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The Austrian Business Cycle – A Role for Technology Shocks?

by

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I. Introduction

Whether technology represents a major driver of observed business cycles has been an ongoing debate for over two decades. While simulations of parameterized versions of stochastic growth models point at technology as a dominant contributor more recent applications of structural vector autoregression methods cast serious doubt on the role of technology for business cycle variations. In all these studies neutral technology shocks refer to aggregate, sector-neutral productivity shocks, while investment specific technology shocks relate to productivity-enhancing shocks to technology embodied in capital goods which necessitate investment to unfold and affect output.

Specifically, Galì (1999) shows that aggregate neutral technology shocks played a secondary role in explaining the cyclical variation of output and total hours worked in the U.S. between 1948 and 1994. On the other hand, Fisher (2002), Lawrence et al. (2003) and Gambetti (2005) explicitly calculate the contribution of variations in U.S. output and hours worked due to different technology shocks to the variables' overall variations.

Depending on different model specifications, Lawrence et al. (2003) identify the role of neutral technology shocks only for observed business cycle variations in output and hours worked accounting for 64 to 1.3 percent of business cycle variations in output and for 33 to 4.1 percent of cyclical variations in hours worked[a].

According to Fisher (2002) who first emphasizes the importance of investment specific technology shocks for observed business cycle variations, investment specific and neutral technology shocks both explain between 40 and 76 percent of overall variations in output and between 52 and 64 percent of business cycle variations in hours worked, depending on the model specification. Neutral technology shocks alone, however, only account for 9 to 28 percent of variations in output and 4 percent of variations in hours worked.

In the same vein, applying a trivariate Time-Varying Coefficients Bayesian Vector Autoregression approach, Gambetti (2005) stresses that depending on the particular specification chosen, investment specific and neutral technology shocks together explain about 39 to 53 percent of total business cycle volatility of output and hours worked while neutral technology shocks alone only account for 11 to 34 percent of output fluctuations and for 10 to 36 percent of variations in hours worked.

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[a] The role of technology is significantly more pronounced in level specification models as compared to models specified in terms of first differences. Under the level specification scheme contributions of output and hours worked to overall cyclical variations show dramatic reductions once the inflation rate, the Federal Funds rate or consumption and investment are included. While, under difference specification, the contribution of variations in hours worked only negligibly falls after inclusion of additional variables, the contribution of output drastically falls from 11 to 2 percent only.

In general, all authors point at the secondary role neutral technology shocks play for observed U.S. business cycles and the necessity to also include investment specific technology shocks to better capture the overall role of technology for observed business cycle variations.

This paper attempts to identify the contribution of technological change to observed business cycles applying the empirical platform of the small and open economy Austria as opposed to the large and alleged technological leader the U.S. to shed light on the role of size and the distance to the technological frontier for the significance of technology in molding business cycles.

A key variable in the underlying model is the price for a newly produced unit of equipment, expressed in terms of consumption goods. Proxied by the ratio of the equipment investment deflator to the total consumption deflator, the index captures investment specific technological change. While neutral technological change affects the investment and consumption sector symmetrically, relative prices, i.e. the real investment price remains unchanged and only labor productivity is affected in the long run, investment-specific technological change affects both, the real investment price and long-run labor productivity.

Methodologically, a structural vector autoregression approach is applied to capture the roles of both investment specific and neutral technology shocks for business cycle variations in output and hours worked. In order to do so, it is assumed that (1) investment specific and neutral technology shocks are the only shocks affecting labor productivity in the long run and that (2) only investment specific technology shocks have permanent effects on the real price of investment. Once the structural neutral and investment specific technology shocks are identified, their individual as well as mutual effects on output and hours worked are simulated accordingly. The ratio of filtered technology-related responses of output (or hours worked) to filtered overall variations in output (or hours worked) will account of the percentage contribution of technology to observed variations.

The results show that technology has a non-negligible role in explaining variations in output but plays a secondary role in determining business cycle variations in hours worked in the sub-aggregate of Industry. Furthermore, partly due to the inferior proxy for investment specific technology shocks, a decomposition of the overall effect into a component explained by investment specific technology shocks and a component explained by neutral technology shocks emphasizes the dominant role neutral technology shocks play.

The remainder of the paper is organized as follows: the next section outlines the theoretical framework while section III discusses the methodology of the vector autoregression and structural vector autoregression to help identify the contribution of different technology shocks to business cycles. Section IV highlights data coverage and data sources used. The findings are presented in section V while section VI concludes.

II. Framework

The model is adopted from Fisher (2002) where due to the absence of market imperfections, a social planner chooses consumption C_t, investment X_t, hours worked H_t and next period's capital stock K_{t+1} according to the following maximization problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, H_t) \tag{1}$$

subject to:

$$Y_t = C_t + X_t \leq A_t K_t^{\alpha} H_t^{1-\alpha} \qquad \text{with: } \alpha \in (0,1) \tag{2}$$

$$K_{t+1} \leq (1-\delta) K_t + V_t X_t \qquad \text{with: } K_0 \textit{ given} \text{ and } \delta \in (0,1) \tag{3}$$

and:

$$A_t = \exp(\gamma + C_a(L)\varepsilon_{at}) A_{t-1} \qquad \text{with: } \gamma \geq 0 \tag{4}$$

$$V_t = \exp(\upsilon + C_\upsilon(L)\varepsilon_{\upsilon t}) V_{t-1} \qquad \text{with: } \upsilon \geq 0 \tag{5}$$

By definition, the production function implies constant returns to scale so that scale economies cannot erroneously be interpreted as technology shocks. A_t and V_t are the levels of neutral and investment specific technology, respectively, and C_{at} and $C_{\upsilon t}$ are square summable polynomials in the lag operator L. ε_{at} and $\varepsilon_{\upsilon t}$ are white noise innovations interpreted as exogenous neutral and investment specific technology shocks, respectively, with $E(\varepsilon_{at}) = E(\varepsilon_{\upsilon t}) = 0$ and diagonal covariance matrices specified by $E(\varepsilon_{at}\varepsilon'_{at}) = \Sigma_{at}$ and $E(\varepsilon_{\upsilon t}\varepsilon'_{\upsilon t}) = \Sigma_{\upsilon t}$. The two stochastic technology processes imply that the logs of A_t and V_t follow a random walk with drifts γ and υ so that shocks to technology can have permanent effects.

The long run implications of the model can be identified by considering its balanced growth properties with output, consumption, investment and the stock of capital displaying similar average growth rates over sufficiently long time horizons and constant hours worked per capita.

Given the above specification of the resource constraint (2), consumption, investment, output and labor productivity all grow at the same rate $g = g_C = g_X = g_Y = g_{Y/H}$, while the accumulation equation for capital (3) points at the capital stock to grow at a higher rate $g_K = \upsilon g$, provided $\upsilon > 1$.

Finally, the specification of the production function (2) implies that $g = \gamma g_K^{\alpha}$. Hours worked are stationary. Thus, the following restrictions are imposed on balanced growth: $g = \gamma^{1/(1-\alpha)} \upsilon^{\alpha/(1-\alpha)}$ [b].

Stationarity is guaranteed if all variables grow at a constant rate. Hence, with $\hat{x} = x_t / g$ and $x_t = C_t, X_t, Y_t, Y_t/H_t$, consumption, investment, output and labor productivity all grow at $(\gamma + \alpha\upsilon)/(1-\alpha)$ and with $\hat{k}_t = k_t / g_K$, the capital stock grows at $g_K = (\gamma + \upsilon)/(1-\alpha)$.

Additionally, any shocks to the neutral or investment specific technology level (i.e. ε_{at} or $\varepsilon_{\upsilon t}$) have permanent effects while leaving hours worked unaffected in the long-run. Hence, labor productivity is affected by both types of technology shocks.

Since according to equation (2) investment and consumption goods can be traded on a one-for-one basis, the real price of one unit of investment good is given by the number of consumption goods that need to be given up in order to get one additional unit of the investment good which is $1/V_t$. Hence, only a shock to the investment specific technology level captured by $\varepsilon_{\upsilon t}$ can have any permanent effect on the real price of investment.

Said long term implications of investment specific and neutral technology shocks help determine and specify the structural vector autoregression system that will be discussed next.

III. Methodology

Vector Autoregressions (VARs hereafter) are multivariate, linear representations of a vector of observables on its own lags and possibly lags of other variables (as trend or constant).

Consider the following VAR(p) representation without exogenous variables or a constant term

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + ... + A_p y_{t-p} + u_t \tag{6}$$

where $y_t = (y_{1t}, ..., y_{Kt})'$ is a $(K \times 1)$ random vector, the A_i's are fixed $(K \times K)$ matrices of parameters and u_t is a $(K \times 1)$ vector of white noise disturbances with zero mean and covariance Σ_u, i.e. $u_t \sim (0, \Sigma_u = E(u_t u_t'))$.

[b] With stationarity in hours worked, total output grows at: $g_Y = g = \gamma(\upsilon g_X)^{\alpha}$. With $g_Y = g_X = g$, output grows at the rate $g = \gamma(\upsilon g)^{\alpha}$ which is equivalent to $g^{1-\alpha} = \gamma\upsilon^{\alpha}$ and results in: $g = \gamma^{1/1-\alpha}\upsilon^{\alpha/1-\alpha}$.

Above process has the following lag operator notation:

$$A(L)y_t = u_t \qquad \text{with } A(L) = I_K - A_1 L - ... - A_p L^p \qquad (6')$$

If the process is stable, i.e. all eigenvalues of A_i have modulus less than 1, Lütkepohl (2005) shows that the VAR(p) process has the following Moving Average (MA) representation, where y_t is expressed in terms of past and present disturbance terms

$$y_t = \sum_{i=0}^{\infty} \Phi_i u_{t-i} \qquad \text{with} \qquad \Phi_i = I_K \qquad \text{if: } i = 0 \text{ and} \qquad (7)$$

$$\Phi_i = \sum_{j=1}^{i} \Phi_{i-j} A_j \qquad \text{if: } i = 1,2,3,.......$$

Since the coefficient matrices A_j's are absolutely summable, so are the Φ_i's. The Φ_i's as coefficients of the MA representation are the *impulse-response functions* at horizon i, where the x, y element of Φ_i gives the effect of a one-time one-unit increase in an error term to variable y on variable x after i periods holding everything else constant. Formally, this is expressed as

$$\Phi_{i,xy} = \frac{\partial y_{x,t+i}}{\partial u_{y,t}} \qquad \text{with } y_x \in y_t = (y_{1t},..., y_{Kt})'. \qquad (8)$$

Additionally, the long-term effect of such a one-time one-unit shock after m periods is the sum of all individual impulse-responses per period: $\sum_{i=0}^{m} \Phi_{i,xy}$.

However, results from above MA representation are not attributable to single economically-interpretable shocks but to all shocks correlated with the responding variable if the components of u_t are instantaneously correlated. Hence, in order to disentangle observed shocks and attribute them to single sources, a structural VAR (SVAR hereafter) with structural assumptions leading to unique impulse-responses is applied. With reference to the above discussion of the theoretical framework the structural assumptions are: (1) only investment specific technological shocks affect the real price of investment in the long run and (2) both, investment specific and neutral technology shocks have permanent effects on labor productivity.

In order to impose these structural long term restrictions, Shapiro and Watson (1988) suggest entering the other variables in double-differences in the estimation. Specifically, assume the following trivariate case in which the real price of investment p_t, labor productivity x_t and hours worked n_t are difference stationary and functions of their current and lagged values:

$$\Delta p_t = \sum_{j=1}^{m} \alpha_{pp,j} \Delta p_{t-j} + \sum_{j=0}^{m} \alpha_{px,j} \Delta x_{t-j} + \sum_{j=0}^{m} \alpha_{pn,j} \Delta n_{t-j} + v_t$$

$$\Delta x_t = \sum_{j=1}^{m} \alpha_{xp,j} \Delta p_{t-j} + \sum_{j=1}^{m} \alpha_{xx,j} \Delta x_{t-j} + \sum_{j=0}^{m} \alpha_{xn,j} \Delta n_{t-j} + a_t$$

$$\Delta n_t = \sum_{j=1}^{m} \alpha_{np,j} \Delta p_{t-j} + \sum_{j=1}^{m} \alpha_{nx,j} \Delta x_{t-j} + \sum_{j=1}^{m} \alpha_{nn,j} \Delta n_{t-j} + \varepsilon_{nt}$$

Assuming that only investment specific technology shocks affect the real price of investment in the long-run, requires the long-term multipliers of Δx_t and Δn_t to be zero and the coefficient of its lags to sum to zero. Hence, the above specification for the real price of investment becomes

$$\Delta p_t = \sum_{j=1}^{m} \alpha_{pp,j} \Delta p_{t-j} + \sum_{j=0}^{m-1} \alpha_{px,j} \Delta^2 x_{t-j} + \sum_{j=0}^{m-1} \alpha_{pn,j} \Delta^2 n_{t-j} + v_t$$

and labor productivity and hours worked enter in double-differences[c]. Since current values of $\Delta^2 x_t$ and $\Delta^2 n_t$ are correlated with the error term v_t, the equation must be estimated using instrumental variables, with lags one through m of Δp_t, Δx_t and Δn_t as instruments. The estimates of the error term v_t, $\hat{v}_t$, represent the estimates of the structural investment specific technology shocks.

Similarly, the equation for labor productivity is specified as

$$\Delta x_t = \sum_{j=1}^{m} \alpha_{xp,j} \Delta p_{t-j} + \sum_{j=1}^{m} \alpha_{xx,j} \Delta x_{t-j} + \sum_{j=0}^{m-1} \alpha_{xn,j} \Delta^2 n_{t-j} + \alpha_{xv} \hat{v}_t + a_t$$

where differences of Δn_t are included to impose the long term constraint that only investment specific and neutral technology shocks permanently affect labor productivity. The equation must again be estimated using instrumental variables with lags one through m of Δp_t, Δx_t and Δn_t as instruments and $\hat{v}_t$, the estimated residual from the real price of investment equation, as additional independent variable. The estimates of the error term a_t, $\hat{a}_t$, represent the estimates of the structural neutral technology shocks.

In the absence of long term structural assumptions for hours worked, the above equation remains unaltered except for the inclusion of the two error terms of the real investment price equation and the labor productivity equation as additional independent variables:

$$\Delta n_t = \sum_{j=1}^{m} \alpha_{np,j} \Delta p_{t-j} + \sum_{j=1}^{m} \alpha_{nx,j} \Delta x_{t-j} + \sum_{j=1}^{m} \alpha_{nn,j} \Delta n_{t-j} + \alpha_{nv} \hat{v}_t + \alpha_{na} \hat{a}_t + \tilde{\varepsilon}_{nt}$$

[c] For a detailed discussion refer to the data appendix.

To isolate the contribution of technology shocks to observed business cycles, the procedure is as follows: first, based on a pre-specified number of lags derived from different information criteria a VAR is estimated and the matrices of parameters are calculated. Second, an SVAR with long-run restrictions on the real price of investment and labor productivity is estimated to isolate the structural shock terms $\hat{v}_t$ and $\hat{a}_t$. A simulation with the estimated structural technology shock vectors $\hat{v}_t$ and $\hat{a}_t$ replacing the error vectors in the VAR on the one hand, and zero non-technology shocks on the other is applied to derive the dynamic response of the real price of investment, labor productivity, output and hours worked to the structural neutral and investment specific technology shocks only. The number of lags specified by different information criteria is used to initialize the simulation. Finally, to isolate the business cycle related variations from overall variations derived that are contaminated with growth components, the time series are filtered. The Band-Pass Filter suggested by Baxter and King (1999) is applied to eliminate the long-term growth components from the data. Following suggestions by Burns and Mitchell (1946), the filter excludes frequencies higher than 1.5 years and frequencies lower than 8 years to capture the average length of business cycles observed in industrialized countries. As suggested by Baxter and King (1999), the number of lags and leads are set equal to 12 to guarantee that major features of business cycles are retained.

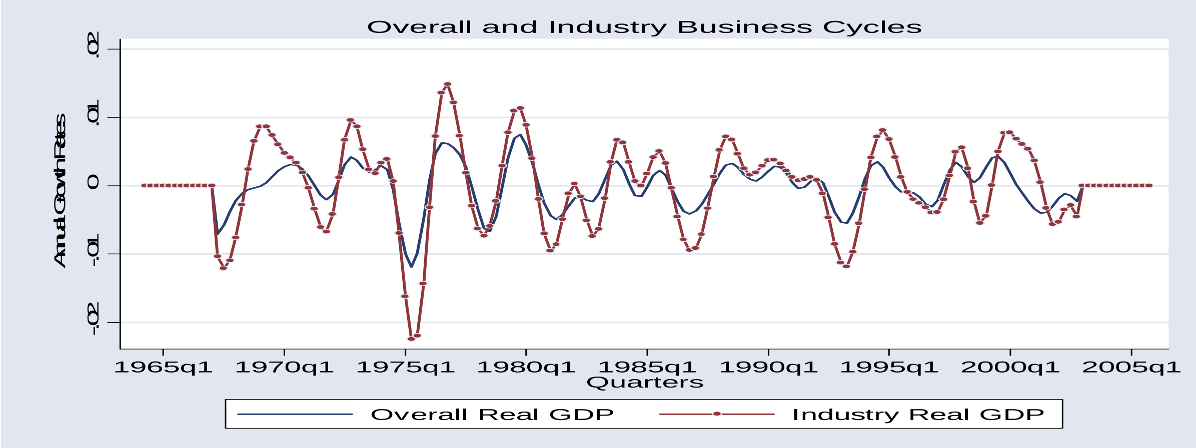
The contribution of both technology shocks, i.e. investment specific and neutral technology shocks, is reported for output as well as hours worked and defined as the ratio of filtered variations of technology-related output (or hours worked) to filtered variations of overall output (or hours worked).

IV. Data Sources and Definitions

All data series are quarterly. Monthly hours worked are seasonally adjusted by means of a three-lag moving average smoothing procedure to eliminate the prevailing seasonal root identified by the Hylleberg, Engle, Granger and Yoo (1990) seasonal root test. Data are either taken from the Quarterly National Accounts, the Main Economic Indicators or the Economic Outlook administered by the Austrian Institute of Economic Research (WIFO).

The hours measure is hours worked by wage earners and apprentices in Industry, excluding Construction, available for 1965:1 – 2005:4. Labor productivity in Industry is available for 1965:1 – 2005:4 and defined as the sector’s total real GDP divided by hours worked per wage earner and apprentice in Industry. However, hours worked are not available at the macro-level. Given high and positive correlations (0.873) between Industry and macro-level real GDP growth rates at business cycle frequencies and the suggested dominant role of Industry performance for the overall macroeconomic performance, dynamics in Industry (NACE C, D and E) are subject of the analysis.

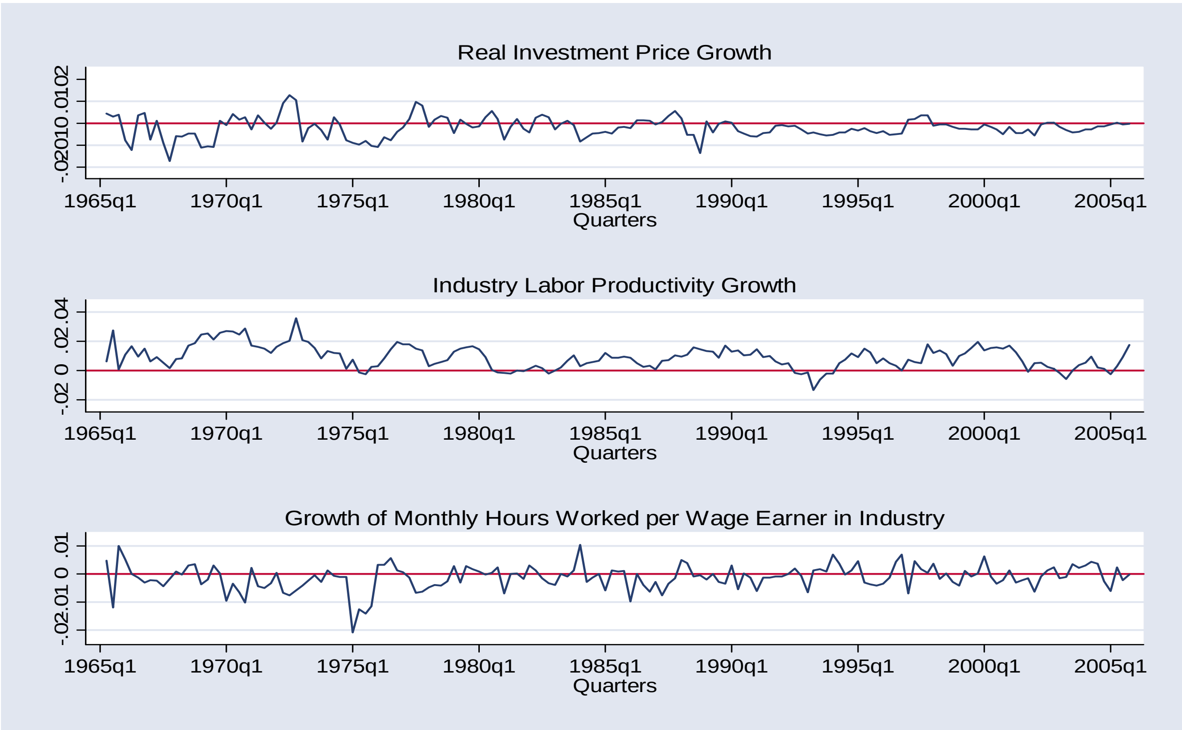
Figure 1: Macro-Level and Industry Business Cycles



Source: Own calculations

Business cycle variations in Industry strongly resemble cyclical variations at the overall macroeconomic level but exhibit higher volatility in terms of the measured standard deviation of 0.0061 at the level of the Industry versus 0.0031 at the overall macroeconomic level.

Figure 2: Variables in the Models



Source: Own calculations

The time series for the real investment price is calculated as the ratio of the equipment investment deflator to the total consumption deflator. Nominal and real quarterly equipment investment series are explicitly available only for the period 1988:1 to 2006:2 within the European Standard Accounts 1995 (ESA 1995) accounting approach, while one of the preceding accounting schemes, the System of

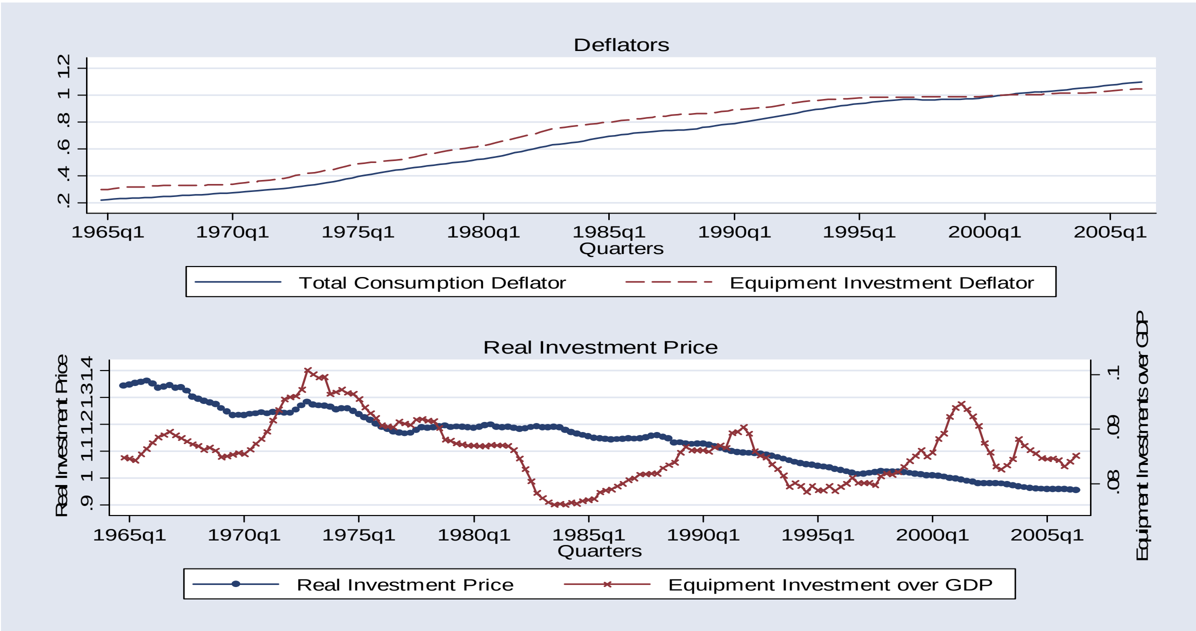
National Accounts 1968 (SNA 1968), only gathered information on quarterly gross fixed capital formation. Hence, based on the high and significant correlation between nominal and real gross fixed capital investment expenditures and its subgroup real and nominal equipment investment expenditures between 1988:1 and 2006:2, (both, in levels and in growth rates), quarterly growth rates of gross fixed capital formation were applied to extend the time series on nominal and real equipment investments backwards to 1965:1, starting from 1987:4.

A similar procedure was applied to nominal and real total consumption (i.e. private and public consumption) which is available under both accounting approaches, the ESA 1995 and the SNA 1968. Starting from 1987:4, the observed time series extracted from the ESA 1995 was extended into the past to 1965:1 by means of annual growth rates calculated for real and nominal total consumption under the SNA 1968 accounting approach.

The analysis was conducted for the period covering 1965:1 to 2005:4.

Figure 2 displays the basic variables in the model while Figure 3 depicts the equipment investment and the total consumption deflators, the evolution of the real equipment investment price and the equipment-to-GDP ratio.

Figure 3: Deflators and the Real Investment Price



Source: Own calculations

Austrian equipment deflators are not quality-adjusted to account for innovation-induced changes in quality of investment goods and no comparable analysis was conducted to derive equipment deflators in the tradition of Gordon (1989). A closer look at the real investment price still reveals a noticeable decline from 1.343 in 1964:4 to 0.9549 in 2005:4, an average decline of 0.87 percent per year or 0.214 percent per quarter. However, the equipment-to-GDP ratio depicted in the lower graph of Figure 3, as a measure of the (changing) role of equipment investments in overall GDP, remains fairly stable over the 40-year period. Hence, although equipment experienced technology-induced price reductions, equipment investments did not expand on average and a fairly negligible role of investment specific technology shocks for observed business cycle variations is expected.

V. The Role of Technology

Based on the above structural assumptions, the following trivariate system with the real price of investment p_t, labor productivity x_t and hours worked n_t as difference-stationary variables is formalized

$$\begin{bmatrix} \Delta p_t \\ \Delta x_t \\ \Delta n_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & 0 & 0 \\ C^{21}(L) & C^{22}(L) & 0 \\ C^{31}(L) & C^{32}(L) & C^{33}(L) \end{bmatrix} \begin{bmatrix} \upsilon_t \\ a_t \\ \varepsilon_{nt} \end{bmatrix}$$

with υ_t and a_t as the orthogonal investment specific and neutral technology shocks, respectively, and ε_{nt} as the orthogonal non-technology shocks.

Augmented Dickey Fuller (ADF), Dickey-Fuller GLS (DF-GLS) and Phillips-Perron tests for difference stationarity were applied to the time series. The null hypothesis of difference stationarity of the series cannot be rejected at conventional significance levels. Since non-rejection of the null hypothesis does not automatically lead to rejection of the alternative hypothesis, the Kwiatkowski, Phillips, Schmidt and Shin (1992) test of the null hypothesis of level stationarity against the alternative hypothesis of a unit root was applied. The null hypothesis is rejected at conventional significance levels and all variables are found to be I(1).

Order selection was based on conventionally applied selection order criteria. While the Hannan-Quinn and Schwarz information criteria suggest a lag period of 1, the Final Prediction Error and the Akaike information criterion point at an optimal lag period of 5. To account for potential mistakes incorporated by choosing one group of selection criteria over another, results are presented for both lag periods suggested.

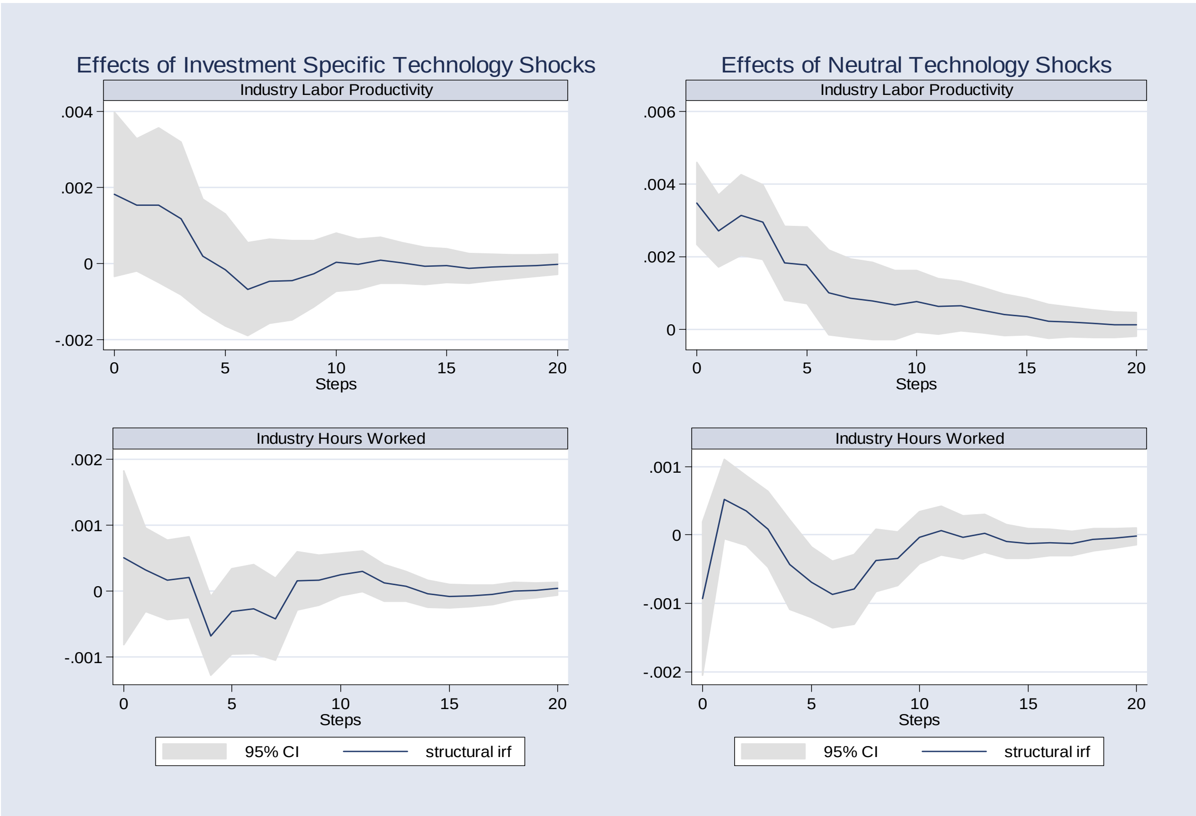
V.I. Findings

The contributions of investment specific and neutral technology shocks to the Austrian Business Cycle between 1965 and 2005 are estimated in terms of variations in output and hours worked in Industry.

V.I.I Impulse-Response Functions

The impulse-response functions (solid line) and their 95 percent Hall percentile confidence intervals (grey band) for the five-lag scenario are depicted in Figure 4 below and show the short-term response of a positive one-time unit structural shock to one variable on other variables. Specifically, the three graphs on the left-hand side of Figure 4 show the effect of a positive one-time unit shock to the real investment price on the real investment price, labor productivity and hours worked per wage earner, while the three graphs on the right-hand side of Figure 4 depict the effect of a one-time unit shock to labor productivity on the real investment price, labor productivity and hours worked. By construction, structural shocks to the real investment price represent investment specific technology shocks, structural shocks to labor productivity represent neutral technology shocks while structural shocks to hours worked are associated with non-technology (demand) shocks.

Figure 4: Structural Impulse-Response Functions to Structural Technology Shocks



Source: Own calculations

Investment specific technology shocks initially result in a positive response of industry labor productivity, before it drops below zero in period 5. The effect basically remains negative with short and unsustainable positive responses in periods 10, 12 and 13 and eventually levels off thereafter.

At impact, the response of hours worked in industry to an investment specific technology shock is positive. The effect quickly diminishes and becomes negative throughout periods 4 to 7. Thereafter, between periods 8 to 13, hours worked again exhibit positive responses to said technology shocks, before another 4-period phase of negative responses sets in. Overall, the initially positive response of hours worked slowly dies off in an oscillating manner, where 4-to 5-period phases of positive effects are interrupted by 4- to 5-period phases of negative responses.

The impact effect of a one-time unit neutral technology shock to industry labor productivity is positive and comparably high and slowly dies off until after period 20. Finally, a neutral technology shock causes a negative impact effect on hours worked in industry, a positive effect in the three following periods and again negative responses thereafter. The effect appears to vanish after period 15.

Interestingly, hours worked in industry respond differently to both technology shocks considered: positive in response to investment specific technology shocks and negative to neutral technology shocks. The negative responses of hours worked to neutral technology shocks are at odds with predictions of the Real Business Cycle theory but in line with recent empirical studies on the cyclical reaction of the hours/input measure to positive technology shocks (Shea (1998), Galì (1999), Fisher (2002) or Basu et al. (2004) to name a few).

According to the Real Business Cycle Theory, exogenous sector neutral technology shocks enhance labor productivity and - given that labor is paid its marginal product - real wages increase. Consumers maximize expected lifetime utility from consumption of goods and services c_t as well as leisure $1-l_t$. With respect to labor supply, an intertemporal decision rule is applied based on a comparison of the relative real wage rates in periods 2 and 1: with an increase in the real wage rate in period 1, supply of labor also increases.

Above negative responses of hours worked due to neutral technology shocks can be explained by the resource-saving aspect of technology shocks. Given any improvement in technology, a prevailing output-level can be produced with lesser factor inputs like labor, leading to a decline in hours worked.

V.I.II The Role of Technology for the Variation in Monthly Hours Worked

The role of technology for the business cycle is captured by the percentage contribution of the technology-induced variance of output and hours worked at business cycle frequencies to the overall variance of output and hours worked at business cycle frequencies and calculated as the ratio of the filtered variance in simulated output or monthly hours worked to the filtered variance in actual output or monthly hours worked.

Results of the percentage contribution of either technology shocks to cyclical variations in hours worked and output in Industry are presented in Panels A and B of Table 1. Clearly, overall technology shocks explain only about 1 percent of the business cycle variation observed of hours worked in the one-lag approach and about 32 percent in the five-lag approach. A decomposition of the overall effect furthermore highlights the dominant role neutral technology shocks play in explaining observed variations in the five-lag approach. In that respect, neutral technology only explains about 26 percent of business cycle variations in hours worked, while investment specific technology shocks account for only about 5 percent of overall variations in hours worked.

Table 1: Three Variable Specification:
Percentage Contribution of Technology Shocks to Hours Worked and Output

Statistics	No. of lags	All Technology	Neutral Technology	Investment Specific Technology
A. Hours Worked				
$\sigma^2_{HS} / \sigma^2_{HT}$	1	1	0.1	1
$\sigma^2_{HS} / \sigma^2_{HT}$	5	32	26	5
B. Output				
$\sigma^2_{HS} / \sigma^2_{HT}$	1	68	66	1
$\sigma^2_{HS} / \sigma^2_{HT}$	5	64	61	5

Source: Own Calculations

V.I.III Exogeneity Test

However, above results on the role of technology-related shocks for observed cyclical variations critically depend on the standard Real Business Cycle assumption of exogenous technology shocks that are uninfluenced by other economic factors. Hall (1988) and Evans (1992) argue that therefore technology shocks should not be correlated with any other exogenous shocks that are not related to technology. By stressing the importance of money, interest rates and government spending for explaining the Solow residual, Evans (1992) casts serious doubts on the underlying exogeneity assumption for the U.S economy covering the period 1954:4 to 1978:4 and emphasizes that the standard Solow residual therefore overstates the true role of neutral technology shocks for economic fluctuations. To account for this potential upward bias, an Evans-Hall exogeneity test is conducted on estimated investment-specific and neutral technology shocks identified by means of the instrumental variables method suggested by Shapiro and Watson (1986).

Specifically, in accordance with Francis and Ramey (2005), oil shock dummies as suggested by Hoover and Perez (1994) and extended beyond 1981 as well as the interbank money market rate are included since they are generally viewed as unrelated to technology shocks. In accordance with Hoover and Perez (1994) and based on quarterly growth rates of crude oil prices, 11 oil price shocks are identified between 1965:1 and 2005:4: 1969:1, 1970:1, 1974:1, 1978:1, 1979:3, 1981:1, 1987:1, 1990:4, 1996:4, 1999:1 and 2003:1.

Estimated investment-specific and neutral technology shocks are regressed on a constant and current and four lagged values of the oil shock dummies and on a constant and four lagged values of the interbank money market rate since the interbank money market rate may respond to current technology shocks:

$$\varepsilon_{it} = \alpha_i + \beta(L) z_{t-1} + \omega_t ,$$

where $\beta(L)$ are polynomials in the lag operator L. Lags of the technology shocks ε_i are not included since, by construction, they are not serially correlated. By assumption, z should be unrelated to either technology shock. The interest rate variable is proxied by the change in the interbank money market rate while the growth rate of the GDP-deflator is used to capture the inflation rate.

Table 2 shows that the results of the F-test that the coefficients of all variables are jointly equal to zero are rejected for all variables.

Table 2: Exogeneity Test - p-values

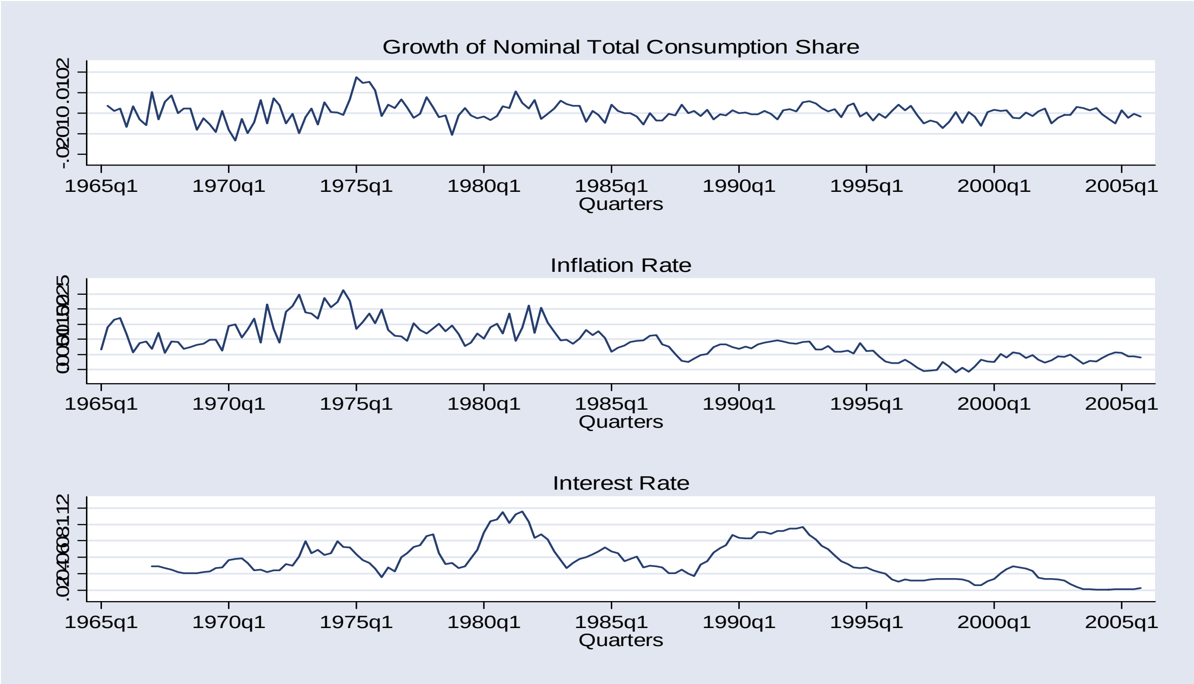
Shock	Oil price shocks	Interbank money market rate	Inflation
Investment-specific	0.421	0.718	0.779
Neutral	0.237	0.667	0.754

To prove the validity of exogeneity of technology shocks an extended six-variable SVAR is estimated, additionally accounting for the inflation rate, the interest rate and the ratio of nominal total consumption to nominal GDP.

The theoretical framework discussed in section II suggests nominal total consumption and investment ratios defined as nominal total consumption (public and private) over nominal GDP and nominal investment over nominal GDP as potential extensions. However, SNA 1968 does not provide gross investments but the subgroup of gross fixed capital formation only. Since the growth rate of total gross fixed capital formation was already applied to derive the extended time series for gross equipment investments, inclusion of the nominal investment share was refrained from to avoid statistical problems. Instead, the total nominal consumption share - as the sum of public and private consumption - along with the inflation rate (defined as the GPD deflator) and the short-run interest rate are included as additional endogenous variables.

With the establishment of the European Monetary Union, marked by the introduction of the EURO as a real currency, EU-member countries (like Austria) no longer reported country-specific interest rates but the European Central Bank, as the Union’s monetary authority, commenced to identify Euro-Region specific interest rates. Hence, Austrian short-term interest rates, available for 1967:1 up to 1998:4, were completed by short-term EURIBOR rates for the period 1999:1 to 2005:4 and the analysis was conducted covering the period 1967:1 to 2005:4.

Figure 5: Additional Variables



Source: Own calculations

Augmented Dickey Fuller (ADF), Dickey-Fuller GLS (DF-GLS) and Philips-Perron tests for difference stationarity were applied to the data. The null hypothesis of difference stationarity cannot be rejected at conventional significance levels. Additionally, the Kwiatkowski, Phillips, Schmidt and Shin (1992) test of the null hypothesis of level stationarity against the alternative hypothesis of a unit root was applied to the nominal consumption ratio and rejected for all lags. Hence, the variables are I(1).

Lag-order selection was again based on conventionally applied selection order criteria and specified with one lag according to the Hannan-Quinn and Schwarz information criteria and with five as suggested by the Final Prediction Error and the Akaike information criterion.

Table 3: Six Variable Specification:
Percentage Contribution of Technology Shocks to Hours Worked and Output

Statistic	No. of lags	All Technology	Neutral Technology	Investment Specific Technology
A. Hours Worked				
$\sigma^2_{HS} / \sigma^2_{HT}$	1	1	0	1
$\sigma^2_{HS} / \sigma^2_{HT}$	5	42	23	17
B. Output				
$\sigma^2_{HS} / \sigma^2_{HT}$	1	57	56	2
$\sigma^2_{HS} / \sigma^2_{HT}$	5	55	48	8

Source: Own Calculations

Results are shown in Table 3. In the extended six variable setting, overall technology shocks explain 1 and 42 percent of overall business cycle fluctuations in hours worked in the one- and five-lag models, respectively. Again, neutral technology shocks account for the majority of cyclical variations observed in the five-lag approach. While neutral technology shocks explain 23 percent of overall fluctuations in hours worked in the five-lag model, investment specific technology shocks only account for 1 and 17 percent in both settings, respectively.

Similar inferences can be drawn for the role of either technology shock to business cycle variations in output in Industry: variations in output are predominantly driven by neutral technology shocks and account for 56 and 48 percent of overall variations in the one- and five-lag approaches, respectively; investment specific technology shocks only explain between 2 and 8 percent of variations in output.

Over the first 12 quarters, investment specific and neutral technology shocks account for over 80 percent of the forecast error variance of the real price of investment labor productivity, respectively (Table 5).

Table 4: Six Variable Specification:
Percentage Contribution of Technology Shocks the Additional Variables

Statistic	No. of lags	All Technology	Neutral Technology	Investment Specific Technology
Net Consumption Share				
$\sigma_{HS}^2 / \sigma_{HT}^2$	1	14	12	2
$\sigma_{HS}^2 / \sigma_{HT}^2$	5	10	7	3
Inflation Rate				
$\sigma_{HS}^2 / \sigma_{HT}^2$	1	12	6	5
$\sigma_{HS}^2 / \sigma_{HT}^2$	5	13	4	9
Interest Rate				
$\sigma_{HS}^2 / \sigma_{HT}^2$	1	15	14	1
$\sigma_{HS}^2 / \sigma_{HT}^2$	5	23	12	10

Source: Own Calculations

Table 4 additionally reports the percentage contributions of either technology shocks to cyclical variations of the net consumption share, the inflation rate and short-term interest rate. In general, technology shocks play a negligible role for variations in all additional variables and only explain between 10 to 23 percent of the variables' cyclical variations. By decomposing the overall technology-induced variations into variations originating from neutral or investment specific technology shocks, the dominance of neutral technology shocks for variations at business cycle frequencies becomes apparent. In contrast, the inflation rate exhibits stronger effects in response to investment specific as compared to neutral technology shocks in the five-variable setting.

Clearly, the robustness test indicates that – as suggested by the exogeneity test - inclusion of additional (monetary) variables appears to leave the basic results unaltered: investment specific technology shocks only play a secondary role in explaining business cycle variations of output and hours worked.

VI. Summary and Conclusion

As opposed to previous research on the U.S economy, the small and open economy of Austria was selected as an empirical platform to contribute to the discussion as to the role technology plays for observed business cycle variations. Based on the assumption that only technology shocks have permanent effects, a structural vector autocorrelation approach was chosen to account for technology-induced variations in output and hours worked, and to decompose the overall effect into a component attributable to neutral technology shocks as advocated by the Real Business Cycle Approach and a component ascribable to investment specific technology shocks.

The results show that overall technology shocks account for about 64 to 68 percent of variations in output and between 1 and 32 percent in hours worked in the simple trivariate system and for between 55 to 57 percent of variations in output and for 1 to 42 percent of variations in hours worked in an extended six-variable system. The overall picture emphasizes the dominant role neutral technology shocks play in explaining cyclical variations in hours worked and the negligible role investment specific technology shocks seem to play. These quantitatively different roles of investment specific and neutral technology shocks can be partly traced back to the qualitatively inferior investment specific technology measure of the real investment price.

From the perspective of the overall effect of technology shocks, the results are perfectly in line with those observable for the U.S for a comparable time period but partly underestimated given the inferior measure of investment-specific technology shocks. Hence, neither size nor the distance to the technology frontier seems to matter for the cyclical effects of technology shocks, at least for an economically and technologically sufficiently developed country like Austria.

Whether the significance of technology shocks, either neutral or investment specific, hinges on the level of economic development is left for future research. Access to international capital markets and affordable loans as well as lack of a nation's absorptive capacity to adapt technologically sophisticated machinery and equipment to national production systems or an insufficiently educated labor force to efficiently operate newly implemented technological novelties and associated more extensive adjustment costs are expected to negatively affect investments in machinery and equipment and to almost eliminate the role of investment specific technology shocks.

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Data Appendix

To derive

$$\Delta p_t = \sum_{j=1}^{m} \alpha_{pp,j} \Delta p_{t-j} + \sum_{j=0}^{m-1} \alpha_{px,j} \Delta^2 x_{t-j} + \sum_{j=0}^{m-1} \alpha_{pn,j} \Delta^2 n_{t-j} + v_t \tag{A1}$$

from

$$\Delta p_t = \sum_{j=1}^{m} \alpha_{pp,j} \Delta p_{t-j} + \sum_{j=0}^{m} \alpha_{px,j} \Delta x_{t-j} + \sum_{j=0}^{m} \alpha_{pn,j} \Delta n_{t-j} + v_t \tag{A2}$$

assume a lag-length of m=3 and rewrite (A2) as

$$\Delta p_t = \alpha_{pp,1}\Delta p_{t-1} + \alpha_{pp,2}\Delta p_{t-2} + \alpha_{pp,3}\Delta p_{t-3} + \alpha_{px,0}\Delta x_t + \alpha_{px,1}\Delta x_{t-1} + \alpha_{px,2}\Delta x_{t-2} + \alpha_{px,3}\Delta x_{t-3}$$
$$+ \alpha_{pn,0}\Delta n_t + \alpha_{pn,1}\Delta n_{t-1} + \alpha_{pn,2}\Delta n_{t-2} + \alpha_{pn,3}\Delta n_{t-3} + \upsilon_t$$

Which is equivalent to

$$\Delta p_t = \sum_{j=1}^{m} \alpha_{pp,j} \Delta p_{t-j} + \alpha_{px,0}(\Delta x_t - \Delta x_{t-1}) + [\alpha_{px,0} + \alpha_{px,1}](\Delta x_{t-1} - \Delta x_{t-2})$$
$$+ (\alpha_{px,0} + \alpha_{px,1} + \alpha_{px,2})[\Delta x_{t-2} - \Delta x_{t-3}] + (\alpha_{px,0} + \alpha_{px,1} + \alpha_{px,2} + \alpha_{px,3})\Delta x_{t-3}$$
$$+ \alpha_{pn,0}(\Delta n_t - \Delta n_{t-1}) + [\alpha_{pn,0} + \alpha_{pn,1}](\Delta n_{t-1} - \Delta n_{t-2}) + (\alpha_{pn,0} + \alpha_{pn,1} + \alpha_{pn,2})[\Delta n_{t-2} - \Delta n_{t-3}]$$
$$+ (\alpha_{pn,0} + \alpha_{pn,1} + \alpha_{pn,2} + \alpha_{pn,3})\Delta n_{t-3} + \upsilon_t$$

The long-run restrictions imply: $\alpha_{px,0} + \alpha_{px,1} + \alpha_{px,2} + \alpha_{px,3} = 0$ and $\alpha_{pn,0} + \alpha_{pn,1} + \alpha_{pn,2} + \alpha_{pn,3} = 0$ so that the coefficients of Δx_{t-3} and Δn_{t-3} become zero. Thus, the above expression becomes

$$\Delta p_t = \sum_{j=1}^{3} \alpha_{pp,j} \Delta p_{t-j} + \alpha_{px,0}\Delta^2 x_t + [\alpha_{px,0} + \alpha_{px,1}]\Delta^2 x_{t-1} + (\alpha_{px,0} + \alpha_{px,1} + \alpha_{px,2})\Delta^2 x_{t-2}$$
$$+ \alpha_{pn,0}\Delta^2 n_t + [\alpha_{pn,0} + \alpha_{pn,1}]\Delta^2 n_{t-1} + (\alpha_{pn,0} + \alpha_{pn,1} + \alpha_{pn,2})\Delta^2 n_{t-2} + \upsilon_t$$

With the β's as functions of the α's, this expression can be rewritten as

$$\Delta p_t = \sum_{j=1}^{3} \alpha_{pp,j} \Delta p_{t-j} + \sum_{j=0}^{2} \beta_{px,j} \Delta^2 x_{t-j} + \sum_{j=0}^{2} \beta_{pn,j} \Delta^2 n_{t-j} + \upsilon_t$$

which is equivalent to (A2).

Table 5: Forecast error decomposition of the real price of equipment and labor productivity

Horizon	Percentage of forecast error variance of the real price of investment explained by investment specific TS		Percentage of forecast error variance of the labor productivity explained by neutral TS	
	3-variable model	6-variable model	3-variable model	6-variable model
1	87	88	78	85
3	86	88	76	87
6	85	86	81	88
9	84	84	80	85
12	83	83	80	85