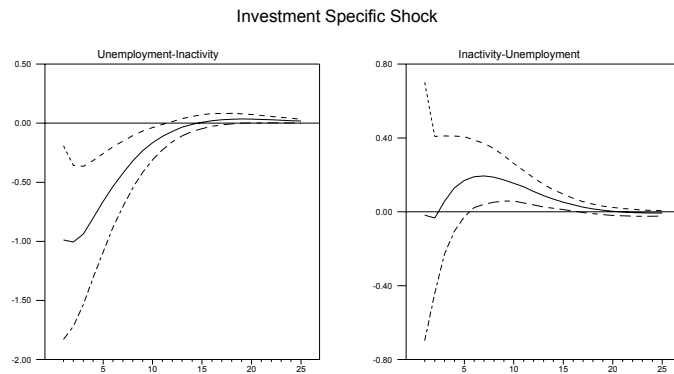


Figure 13: Responses of the rate from unemployment to inactivity and viceversa. Sample period 1967:I-2000:IV, VAR with 11 variables in the dummy specification. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to the median estimate.

rates. They argue that recessions are mainly explained by a fall in the job finding rate. Our impulse responses suggest instead that the separation rate plays a major role in determining the impact effect of technology shocks on unemployment.

To evaluate more formally the role of the separation rate, we use a simple two states model of the labor market (see Layard et al. (1989) and recently Shimer (2005)) and we assume that the stock of unemployment evolves as:

$$\dot{u}_t = S(l_t - u_t) - Fu_t \quad (3)$$

where  $l_t$  and  $u_t$  are the size of the labour force and the stock of unemployment, respectively, while  $S$  and  $F$  are the separation and finding rates, respectively. The unemployment rate tends to converge to the following *fictional* unemployment rate:

$$\tilde{u} = \frac{S}{S + F} \equiv \frac{\exp(s)}{\exp(s) + \exp(f)}$$

Shimer (2005) shows that the fictional unemployment rate  $\tilde{u}$  tracks quite closely the actual unemployment rate series. Hence, one can fully characterize the evolution of the stock of unemployment just by characterizing the dynamics of labour market flows. Second, more generally, the responses of  $\tilde{u}$  and actual unemployment might differ if either other labour market flows (due to workers movements in and out of the labor force) explain unemployment or if transitional dynamics (for given transition rates) are important.

We can linearize the log of  $\tilde{u}$  and calculate its response using the information contained in the response of the separation rate  $s$  and the finding rate  $f$ . With these responses we can do two things: a) measure the contribution of finding and separation rates to the cyclical fluctuations of fictional unemployment  $\tilde{u}$ ; and b) evaluate how accurately fictional unemployment approximates actual unemployment.

Figure 14 reports the results for the specification with approximated rates, Figure 15 deals with the exact rates. In both cases a nine variable VAR is used. In each figure, the response of the true unemployment rate appears with a solid line and the response of (logged)  $\tilde{u}$  appears with a dotted line. The dash-dotted line corresponds instead to the response of (logged)  $\tilde{u}$  that would be obtained if the job finding rate had remained unchanged at its average level in the sample. It therefore represents the

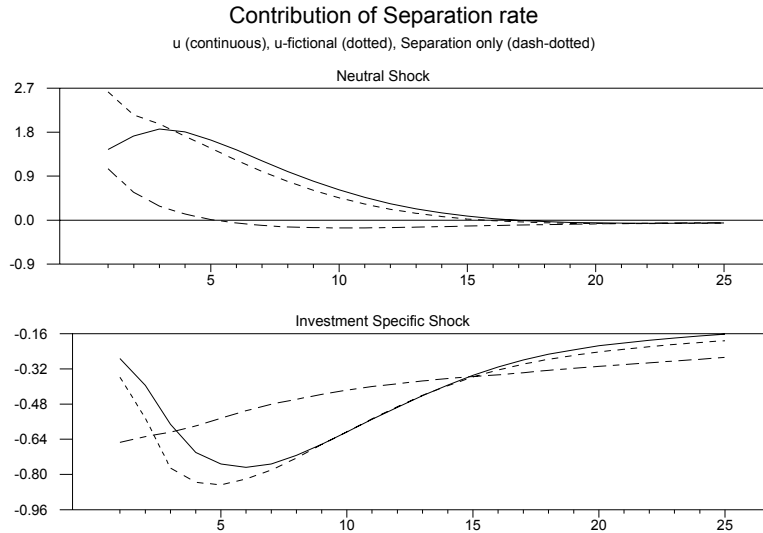


Figure 14: Nine variables VAR with approximated rates. Full sample with deterministic time dummies. Reported are median estimates from 500 bootstrap replications.

contribution of the separation rate to fluctuations in fictional unemployment.

There are few important features of these figures which are worth discussing. First, the dynamics of fictional unemployment after a neutral shock is explained to a large extent by fluctuations in the separation rate, especially in the specification with exact rates. In agreement with previous results, the separation rate almost fully account for the impact effects on fictional unemployment: it explains almost 90 per cent of the impact effect. However, after only one quarter, its contribution falls to 40 per cent and drops to just 20 per cent one year after the shock occurred. Moreover, there are important quantitative differences in the impact response of actual and fictional unemployment. This suggests that workers movements in and out of the labor force play an important role in characterizing the response of the unemployment rate, at least on impact.

Following an investment specific shock and in the specification with approximated rates, unemployment falls little on impact because the fall in the separation rate makes unemployment decrease while the fall in the job finding rate makes unemployment increase. The differences between the response of fictional and actual unemployment

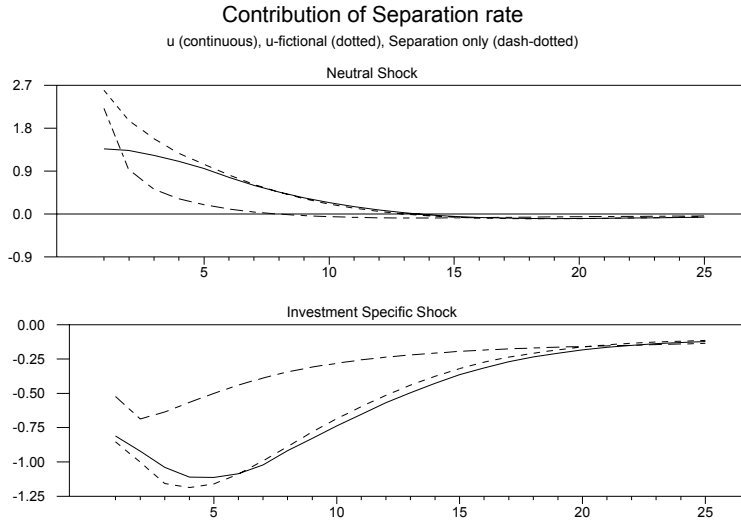


Figure 15: Nine variables VAR with Exact rates. Full sample with deterministic time dummies. Impulse responses correspond to median estimates from 500 bootstrap replications.

are now minimal with exact and approximate specifications. Hence, other labor market flows appear to play a small role in determining the unemployment responses to investment specific shocks. This reinforces the conclusion that in response to these disturbances labor market adjustment mainly occur along the intensive margin.

## 7 The contribution of technology shocks

Next we analyze the contribution of technology shocks to the cyclical variations in the variables of the system. We do so in the nine variables VAR previously used. Table 1 reports results using both the approximated rates and the exact rates.

Neutral technology shocks explain a substantial proportion of the volatility of unemployment and output. In the specification with approximated rates, neutral technology shocks explain between 30 and 50 per cent of output fluctuations at a time horizons between 4 and 8 years and 20 percent of unemployment volatility (see panel A). The contribution of neutral technology shocks to fluctuations in hours worked per employee is however small. Investment specific technology shocks instead account for a substantial proportion of the volatility of hours worked: they explain around 20 per cent of the

Variable	Investment specific				Neutral			
	Horizon (quarters)				Horizon (quarters)			
	1	8	16	32	1	8	16	32
<b>A. Approximated rates, full sample</b>								
Investment Relative Price	42	45	46	46	16	13	12	12
Labor Productivity	3	4	4	4	23	21	21	21
Output	3	5	5	4	1	6	30	55
Hours	14	16	21	22	8	9	8	7
Hours per Worker	17	23	29	29	5	5	4	4
Unemployment	3	3	6	6	23	21	21	21
Finding Rate	0	1	2	2	17	17	17	17
Separation Rate	5	8	12	14	10	8	7	6
<b>B. Approximated rates, 1973:II-2000:IV sample</b>								
Investment Relative Price	38	36	34	35	4	3	4	3
Labor Productivity	0	1	1	1	18	18	18	18
Output	22	11	10	9	1	4	24	43
Hours	37	18	20	21	12	14	12	11
Hours per Worker	44	30	31	32	10	10	9	8
Unemployment	13	2	2	3	12	18	16	14
Finding Rate	4	1	2	2	7	13	12	12
Separation Rate	2	4	8	12	28	28	12	14
<b>C. Exact rates</b>								
Investment Relative Price	35	35	34	34	3	2	3	3
Labor Productivity	1	1	2	2	7	11	11	11
Output	14	8	6	6	8	4	17	37
Hours	24	15	14	14	22	19	18	16
Hours per Worker	35	27	28	28	14	12	11	10
Unemployment	3	1	1	1	34	30	29	27
Finding Rate	0	1	2	3	1	25	24	24
Separation Rate	0	1	1	1	34	34	30	26

Table 1: Forecast Error Variance Decomposition: percentage of variance explained by neutral or investment-specific technology shocks at different time horizons for the selected variables. All VARs have nine variables with intercept deterministically broken at 1973:II and 1997:I. Panel A deals with a VAR with approximated rates, Panel B restrict the analysis to the 1973:II-2000:IV sub-sample, Panel deals C with the exact rates.

volatility of hours per capita and 30 per cent of the volatility of hours per employee. The contribution of investment specific technology shocks to output and unemployment volatility is instead small (generally smaller than 10 per cent). Taken together, technology shocks explain a relevant proportion of the business cycle volatility of key cyclical variables: at horizons between 2 and 8 years they explain around 40 per cent of the volatility of output, and about 30 per cent of the volatility of unemployment and hours. The importance of technology shocks is generally greater when exact rates are used (see panel C). This is however due to the greater importance of technology shocks in the 1973:II-2000:IV sample period. When we estimate the VAR with approximated rates by using data only from the 1973:II-2000:IV sample period, we find that technology shocks explain roughly the amount with approximate and exact rates (see panel B). The only exception is in the contribution of neutral technology shocks to the volatility of the separation rate, which is three times bigger when considering exact rates.

Despite the fact that our technology shocks do not seem to proxy for potentially omitted variables, it is still possible that they stand in for other potential sources of supply disturbances and display a time profiles which do not match a-prior expectations. To examine this possibility, we first plot in

figure 16 the two technology shocks recovered from the nine variables VAR in the dummy specification with the approximated rates, together with the NBER recession episodes (the shaded areas). One can notice that, if one excludes the early seventies, the volatility of the two shock series is comparable. More importantly the figure suggests that, while neutral shocks look like business cycle disturbances, this is not necessarily the case for investment specific shocks. Indeed, the time series properties of neutral shocks match pretty well NBER phases: the series displays deep troughs which typically coincide with the start of NBER recessions. Instead, the patterns of ups and downs in the shock to the relative price of investment only partially coincide with the NBER business cycle chronology. Generally, investment specific technology shocks exhibit pronounced high frequency movements but they fail to display any special pattern in episodes such as the 1990-1991 and the 2000 recessions.

Second, we have correlated our estimated technology shocks obtained from the nine

## Structural Shocks

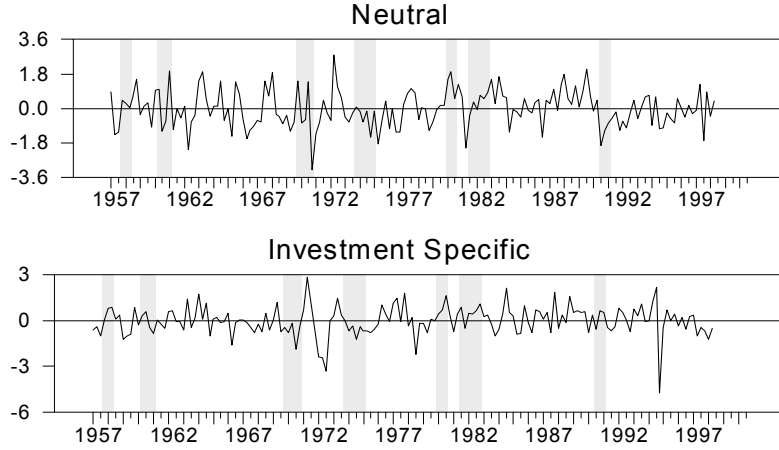


Figure 16: Estimated structural shocks in the nine variables VAR with the 'dummy specification', i.e. the intercept is deterministically broken at 1973:II and 1997:I.

variables VAR with the approximated rates with oil price and the federal fund rate shocks.<sup>5</sup> We report these correlations in Figure 17 together with an asymptotic 90 per cent confidence interval around zero. One can see that shocks to these two variables are not significantly correlated with the structural shocks we extract. Therefore, our technological disturbances are not necessarily standing-in for other sources of technological disturbances or other types of shocks.

## 8 Robustness

This section shows that the results we obtain are robust to a number of modification of the assumptions we have used. In particular, we show that our results do not change when we employ i) alternative ways of removing low frequency trends, ii) different lag length in VAR, iii) different restrictions for identifying technology shocks, iv) alternatives ways to deflate the price of investment goods.

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<sup>5</sup>The mnemonics for the corresponding variables are PZTEXP and FFED, respectively. Technology shocks are correlated with  $\ln(\text{FFED})$  and  $\ln(\text{PZTEXP}) - \ln((\text{CN} + \text{CS}) / (\text{CNH} + \text{CSH}))$ , the last term being the consumption deflator.

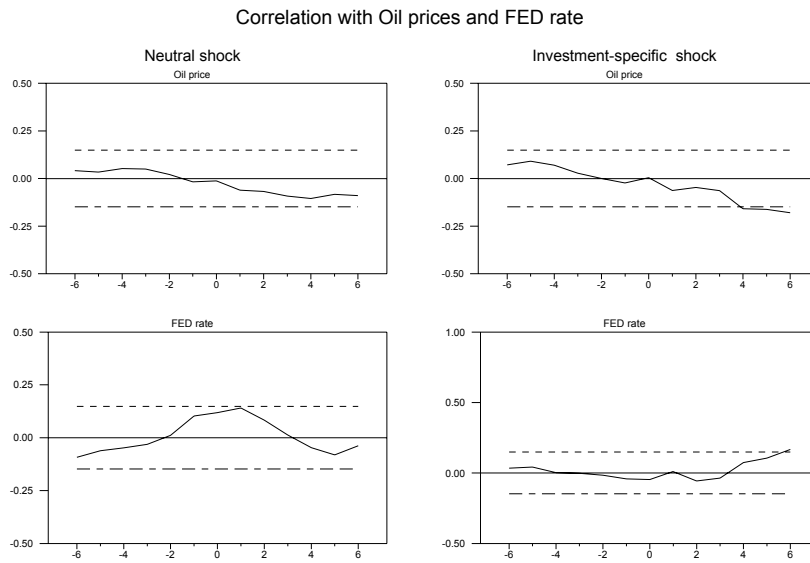


Figure 17: Left column corresponds to neutral technology shocks; right column to investment specific technology shocks. The first row plots the correlation of the corresponding technology shock with relative oil price shocks(i.e. relative to consumption). The second row with Federal fund rate shocks at different time horizons. The shocks are estimated from the nine variables VAR, approximated rates, full sample with deterministic dummies. The horizzontal lines correspond to an asymptotic 95 percent confidence interval centered around zero.



**Alternative treatments of trends** We have considered several alternatives to remove low frequency movements in the variables in the VAR. First, we have allowed the intercept to be up to a fifth order polynomial in time. Second, we detrended all the variables, before entering them in the VAR, with a high-pass filter such as the Hodrick Prescott filter with a smoothing parameter  $\lambda = 12800$ . Figures 20 and 21, in Appendix B, show that when approximate rates are used, responses have the same shape and approximately the same size as those obtained with the dummy specification.

**VAR lag length** The issue of the length of VAR has been recently brought back to the attention of applied researchers by Giordani (2003) and Chari et al. (2005), who show that a subset of the variables generated by a standard models may have a solution which is not always representable with a finite order VAR, and Rubio et. al. (2005), who provide conditions to construct valid VAR approximations. For the debate on the dynamic response to technology shocks, this issue is important because the VAR typically includes only a small subset of the potentially interesting variables and because standard information criteria may not be able to appropriately estimate the lag length of a VAR, when the true DGP is an ARMA with large MA roots (see e.g. the simple model used by Galí 1999). To investigate this issue, we have reestimated our VAR system using alternative lag lengths. The results using approximated rates for the dummy specification are reported in Figures 22 and 23 in Appendix B: responses are practically unchanged when four, eight or twelve lags are used.

**Medium versus long-run identifying restrictions** We have also altered the identification restrictions we have used. Uhlig (2004) has forcefully argued that disturbances other than neutral technology shocks may have long run effects on labor productivity and that, in theory, there is no horizon at which neutral ( and investment specific) shocks fully account for the variability of labor productivity. Therefore, the neutral shocks we have extracted may not be structural. To take care of these potential objections we have imposed the restriction that the two shocks are the sole source of fluctuations in labor productivity and the price of investment at varying horizons. We report in Figures 24 and 25 in Appendix B the impulse responses when the restriction is imposed at a time horizon of 3 years ( $k = 12$ ). Similar results are obtained provided

that the restriction is imposed at a time horizon of at least one year. In each graph, we report the baseline estimates obtained imposing long-run restrictions with those obtained using a medium run restriction. It is clear that the sign and the shape of responses are robust to the horizon at which the restriction is imposed.

**Relative price effects** So far we have worked with a specification where both labor productivity and the relative price of investment are deflated by using the output deflator. Fisher (2005) and Michelacci and Lopez-Salido (2005) instead deflate them both using the CPI index. Christiano et al. (2005) appear to deflate the relative price of investment with the CPI index, and output with the output deflator (although they are not entirely clear about the issue). To investigate if this issue matter for our results we have computed responses for the VAR with approximated rates in the dummy specification when we deflate output and the price of investment by the CPI (see figures 26 and 27 in Appendix B). Responses are generally unaffected by the choice of the numeraire. The most notable exception is the response of the price of investment to a neutral technology shock, which becomes much more pronounced when the price of investment is deflated with the CPI index.

## 9 Conclusions

This paper analyzed the labor market effects of neutral and investment-specific technology shocks on unemployment, hours worked and other labor market variables. We have characterized the dynamic response of unemployment in terms of the job separation and the job finding rate. After efficiently taking care of the low frequency movements in the variables of the system we found that the job separation rate accounts for a major portion of the impact response of unemployment. Neutral shocks prompt a contemporaneous increase in unemployment because of a sharp rise in the separation rate. The increase in unemployment is then prolonged by a persistent fall in the job finding rate. Investment specific shocks rise employment and hours worked. We show that these findings are robust to the choice of the lag length of the VAR, to the presence (or absence) of omitted variables, to the identification scheme used and to other auxiliary statistical assumptions one is forced to made in specifying the VAR. This evidence

suggests that neutral progress is consistent with Schumpeterian creative destruction, while investment-specific progress operates as in a neoclassical growth model.

# Appendix A

## Long-run determinants of labour productivity in an open economy

As discussed in the text, there is some controversy on how the price of investment and GDP should be deflated so as to make equation (1) hold. In this note we investigate on the relative price that determines labour productivity in the long run. The question is relevant just in an open economy since in a closed economy the consumer price index and the output deflator should be the same (except possibly because of the wedge introduced by indirect taxes). We start considering a simple static model. This is just intended to characterize the steady state of an economy with intertemporal maximization. The intuition of the results are probably easier to grasp in this simple set-up. We then consider a intertemporal version of the same model with perfect capital mobility. This is made just to get fully reassured that the results also hold in a more conventional set-up.

**The static model** In the economy there are four goods: two consumption goods and two investment goods. The ‘*H*’ome economy is the only producer of one consumption good and one investment good. The other two goods are produced by the ‘*F*’oreign economy. We start considering as a numeraire the domestic consumption good. This will be equivalent to deflating nominal quantities with the output deflator. In the economy there is a representative consumer who maximize his period by period utility (i.e. his discount factor is zero) given by

$$U = a \ln C^H + (1 - a) \ln \frac{C^F}{P_c^F} \quad (4)$$

where  $C^H$  and  $C^F$  denotes the consumption expenditures in the good produced by the *H* and *F* economy, respectively.  $P_c^F$  is the price (in domestic consumption units) of the consumption good produced abroad. Hereafter we use the convention that the superscript always indicates where the good is produced (‘*H*’ome or ‘*F*’oreign), while the subscript refers to the type of good (‘*c*’onsumption or ‘*i*’nvestment).

The problem is subject to the resource constraint:

$$Y = I^H + C^H + X \quad (5)$$

where  $I^H$ ,  $C^H$ , and  $X$  are investment expenditures in domestic goods, in the consumption of domestic goods, and exports (in either consumption or investment goods). Domestic output is produced according to the constant-return to scale Cobb-Douglas production function:

$$Y = Z (K^H)^\alpha (K^F)^\beta \quad (6)$$

where, without loss of generality, the work force is normalized to one ( $L^{1-\alpha-\beta} = 1$ ). Thus  $Y$  also denotes labour productivity.  $K^H$  and  $K^F$  are the stock of capital of the

Home economy produced at home and abroad, respectively. The law of evolution of capital is

$$K^j = \frac{I^j}{P_i^j}, \quad j = H, F \quad (7)$$

where, for simplicity we assume that capital fully depreciates after use (i.e. capital in the previous period does not influence capital in this period). This simplifies the analysis and it is without loss of generality given that we are interested in the long run properties of the model. Notice that we are assuming that newly purchased capital can be used to produce in this period. This assumption is particularly convenient given the static nature of the model. Finally notice that the production function (6) implies that foreign and domestic capital are separate factors of production. If instead they were perfect substitutes, all capital would be produced just by the economy with the lowest capital price. In this sense the model where the two types of capital are perfect substitutes corresponds to the particular case of our economy when either  $\alpha$  or  $\beta$  are exactly equal to zero (so that just one type of capital is used in production). One can easily check that results remain unchanged when considering this limit case.

To close the model we impose the condition that the trade balance has to be zero. This is consistent with the existence of an intertemporal budget constraint that usually states that the present discounted value of future trade surpluses has to be equal to the current value of foreign debt. Thus the following condition generally holds on average:

$$I^F + C^F = X. \quad (8)$$

This says that the value of imports is equal to exports, i.e. the trade balance is zero.

**Maximization** The problem of the representative household of the  $H$  economy can then be written as follows:

$$\begin{aligned} & \max_{I^F, I^H, X} a \ln C^H + (1-a) \ln C^F - (1-a) \ln P_c^F \\ & s.t. \\ & C^H = Z (K^H)^\alpha (K^F)^\beta - I^H - X \\ & C^F = X - I^F \end{aligned}$$

and where  $K^H$  and  $K^F$  are given by (7). By maximizing with respect to  $I^H$  we obtain

$$\alpha Y = I^H, \quad (9)$$

while by maximizing with respect to  $X$  yields

$$\frac{a}{C^H} = \frac{1-a}{C^F}. \quad (10)$$

Finally, by maximizing with respect to  $I^F$  we obtain:

$$\frac{a}{C^H} \cdot \frac{\beta Y}{K^F P_i^F} = \frac{1-a}{C^F},$$

which after using (10) yields

$$\beta Y = I^F. \quad (11)$$

**Our decomposition** By using (9) and (11) to substitute for  $K^H$  and  $K^F$ , we have that  $Y$  satisfies

$$Y = Z \left( \frac{\alpha Y}{P_i^H} \right)^\alpha \left( \frac{\beta Y}{P_i^F} \right)^\beta .$$

Now we take logs and we denote with small letters the log of the corresponding quantity in capital letters. After solving for  $y$  (which corresponds to the steady state value of the intertemporal model) we obtain:

$$y = cte + \frac{1}{1 - \alpha - \beta} z - \frac{\alpha + \beta}{1 - \alpha - \beta} \left[ \frac{\alpha}{\alpha + \beta} p_i^H + \frac{\beta}{\alpha + \beta} p_i^F \right] \quad (12)$$

where  $cte = \alpha \ln \alpha + \beta \ln \beta$  is a constant. Now notice that the term in square brackets is a weighted average of the relative price of equipment goods produced at home and abroad. The weights are the total value of capital as a share of domestic GDP. This should approximately be the index calculated by Gordon (1990) and extended by Cummins and Violante (2002), once this is deflated by using the GDP deflator rather than the CPI index. To be more formal one can note that the exact index for the price of investment good that would permit perfect aggregation in the model (see next section for more on this) would be

$$P_i = (\alpha + \beta) \left( \frac{P_i^H}{\alpha} \right)^{\frac{\alpha}{\alpha + \beta}} \left( \frac{P_i^F}{\beta} \right)^{\frac{\beta}{\alpha + \beta}} \quad (13)$$

so we can think that the Gordon's index for the investment specific technology in logs is

$$q = cte - \left[ \frac{\alpha}{\alpha + \beta} p_i^H + \frac{\beta}{\alpha + \beta} p_i^F \right]$$

where  $cte$  is an appropriately defined constant. Thus by using the GDP deflator, we obtain that, in the long run, labour productivity is just explained by the evolution of  $q$  and  $z$  and it is equal to

$$y = cte + \frac{1}{1 - \alpha - \beta} z - \frac{\alpha + \beta}{1 - \alpha - \beta} q.$$

This justifies using the long run identifying restrictions imposed in the paper and our choice of the numeraire. The neutral technology shock that we identify is a shock that has permanent effects on  $z$  in the long-run.

**The Fischer decomposition** What would it have happened if we had deflated everything by the CPI index? Now notice that the exact index for the price of consumption good that would permit perfect aggregation in the model is

$$P_c = \left( \frac{P_c^H}{a} \right)^a \left( \frac{P_c^F}{1 - a} \right)^{1 - a} \quad (14)$$

(see next section for more on this). Thus it is reasonable to think of the log of the Consumer Price Index as equal to

$$p_c = cte + ap_c^H + (1 - a)p_c^F$$

where again  $cte$  is an appropriately defined constant. Then we can define labour productivity deflated by the CPI index as equal to

$$y^c \equiv y + p_c^H - p_c = y + (1 - a)(p_c^H - p_c^F).$$

By adding  $(1 - a)(p_c^H - p_c^F)$  to both sides of equation (12) we obtain that

$$\begin{aligned} y^c &= cte + \frac{1}{1 - \alpha - \beta}z - \frac{\alpha + \beta}{1 - \alpha - \beta} \left[ \frac{\alpha}{\alpha + \beta}p_i^H + \frac{\beta}{\alpha + \beta}p_i^F + (1 - a)(p_c^H - p_c^F) \right] \\ &\quad + \frac{1}{1 - \alpha - \beta}(1 - a)(p_c^H - p_c^F). \end{aligned} \quad (15)$$

Now notice that the term in square brackets is the price of investment goods relative to aggregate consumption (i.e. deflated by the CPI index). That is

$$q^c = cte - \left\{ \frac{\alpha}{\alpha + \beta} [p_i^H + (1 - a)(p_c^H - p_c^F)] + \frac{\beta}{\alpha + \beta} [p_i^F + (1 - a)(p_c^H - p_c^F)] \right\}$$

is the original index produced by Gordon (1990) and extended by Cummins. and Violante (2002). Thus when both output and the relative price of investment are deflated by the CPI index we have that

$$y^c = cte + \frac{1}{1 - \alpha - \beta}z + \frac{\alpha + \beta}{1 - \alpha - \beta}q^c + \frac{1}{1 - \alpha - \beta}(1 - a)(p_c^H - p_c^F) \quad (16)$$

It is obvious from the last term in the expression that with this choice of the numeraire a permanent change in the price of domestic consumption relative to foreign consumption affects the long run level of labour productivity measured in CPI units—i.e. a change in  $p_c^H - p_c^F$  affects  $y^c$  in the long run. This means that  $z$  and  $q^c$  are not the only long run determinants of labour productivity measured in consumption units. When we consider a VAR with the first difference of  $y^c$  and  $q^c$ , a neutral technology shock is a shock that has permanent effects on either  $z$  or the relative price of consumption goods. Thus permanent changes in the relative price of consumption goods will be identified as “neutral” technology shocks in a VAR with  $y^c$  and  $q^c$ .

**The Christiano et al. decomposition** Christiano et al (2005) measure the price of investment relative to consumption and output using the GDP deflator. Then, after adding and subtracting  $(1 - a)(p_c^H - p_c^F)$  inside the square brackets of (12), we obtain that

$$y = cte + \frac{1}{1 - \alpha - \beta}z + \frac{\alpha + \beta}{1 - \alpha - \beta}q^c + \frac{\alpha + \beta}{1 - \alpha - \beta}(1 - a)(p_c^H - p_c^F) \quad (17)$$

Again a permanent change in  $p_c^H - p_c^F$  has long run effects on  $y$ . This means that  $z$  and  $q^c$  are not the only long run determinants of labour productivity measured by using the output deflator. When we consider a VAR with the first difference of  $y$  and  $q^c$ , a neutral technology shock is a shock that has permanent effects on either  $z$  or the relative price of consumption goods. Thus permanent changes in the relative price of consumption goods will be identified as “neutral” technology shocks in a VAR with  $y$  and  $q^c$ .

In the light of this result I would say that using the GDP deflator is the appropriate choice.

**What determines the relative price of consumption goods?** Of course the relative price of domestic and foreign consumption goods is endogenous. So it may be moved by the two technology shocks. If these are the only long-run determinants of the relative price, there would be nothing wrong in using a VAR with (the first difference of)  $y^c$  and  $q^c$ , rather than one with  $y$  and  $q$ . We next show that when we endogenize the relative price of consumption goods by imposing market clearing in the international market for consumption goods,  $p_c^H - p_c^F$  is affected by the ratio of the neutral technology of the  $H$  economy to the neutral technology of the  $F$  economy. Thus changes in the neutral technology of the  $F$  economy that are not accompanied by an equal change in the neutral technology of the  $H$  economy are identified as a neutral technology shock when considering a VAR with  $y^c$  and  $q^c$ , while this would not be the case in a VAR with  $y$  and  $q$ . Arguably the interpretation of a neutral technology shock in the two alternative VARs is somewhat different.

To see this, assume that the  $F$  economy is characterized by the same preferences, and the same technology as the  $H$  economy. That is equation (4), (6), and (7) remain valid for the  $F$  economy as well. This means that the representative consumer of the  $F$  economy will maximize

$$U = a \ln C^{*H} + (1 - a) \ln \frac{C^{*F}}{P_c^F} \quad (18)$$

where  $C^{*H}$  and  $C^{*F}$  denotes the consumption expenditures of the representative consumer of the  $F$  economy in the consumption goods produced by the  $H$  economy and the  $F$  economy, respectively.  $P_c^F$  is the price (in domestic consumption units) of the consumption good produced by the  $F$  economy. Notice that we use the convention that the superscript ‘\*’ denotes the analogue for the  $F$  economy of the previously defined quantities for the  $H$  economy. Output of the  $F$  economy is produced according to the constant-return to scale Cobb-Douglas production function:

$$Y = Z^* (K^{*H})^\alpha (K^{*F})^\beta \quad (19)$$

where  $Z^*$  is the neutral technology of the  $F$  economy, while  $K^{*H}$  and  $K^{*F}$  are the stock of capital of the  $F$  economy produced by the  $H$  and  $F$  economy, respectively. Notice that again the work force is normalized to one ( $L^{*1-\alpha-\beta} = 1$ ). Thus  $Y^*$  also denotes



labour productivity. The law of evolution of capital is

$$K^{*j} = \frac{I^{*j}}{P_i^j}, \quad j = H, F \quad (20)$$

The analogous of constraint (5) and (8) for the foreign economy will be

$$P_c^F Y^* = I^{*F} + C^{*F} + X^* \quad (21)$$

$$I^{*H} + C^{*H} = X^*. \quad (22)$$

The first equation says that the value of production of the  $F$  economy is equal to the value of its uses. The second that the trade balance of the  $F$  economy is equal to zero.

**Maximization in the  $F$  economy** The problem of the representative household of the  $F$  economy can then be written as follows:

$$\begin{aligned} & \max_{I^{*F}, I^{*H}, X^*} a \ln C^{*H} + (1-a) \ln C^{*F} - (1-a) \ln P_c^F \\ & s.t. \\ & C^{*H} = P_c^F Z^* (K^{*H})^\alpha (K^{*F})^\beta - I^{*H} - X^* \\ & C^{*F} = X^* - I^{*F} \end{aligned}$$

and where  $K^{*H}$  and  $K^{*F}$  are given by (20). By maximizing with respect to  $I^{*H}$  we obtain

$$\alpha P_c^F Y^* = I^{*H}, \quad (23)$$

while by maximizing with respect to  $X^*$  yields

$$\frac{a}{C^{*H}} = \frac{1-a}{C^{*F}}. \quad (24)$$

Finally, by maximizing with respect to  $I^{*F}$  we obtain that

$$\frac{a}{C^{*H}} \cdot \frac{\beta Y^*}{K^{*F} P_i^F} = \frac{1-a}{C^{*F}},$$

which after using (24) yields

$$\beta P_c^F Y^* = I^{*F}. \quad (25)$$

**Market clearing in the world economy** We now use (22) to substitute for  $X^*$  in (21). Then we use (23), (24), and (25) to substitute for  $I^{*H}$ ,  $C^{*H}$ , and  $I^{*F}$ , respectively. After some algebra we obtain that

$$C^{*F} = (1-a)(1-\alpha-\beta) P_c^F Y^* \quad (26)$$

By proceeding analogously with the constraints (5) and (8) of the  $H$  economy and the associated first order conditions (9), (10), and (11), we also have that

$$C^F = (1 - a)(1 - \alpha - \beta)Y. \quad (27)$$

Market clearing in the market for the goods produced by the  $F$  economy implies that

$$P_c^F Y^* = C^{*F} + I^{*F} + C^F + I^F$$

which says that the total production of the  $F$  economy is equal to the total demand (either for consumption or investment purposes) by the  $F$  and the  $H$  economy. We can then use (26), (25), (27), and (11) to substitute for  $C^{*F}$ ,  $I^{*F}$ ,  $C^F$  and  $I^F$ , respectively. Manipulating the resulting expression yields

$$P_c^F = \frac{[(1 - a)(1 - \alpha - \beta) + \beta]Y}{[1 - \beta - (1 - a)(1 - \alpha - \beta)]Y^*}. \quad (28)$$

After taking logs, using (12) and its analogous for the  $F$  economy to substitute for  $y$  and  $y^*$ , we finally obtain that

$$p_c^F - p_c^H = cte + \frac{1}{1 - \alpha - \beta} (z - z^*) \quad (29)$$

where  $cte$  is an appropriately defined constant (equal to the log of the constant term in 28). In a model where  $L^*$  was not normalized to one also the log difference between  $L$  and  $L^*$  would affect the relative price of consumption goods. Equation (29) shows that the price of consumption goods produced by the  $F$  economy is greater when its demand is also greater. This tends to be the case when the  $H$  economy becomes relatively more technologically advanced and thereby richer.

**The intertemporal model** To get reassured about the previous results, one can consider a fully specified intertemporal model. I do not think that this part is necessary, but maybe it is useful to us. The notation, the specification of technology and preferences are exactly as in the static previously described model. Now however the representative consumer has a discount factor  $\rho \in (0, 1)$ —so strictly greater than zero. We also replace the constraints (5) and (8) with the more traditional resource constraint, that characterize an economy with perfect capital mobility:

$$B' = (1 + r)B + (Y - C^H - C^F - I^H - I^F) \quad (30)$$

where  $B$  and  $B'$  are the net holdings of foreign assets of the representative consumer in the current and future period respectively.  $r$  is the real interest rate available in international financial markets,  $Y$  is domestic GDP and  $I^H$  and  $I^F$  are investment expenditures in domestic goods and foreign goods, respectively. The law of motion of the two types of capital is given by

$$K^j = (1 - \delta)K_{-1}^j + \frac{I^j}{P_i^j}, \quad j = H, F$$

while GDP satisfies (6). Notice that the combination of a standard No-Ponzi condition and a transversality condition imply that the problem is also subject to the standard intertemporal constraint:

$$B_t = \frac{1}{1+r} \sum_{s=0}^{\infty} \left( \frac{1}{1+r} \right)^s NX_{t+s}$$

where  $NX_{t+s} \equiv Y_t - C_t^H - C_t^F - I_t^H - I_t^F$  is the trade balance at time  $t+s$ .

**Perfect Aggregation** One can easily check that the maximization problem implies that both the relative consumption of domestic and foreign goods and the relative value of foreign and domestic capital remain constant over time. More specifically:

$$\frac{C^H}{C^F} = \frac{a}{1-a}$$

and

$$\frac{K^H P_i^H}{K^F P_i^F} = \frac{\alpha}{\beta}$$

that were also two properties of the static model. This allows to simplify the problem of the representative household as follows:

$$\max E \left( \sum \rho^s \ln C_s \right)$$

*s.t.*

$$B' = (1+r)B + (Y - P_c C - P_i I) \quad (31)$$

$$K = (1-\delta)K_{-1} + \frac{I}{P_i} \quad (32)$$

where  $Y$  is given by (6) while “aggregate” consumption, investment, and capital are defined as equal to

$$C = (C^H)^a (C^F)^{1-a},$$

$$I = (I^H)^{\frac{\alpha}{\alpha+\beta}} (I^F)^{\frac{\beta}{\alpha+\beta}},$$

and

$$K = (K^H)^{\frac{\alpha}{\alpha+\beta}} (K^F)^{\frac{\beta}{\alpha+\beta}},$$

respectively. The price of consumption and investment are  $P_c$  and  $P_i$  which are given by (14) and (13), respectively. Notice that our choice of the numeraire imposes that  $P_c^H = 1$  in (14).

One can then consider the Bellman equation associated with this problem. This would read:

$$V(B, K_{-1}) = \max_{B', K} \ln \left\{ (1+r)B + ZK^{\alpha+\beta} - B' - P_i [K - (1-\delta)K_{-1}] \right\} + \beta E [V(B', K)]$$

where we have set  $B'$  and  $K$  as the relevant control variables by using the aggregate resource constraint (31) and the capital accumulation (32) to express  $C$  and  $I$  as a function just of  $B'$ ,  $B$ ,  $K$  and  $K_{-1}$ .

The envelope conditions with respect to  $B$  and  $K_{-1}$  are:

$$\begin{aligned} V_1 &= \frac{1+r}{C} \\ V_2 &= \frac{(1+\delta)P_i}{C}. \end{aligned}$$

The first order conditions with respect to  $B'$  and  $K$ , after using the two previous envelope conditions can be expressed as

$$\begin{aligned} \frac{1}{C} &= \beta E \left( \frac{1+r}{C'} \right) \\ \frac{(\alpha+\beta)Y - P_i K}{C} &= \beta(1-\delta)KE \left( \frac{P'_i}{C'} \right) \end{aligned}$$

where a “'” always indicates the value of the corresponding variable in the next period. One can then use the first above condition to simplify the second and solve for  $K$ . This yields

$$K = \frac{(\alpha+\beta)Y}{P_i \left[ 1 + \frac{(1-\delta)E(1+g'_i)}{1+r} \right]}$$

where  $E(1+g'_i)$  is the expected future growth rate of the relative price of investment. One can then use this expression for  $K$  to substitute into (6). After taking and solving for  $y$ , we finally obtain a representation for  $y$  analogous to (12) which reads:

$$y = cte + \frac{1}{1-\alpha-\beta}z - \frac{\alpha+\beta}{1-\alpha-\beta}p_i + v \quad (33)$$

where  $cte$  is an appropriately defined constant while  $v$  is a stationary error that arises because the conditional expected value of the rate of growth of the price of investment can fluctuate over time (say because  $p_i$  is not a random walk). One can then proceed as in the previous section to derive the analogous of (16) and (17) in the intertemporal version for the static model. This confirms the conclusions reached by using the static model.

**What determines the relative price of consumption goods?** One could proceed as in the static model and endogenize the relative price of consumption goods. Again one would find that the neutral technology of the  $F$  economy relative to the  $H$  economy,  $z^* - z$ , would be a key determinant of the long run value of the relative price of consumption goods,  $p_c^H - p_c^F$ .

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# Appendix B

## Additional empirical results

In this appendix we report some figures that are discussed in the main text. They are reported here just for completeness.

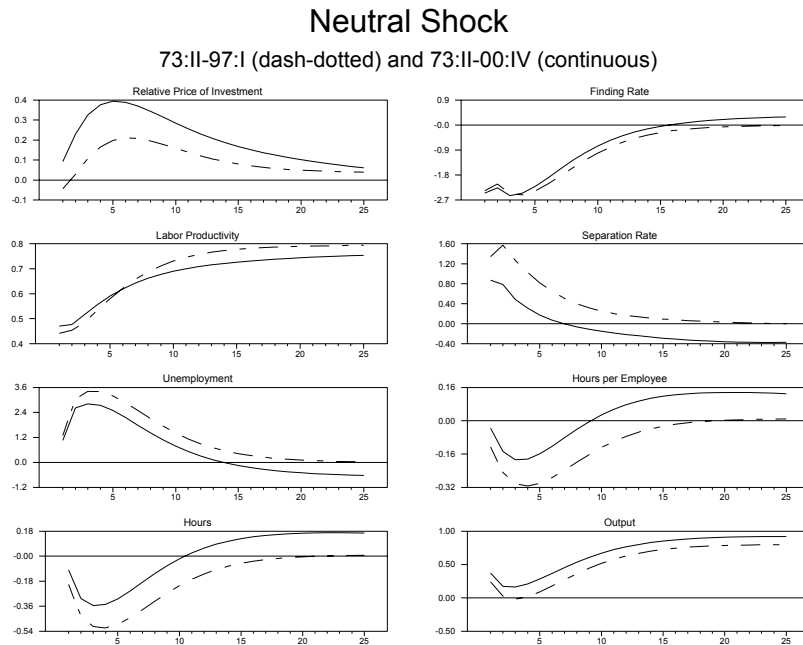


Figure 18: Response to a neutral technology shock in two different sub-periods: 1973:II-1997:I, and 1973:II-2000:IV. The VAR has 8 lags and six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) unemployment rate, and the (logged) aggregate number of hours worked per capita, the log of separation and finding rates. The continuous line corresponds to the 1973:II-2000:IV period, and the dash-dotted line to the 1973:II-1997:II period. Impulse responses correspond to point estimates.

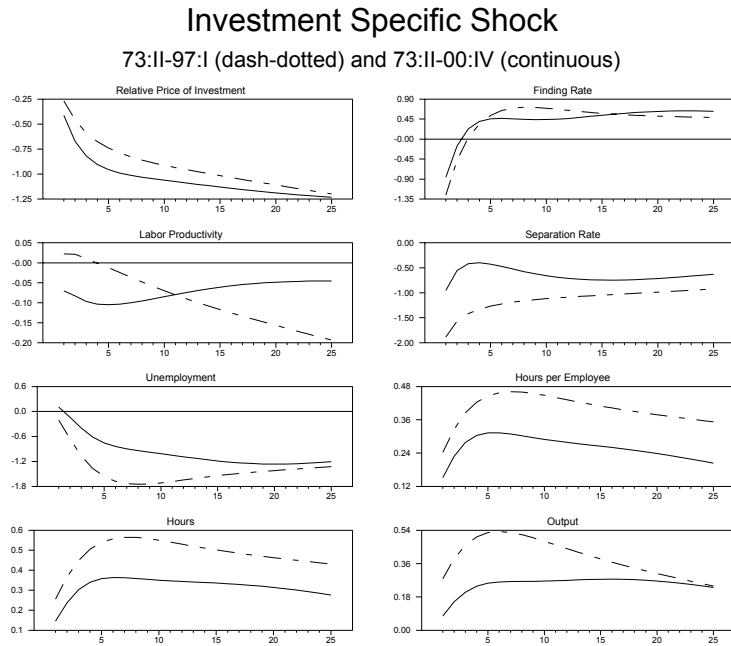


Figure 19: Response to an investment specific in two different sub-periods: 1973:II-1997:I, and 1973:II-2000:IV. The VAR has 8 lags and six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) unemployment rate, and the (logged) aggregate number of hours worked per capita, the log of separation and finding rates. The continuous line corresponds to the 1973:II-2000:IV period, and the dash-dotted line to the 1973:II-1997:II period. Impulse responses correspond to point estimates.

### Neutral Shock

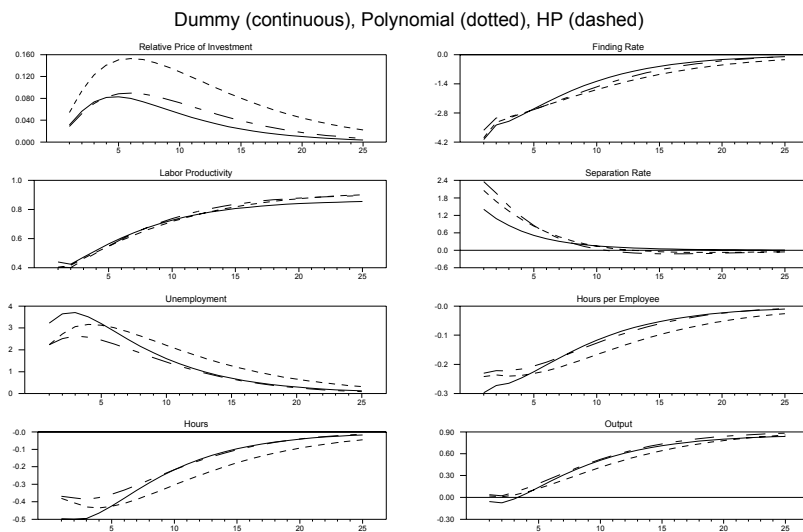


Figure 20: The continuous line corresponds to dummy specification, the dotted line to the case where the intercept is a 3rd order in time. The dashed lines are the responses after detrending the original series with an Hodrick Prescott filter with smoothing parameter  $\lambda=10000$ . VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

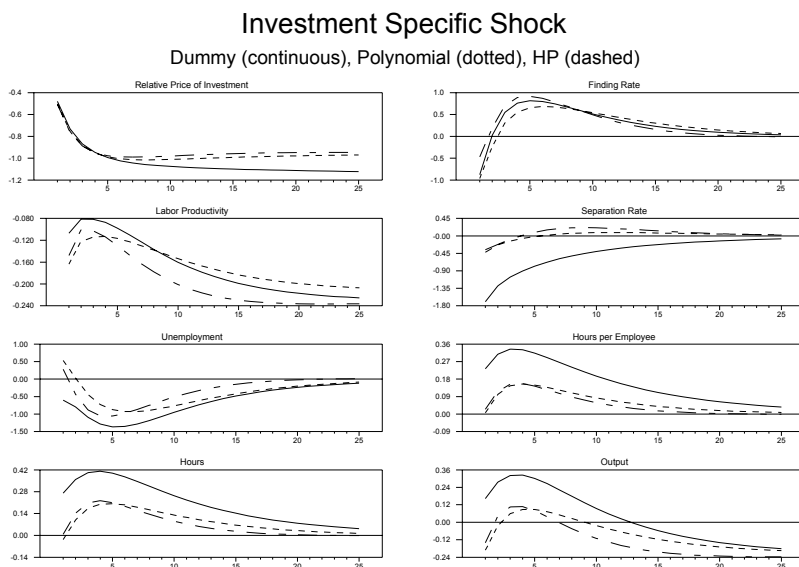


Figure 21: The continuous line corresponds to dummy specification, the dotted line to the case where the intercept is a 3rd order in time. The dashed lines are the responses after detrending the original series with an Hodrick Prescott filter with smoothing parameter  $\lambda=10000$ . VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

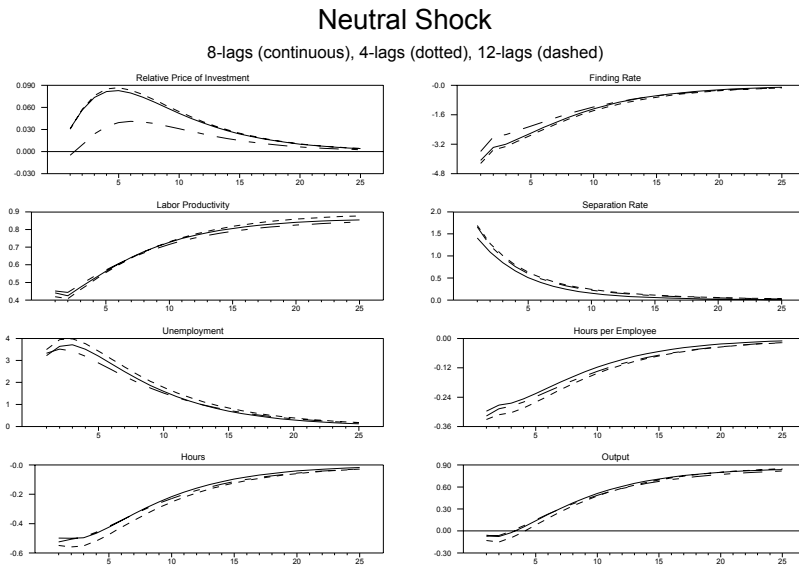


Figure 22: Dummy specification with different lags in the VAR: continuous line corresponds to 8 lags, dotted line to 4 lags, dashed line to 12 lags. VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

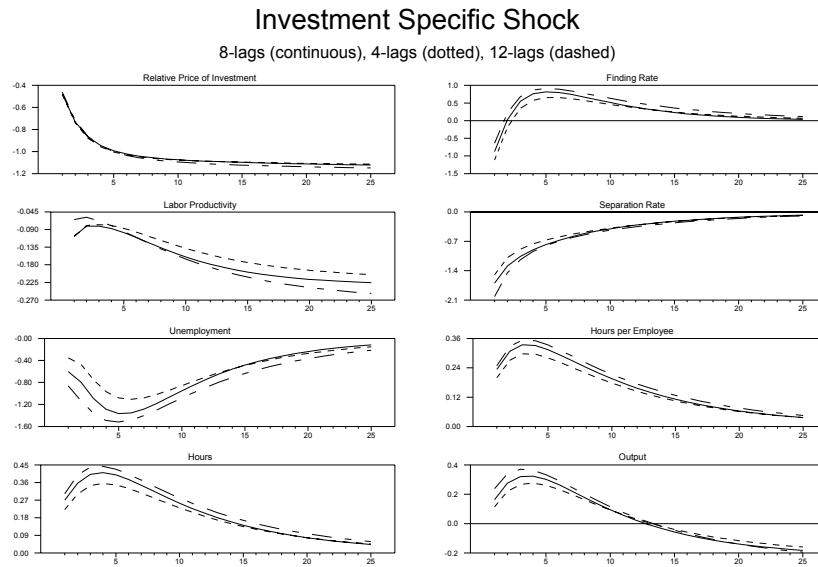


Figure 23: Dummy specification with different lags in the VAR: continuous line corresponds to 8 lags, dotted line to 4 lags, dashed line to 12 lags. VAR with approximated rates, with 8 lags, and six variables. Plotted responses correspond to the median estimates based on 500 bootstraps replications.

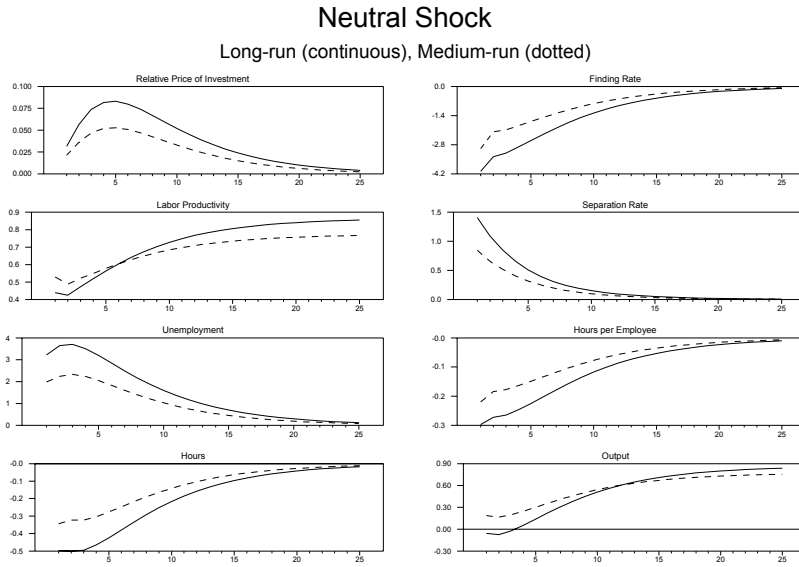


Figure 24: Dummy specification with identifying restrictions imposed at different time horizons: continuous line corresponds to long run restriction, dotted line corresponds to the specification where restrictions are imposed at an horizon of 3 years. VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

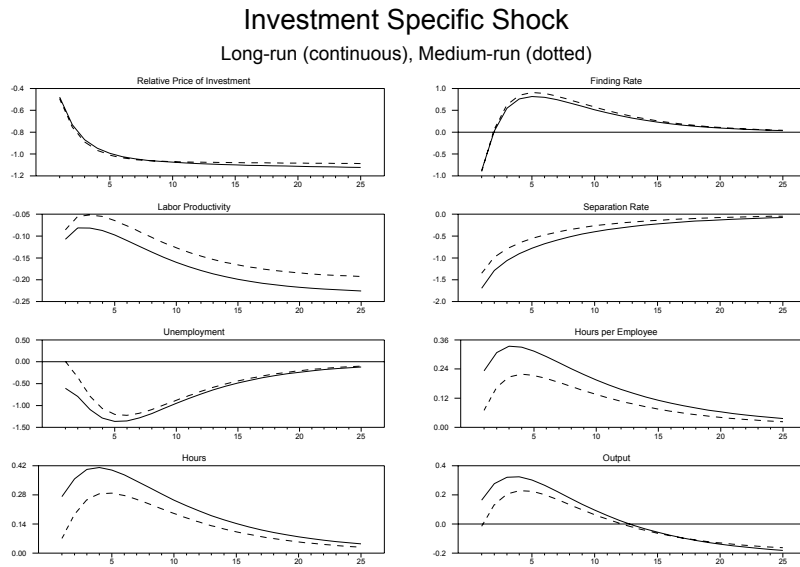


Figure 25: Dummy specification with identifying restrictions imposed at different time horizons: continuous line corresponds to long run restriction, dotted line corresponds to the specification where restrictions are imposed at an horizon of 3 years. VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.



## Neutral Shock

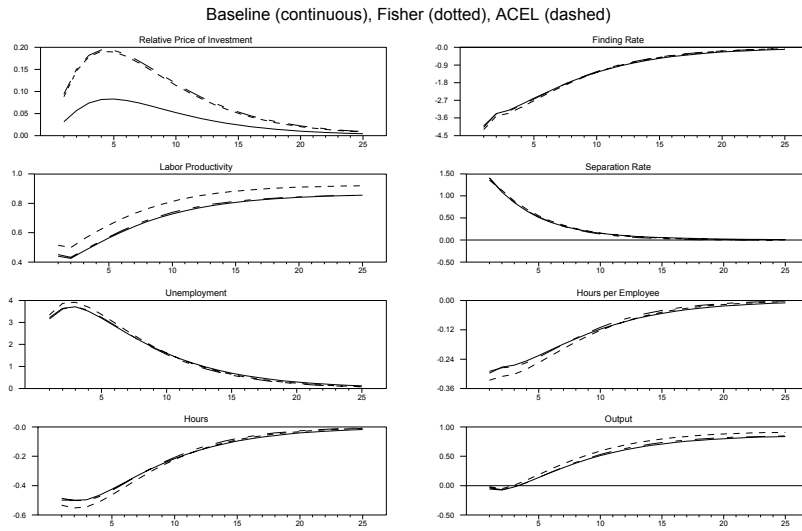


Figure 26: Results from VAR in the dummy specification when the variables in VAR are deflated with a different price index: continuous line corresponds to baseline specification, dotted line corresponds to the VAR where output and price of investment are deflated by using the CPI index, the dashed line corresponds to the case where output is deflated with the output deflator and the price of investment with the CPI index. VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

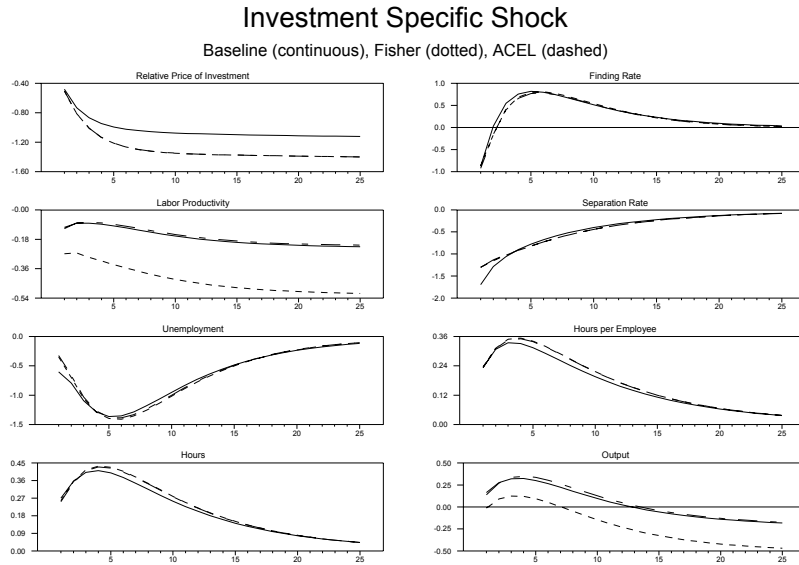


Figure 27: Results from VAR in the dummy specification when the variables in VAR are deflated with a different price index: continuous line corresponds to baseline specification, dotted line corresponds to the VAR where output and price of investment are deflated by using the CPI index, the dashed line corresponds to the case where output is deflated with the output deflator and the price of investment with the CPI index. VAR with approximated rates, with 8 lags, and six variables. Plotted impulse responses correspond to point estimates.

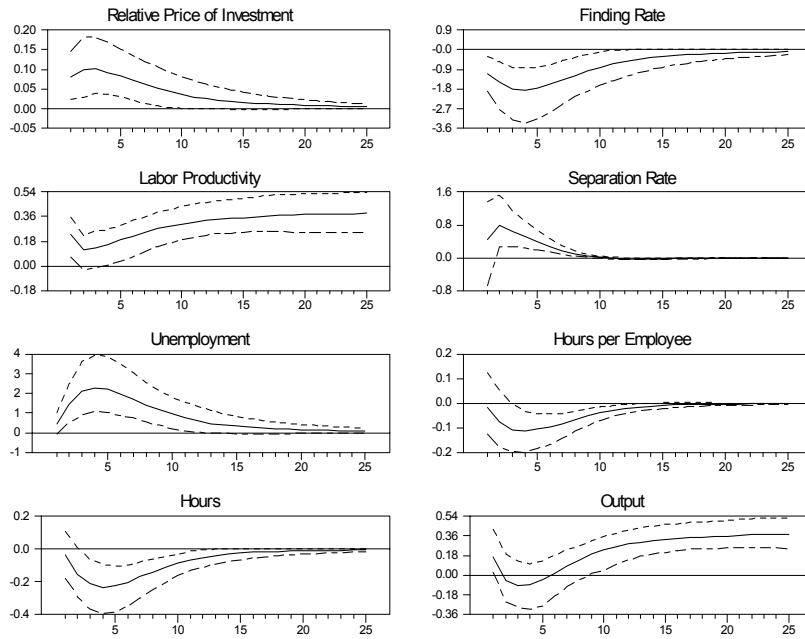


Figure 28: Response of the Ins and Outs of unemployment to a neutral technology shock. The sample period is 1955:I-1973:I. The VAR has eight lags and contains six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) job finding rate, the (logged) job separation rate, the (logged), unemployment rate (logged), and the (logged) aggregate number of hours worked per capita. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate from bootstrap replications.

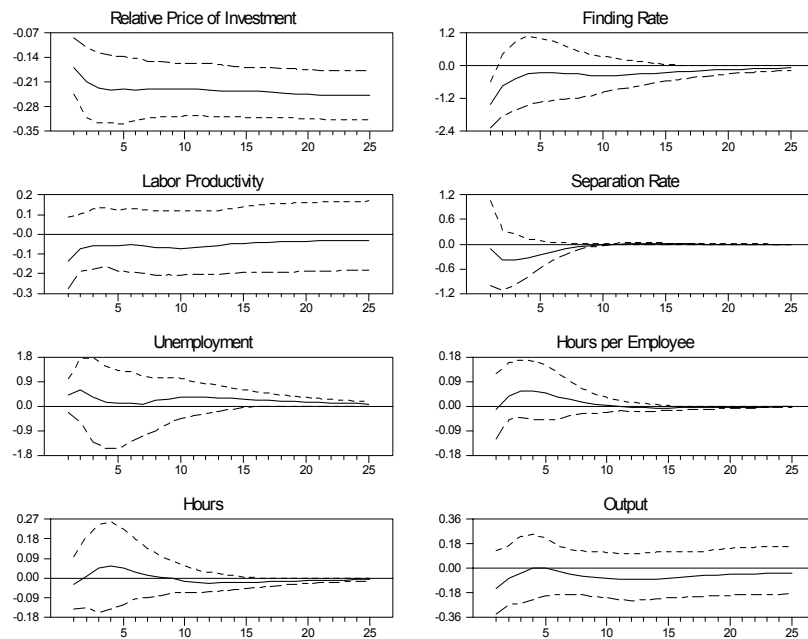


Figure 29: Response of the Ins and Outs of unemployment to an investment specific technology shock. The sample period is 1955:I-1973:I. The VAR has eight lags and contains six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) job finding rate, the (logged) job separation rate, the (logged), unemployment rate (logged), and the (logged) aggregate number of hours worked per capita. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate from bootstrap replications.

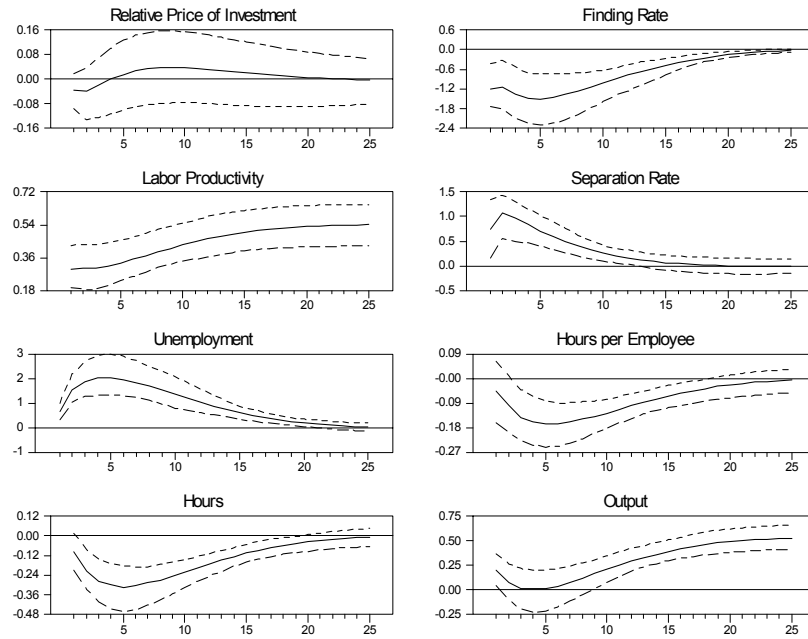


Figure 30: Response of the Ins and Outs of unemployment to a neutral technology shock. The sample period is 1973:II-1997:II. The VAR has eight lags and contains six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) job finding rate, the (logged) job separation rate, the (logged), unemployment rate (logged), and the (logged) aggregate number of hours worked per capita. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate from bootstrap replications.

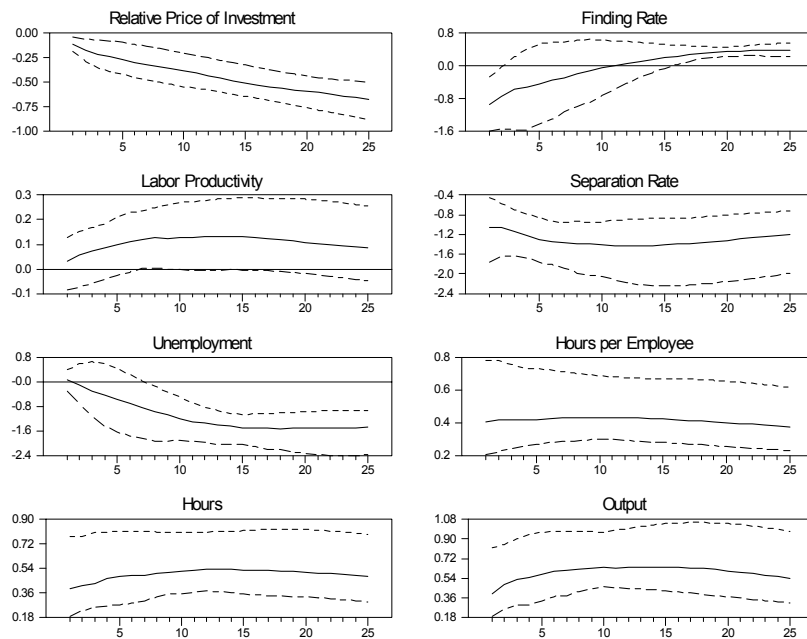


Figure 31: Response of the Ins and Outs of unemployment to an investment specific technology shock. The sample period is 1973:II-1997:II. The VAR has eight lags and contains six variables: the rate of growth of the relative price of investment, the rate of growth of labour productivity, the (logged) job finding rate, the (logged) job separation rate, the (logged), unemployment rate (logged), and the (logged) aggregate number of hours worked per capita. Dotted lines represent the 5% and 95% quantiles of the distribution of the responses simulated by bootstrapping 500 times the residuals of the VAR. The continuous line corresponds to median estimate from bootstrap replications.