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Abstract

This paper examines US wage adjustment in a structural vector autoregression of the factor proportions model of production and trade with energy, capital, and labor inputs. Data cover the years 1949 to 2006. The wage adjusts to changes in inputs levels and output prices over 6 to 8 years. Energy has a more robust wage impact than capital. The wage reacts weakly if at all to the falling price of manufactures and rising price of services over the sample period. Estimates relate directly to factor proportions theory, suggesting robust substitution with labor in the middle of the factor intensity ranking.

Keywords: Wages; Energy; Factor Proportions Model; Vector Autoregression

JEL Classifications: F11

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I. Introduction

The present paper estimates US wage adjustments in yearly data from 1949 to 2006 in a factor proportions model with energy, capital, and labor inputs. Data include the average wage, Btu energy input, labor force, fixed capital assets, and prices of manufactures and services. Structural vector autoregressions estimate dynamic wage adjustments to exogenous shocks in endowments and product prices. The SVAR is motivated by wage "stickiness" due to labor market contracts and the minimum wage.

The empirical literature on wage convergence in factor proportions models generally focuses on the level of trade rather than product prices. This literature reviewed by Rassekh and Thompson (1998) includes Tovias (1982), Gremmen (1985), Dollar and Wolff (1988), Mokhtari and Rassekh (1989), O'Rourke and Williamson (1992), Rassekh (1992), Leamer and Levinshon (1995), and Leamer (1996). The present paper takes a more direct approach to the Stolper-Samuelson theory linking wages to product prices by directly estimating the factor proportions model.

Rassekh and Thompson (1997) uncover some direct support for the Stolper-Samuelson theorem at the industrial level. In papers with capital and labor inputs for US time series, Thompson (2011, 2012) estimates the Heckscher-Ohlin model and the Stolper-Samuelson theorem. The present paper relates to the error correction estimates of Thompson (2010) extending the wage adjustment period and uncovering stronger wage adjustments.

The US has specialized during the nearly six decades of the present sample toward services due to falling prices across a wide range of manufactured products on global markets. The wage effects of this specialization along the contract curve between services and manufactures depend on underlying factor intensity and substitution.

The present evidence relates directly to the factor proportions model, suggesting there is robust substitution among labor, capital, and energy. Over a long time span, substitution is expected to play a role in economic adjustment. The present results place labor in the middle of the factor intensity ranking. Under this factor intensity, the wage would more likely rise with an increase in either price diminishing the argument for protection of manufactures.

The present estimates indicate that energy input has a stronger effect of the wage than does capital. Empirical wage studies should include energy input to avoid misspecification error.

The following section presents the theory followed by a section on the SVAR model and data pretests. Results are then presented followed by a discussion of policy implications in the conclusion.

II. Wages in the Factor Proportions Model

The factor proportions model of production assumes full employment, competitive pricing, cost minimization, and neoclassical constant returns production. The literature grew from the writings of Heckscher (1919) and Ohlin (1933). The algebraic model developed by Stolper and Samuelson (1941), Jones (1965), Chipman (1979), and Takayama (1982) is the core of international trade theory.

The present model has two products, manufactures M and services S. With inputs of capital K and labor L there would be no wage impacts of changing input levels due to the factor price equalization property of Lerner (1952) and Samuelson (1948). Empirical analysis, however, uncovers robust wage effects in an estimate with only K and L inputs. Adding energy E to capital and labor inputs leads to a theoretical model consistent with the present empirical results. Energy proves a more robust input than capital in affecting the wage. The related factor proportions model with three inputs is developed by Ruffin (1981), Thompson (1985), and Jones and Easton (1987).

The two major behavioral assumptions of the factor proportions model are full employment and competitive pricing. Full employment is stated $v_i = \Sigma_j a_{ij} x_j$ where v_i is the available level of input i, a_{ij} is the cost minimizing input of factor i per unit of product j, and x_j is the level of sector output. Inputs are capital, labor, and energy, $i = K, L, E$. Outputs are manufactures and services, $j = M, S$. Differentiate this full employment condition and introduce factor cost shares θ_{Lj} and substitution elasticities σ_{ik} between the price of factor k and input of factor i to derive the first three equations in the comparative static system (1) below. The own price substitution elasticities σ_{ii} are negative. Cross price substitution terms σ_{ij} are positive for substitutes but two of the inputs may be complements.

Competitive pricing of product j is written $p_j = a_{Lj} w + a_{Kj} r + a_{Ej} e$ where p_j is price. The input prices are the wage w, capital rent r, and the price of energy e. Take differences and utilize the cost minimizing envelope theorem to derive the last two equations in (1) where industry share λ_{ij} is the portion of factor i employed in sector j.

This 3x2 comparative static factor proportions model is stated

$$\begin{pmatrix} \sigma_{LL} & \sigma_{LK} & \sigma_{LE} & \theta_{LM} & \theta_{LS} \\ \sigma_{KL} & \sigma_{KK} & \sigma_{KE} & \theta_{KM} & \theta_{KS} \\ \sigma_{EL} & \sigma_{EK} & \sigma_{EE} & \theta_{EM} & \theta_{ES} \\ \lambda_{LM} & \lambda_{KM} & \lambda_{EM} & 0 & 0 \\ \lambda_{LS} & \lambda_{KS} & \lambda_{ES} & 0 & 0 \end{pmatrix} \begin{pmatrix} \Delta \ln w \\ \Delta \ln r \\ \Delta \ln e \\ \Delta \ln x_M \\ \Delta \ln x_S \end{pmatrix} = \begin{pmatrix} \Delta \ln v_L \\ \Delta \ln v_K \\ \Delta \ln v_E \\ \Delta \ln p_M \\ \Delta \ln p_S \end{pmatrix} . \qquad (1)$$

The system matrix is the Hessian of the constrained income maximization with a negative determinant D as shown by Chang (1979). Solve (1) for wage effects with Cramer's rule to find

$$\varepsilon_{wL} \equiv \Delta \ln w / \Delta \ln \mathrm{v}_L = \theta_{KE}\lambda_{KE}/D \qquad (2)$$

$$\varepsilon_{wK} \equiv \Delta \ln w / \Delta \ln \mathrm{v}_K = -\theta_{LE}\lambda_{KE}/D$$

$$\varepsilon_{wE} \equiv \Delta \ln w / \Delta \ln \mathrm{v}_E = \theta_{LK}\lambda_{KE}/D$$

$$\varepsilon_{wM} \equiv \Delta \ln w / \Delta \ln p_M = (\lambda_{KS}\varphi_1 - \lambda_{ES}\varphi_2)/D$$

$$\varepsilon_{wS} \equiv \Delta \ln w / \Delta p_S = (\lambda_{EM}\varphi_2 - \lambda_{KM}\varphi_1)/D ,$$

where

$$\theta_{KE} \equiv \theta_{KM}\theta_{ES} - \theta_{EM}\theta_{KS}$$

$$\theta_{LE} \equiv \theta_{LM}\theta_{ES} - \theta_{EM}\theta_{LS}$$

$$\theta_{LK} \equiv \theta_{LM}\theta_{KS} - \theta_{LS}\theta_{KM}$$

$$\lambda_{KE} \equiv \lambda_{KM}\lambda_{ES} - \lambda_{EM}\lambda_{KS}$$

$$\varphi_1 \equiv (\theta_{KE} - \theta_{LK})\sigma_{LE} - (\theta_{LE} + \theta_{LK})\sigma_{KE}$$

$$\varphi_2 \equiv (\theta_{KE} + \theta_{LE})\sigma_{LK} + (\theta_{LK} + \theta_{LE})\sigma_{EK} .$$

The own labor elasticity ε_{wL} is negative since θ_{KE} and λ_{KE} have the same sign and $D < 0$. Factor intensity determines the signs of θ_{KE}, θ_{LE}, θ_{LK}, and λ_{KE}. One implication of factor intensity is that either ε_{wK} or ε_{wE} must be positive but one could be negative.

The present estimates suggest labor is in the middle of the factor intensity ranking

$$\theta_{EM}/\theta_{ES} > \theta_{LM}/\theta_{LS} > \theta_{KM}/\theta_{KS}, \tag{3}$$

given manufactures is energy intensive relative to services. Intensity ranking (3) implies $\theta_{KE} < 0$, $\theta_{LE} < 0$, $\theta_{LK} > 0$, and $\lambda_{KE} < 0$. There is direct evidence of similar factor shares in Thompson (1990, 1995).

Manufactures is energy intensive relative to capital and labor, and labor intensive relative to capital. It may be a surprise that services is capital intensive relative to labor but services include real estate and business services. The positive ε_{wE} in the estimates suggests manufactures is labor intensive and energy intensive relative to capital, $\theta_{LK} > 0$ and $\lambda_{KE} > 0$. Signs of the price effects on the wage in the estimates of ε_{wM} and ε_{wS} depend on factor intensity and substitution, as do sizes of all wage elasticities.

Collating the partial derivative wage effects in (2) leads to the single equation

$$\Delta\ln w = (\lambda_{KE}(\theta_{KE}\Delta\ln v_L - \theta_{LE}\Delta\ln v_K + \theta_{LK}\Delta\ln v_E) - \varphi_M\Delta\ln p_M + \varphi_S\Delta\ln p_S)/D \tag{4}$$

where $\varphi_M \equiv \lambda_{KS}\varphi_1 + \lambda_{ES}\varphi_2$ and $\varphi_S \equiv \lambda_{EM}\varphi_2 - \lambda_{KM}\varphi_1$. The empirical specification of (4) is

$$\Delta\ln w = \alpha_0 + \alpha_1\Delta\ln v_L + \alpha_2\Delta\ln v_K + \alpha_3\Delta\ln v_E + \alpha_4\Delta\ln p_M + \alpha_5\Delta\ln p_S + \varepsilon \tag{5}$$

adding the constant α_0 and white noise residual ε. Theory specifies a negative α_1 due to concavity of the cost function. Either capital or energy must raise the wage with at least one positive sign for α_2 or α_3. Price elasticities of the wage α_4 and α_5 have four possible sign patterns as shown by Thompson (1985).

Substitution diminishes these wage effects but does not affect directions of adjustments to input changes. Signs and sizes of price effects depend on factor intensity and substitution. Price changes shift outputs along the contract curve as the cost minimized inputs adjust. Labor in the middle of factor intensity ranking (3) suggests p_M and p_S have positive wage effects as in the specific factors model.

III. The VAR Model and Data Pretests

Estimating the factor proportions wage effects in (5) with least squares is robust to specification errors but there are a number of empirical issues. Least squares coefficients would be inefficient with a serially correlated residual. Also, the wage may be persistent. Estimates could be biased since factor proportions theory assumes exogenous right hand variables but endogeneity must be present. Certainly, feedback among variables is likely. Finally, structural interpretations for the error term in (5) are difficult without distinguishing sources of shocks, making policy implications a challenge.

These empirical issues motivate the structural vector autoregression SVAR model,

$$\Delta y_t = A(L)\Delta y_{t-1} + Cu_t \qquad (6)$$

where $y_t = [\ln w, \ln L, \ln K, \ln p_M, \ln p_S, \ln E]'$ is the vector of difference stationary variables, $A(L) = A_1L + \cdots + A_kL^k$ is a lag polynomial, u_t is a vector of corresponding structural shocks, and C is the contemporaneous matrix. Detrending the present variables eliminates the deterministic terms.

Consider orthogonalized structural shocks with unit variances $Eu_tu_t' = I$ and $E(Cu_tu_t'C') = CC' = \Sigma$ where **I** is the identity matrix and Σ is the variance-covariance matrix from the least squares estimation of (6). The conventional method of Sims (1980) just-identifies the system (6). That is, assuming that C is a lower triangular matrix, C is uniquely identified by the Choleski decomposition of the least squares variance-covariance matrix estimate that is symmetric and positive definite. The impulse response function of the level variables is obtained by $y_t\ \Sigma_{j=1}^{k+1}\Gamma_j y_{t-j} + Cu_t$ where $\Gamma_1 = I + A_1$, $\Gamma_j = A_{j+1} = A_j$, $j = 2,\ldots,k$, and $\Gamma_{k+1} = -A_k$. Long term responses of level variables are measured by $(I - A(1))^{-1}C$ and short term responses by C.

Results may not be robust to the variable ordering. While the generalized impulse response analysis proposed by Pesaran and Shin (1998) is free from this ordering problem, Kim (2012) shows it yields response functions based on contradictory assumptions that may lead to misleading inferences.

The ordering of (6) starts with world prices p_S and p_M assumed contemporaneously unaffected by domestic variables. The price of services p_S is ordered first assuming it is stickier than p_M. Services dominate the US economy and include internationally competitive business services. Labor input L is ordered next, based on the assumption that it is not affected by capital or energy inputs due to labor contracts. Capital would be contemporaneously unaffected by energy input and is ordered next. Finally, the endogenous wage *w* is ordered last assuming contemporaneous effects from all other variables. Robustness checks with alternative orderings yield qualitatively similar estimates.

Data are from the US National Economic Accounts of the Bureau of Economic Analysis (2007) except Btu energy input from the Department of Energy (2007). The wage *w* is employee compensation averaged across the labor force *L*. The capital stock *K* is the net stock of fixed capital assets. Both *w* and *K* are deflated by the consumer price index. Energy input *E* is total Btu input. The demeaned series are in Figure 1.

* Figure 1 *

The labor force *L* trends upward in a smooth fashion. The capital stock *K* also trends upward but much more irregularly. Energy input *E* trends erratically upward with an apparent break and slower growth following the energy crises from the middle 1970s to early 1980s.

Prices of manufactures p_M and services p_S are indices relative to the CPI. The price of manufactures p_M falls at an increasing rate as the price of services p_S steadily rises in Figure 1. Import competition accounts for some part of the 68% decrease in p_M. Meanwhile p_S increases 59% during the sample period. The relative price of services p_S/p_M increases five times over the sample period as the output of services relative to manufactures increases by about half.

The differenced series in Figure 2 appear stationary. Table 1 reports conventional augmented Dickey-Fuller ADF pretests for the six y_t variables in (6). The number of lags is based on the general-to-specific rule of Hall (1994) as recommended by Ng and Perron (2001).

* Figure 2 * Table 1 *

The ADF test with an intercept accepts the null hypothesis of a unit root for all variables. The ADF test with an intercept and time trend also fails to reject the null for all variables.

ADF tests strongly reject the unit root null for differenced variables both with an intercept and intercept plus time trend, consistent with difference stationary variables. Cointegration is not considered because pretests are sensitive to normalization of the cointegrating equation.

IV. Factor Proportions VAR Wage Estimates

Table 2 presents the VAR estimates for the contemporaneous matrix C. Standard errors are obtained from 10,000 nonparametric bootstrap simulations. Capital *K* and especially energy *E* have strong short term wage effects. Labor *L* has an insignificantly negative contemporaneous own wage effect.

Both prices p_M and p_S have insignificant wage effects in Table 2 although the effect of the manufactures price is stronger. The magnification effect of Jones (1965) analyzed by Thompson (1993) in the present three factor model suggests insignificant price effects with labor is in the middle of factor intensity ranking as in (3).

*Table 2 *

The long term wage effects of structural shocks given by $(I - A(1))^{-1}C$ with bootstrap standard errors are reported in Table 3 after normalization. The effect of capital K on the wage is insignificant in the long term. The labor force *L* has a significant negative effect on the wage. A 1% initial increase in the labor force lowers the wage immediately as shown in Figure 4 with the effect accumulating and converging to -5.4% over eight years.

* Table 3 * Figure 4 *

The positive effect of energy on the wage is apparent in Figure 4. The energy effect is stronger than the capital effect with a tighter confidence band. An increase of 1% in energy input raises the wage 0.7% contemporaneously, increasing over the next two years to over 1% and converging to 0.9% over 6 years.

An increase in the energy price lowers energy input and the wage. Taxes or tariffs on energy would lower the wage as would a higher price of energy on the international market. This result supports Mountain (1986) who finds higher energy prices lowered the wage in Ontario, especially during the energy crisis of the late 1970s. In contrast, Nasseh and Elyasiani (1984) find higher energy prices led to substitution toward labor in the US, Canada, UK, Germany, and France during the late 1970s.

Wage responses to inputs imply labor is in the middle of intensity ranking (3) and suggest robust substitution. Labor groups rightly opposed to immigration should also support policy that is friendly to energy input.

The 1.3% long-run wage responses to a shock in the price of services are larger than for the manufactures price. Both price effects converge after 6 years. If services were labor intensive, the p_S elasticity would be greater than 1 and the p_M elasticity negative. The present insignificant price effects suggest labor is in the middle of intensity ranking (3). The weak price effects imply relatively flat contract curves with robust substitution as illustrated by Ford and Thompson (1997). The large output adjustments during the sample period are also evidence of strong substitution.

Tariffs on manufactures that purport to raise the wage are unsuccessful in the model. An increase of 10% in the price of manufactures might raise the wage 3.2% based on the insignificant point estimate. At any rate, that much of an increase in the price of manufactures is well beyond the range of protection. Even then, the purchasing power of labor would fall with a manufactures share of consumption over 32%. The bottom line is that labor has little interest in protection of manufactures.

Free trade leading to a higher price of services would be more successful in raising the wage. An increase of 10% in the price of services might raise the wage 12.8%.

Certainly, tightened immigration policy would raise the wage. A 1% decrease in the labor force, within range of current immigration laws, would raise the wage 5.4% based on the point estimate with a 90% confidence interval of [-10.40, -1.05].

The wage reacts to its own shocks from influences outside the model. A 1% wage shock results in a 0.7% wage increase over 8 years. Other variables, especially labor, react positively to their own shocks. Labor and the price of manufactures do not react to other variables, consistent with the assumption they are exogenous.

Energy input responds negatively to the wage. Capital has positive responses to shocks in energy input and the price of services. The price of services falls with capital and labor inputs, but increases with the wage. Energy input stimulates investment rather than vice versa, suggesting economic growth is heavily dependent on energy. Misspecification of a wide range of applied growth models is an issue. A positive labor force shock lowers the wage and the price of services.

The present results relate directly to the error correction estimates of Thompson (2010) where wage adjustments occur over two to three years. The present energy effect is similar in immediacy and size, as is the capital effect. The present labor force effects are about twice as strong over an adjustment period of six to eight years. The positive effects of the price of services are similar. The price of manufactures has no effect in the present estimates but a weak negative effect in the error correction estimate.

The variance decomposition analysis in Table 4 reveals that that only energy plays a role in affecting the variance of *k*-step-ahead wage forecast errors. Capital input and the wage explain significant portions of total variations only up to two years. Labor input explains a significant portion of wage variance only over more years. The contributions of prices to the variance of the wage are insignificant, consistent with the SVAR specification.

* Table 4 *

V. Conclusion

The present results have a wide range of policy implications. The insignificant wage effects of changing prices of manufactures and services suggest robust substitution with labor in the middle of the factor intensity ranking. Tariffs on imported manufactures lower the purchasing power of the wage. Further, a rising price of exported services with free trade might raise the wage. Long term trends of the falling price of manufactures and rising price of services raise the wage. Labor groups would be wise to shun protectionism that may only benefit industry owners over the short run.

A reduced labor force would strongly raise the wage suggesting labor groups should favor enforcement of immigration laws. Reducing capital taxes would raise the wage. Even more critical, reducing energy taxes would have a stronger wage impact. Labor productivity benefits from both capital and energy inputs, but much more from energy.

Directly estimating reduced form equations greatly widens the scope and application of the factor proportions model. Future research can estimate adjustments in the wage and other endogenous variables for other countries and time periods. Different specifications can disaggregate labor, add other inputs, and separate outputs. Various industrial structures and factor market assumptions can be tested directly. The price of energy can be assumed exogenous for small price taking economies with endogenous energy imports. Comparing estimated models across countries can reveal the influence of legal systems, industrial structure, and factor markets.

References

Chang, Winston (1979) "Some Theorems of Trade and General Equilibrium with Many Goods and Factors," *Econometrica* 47, 709-26.

Chipman, John (1979) "A Survey of the Theory of International Trade: Part 3, the Modern Theory," *Econometrica* 34, 18-76.

Dollar, David and Edward Wolff (1988) "Convergence of Labor Productivity among Advanced Economies, 1963-1982, *Review of Economics and Statistics* 70, 549-58.

Efron, Bradley and Robert Tibshirani (1993) *An Introduction to the Bootstrap*, London: Chapman and Hall/CRC.

Ford, Jon and Henry Thompson (1997) "Global Sensitivity of Neoclassical and Factor Proportions Models to Production Technology, *International Economic Journal* 11, 61-74.

Gremmen, Hans (1985) "Testing the Factor Price Equalization Theorem in the EC: An Alternative Approach," *Journal of Common Market Studies* 23, 277-86.

Hall, Alastair (1994) "Testing for a Unit Root in Time Series with Pretest Data-based Model Selection," *Journal of Business and Economic Statistics* 12, 461-70.

Harris, Richard (1992) "Testing for Unit Roots Using the Augmented Dickey-Fuller Test: Some Issues Relating to the Size, Power and the Lag Structure of the Test," *Economics Letters* 38, 381-86.

Heckscher, Eli (1919) "The Effects of Foreign Trade on the Distribution of Income," translated in Harry Ham and June Flanders, *Heckscher-Ohlin Trade Theory*, 1991, Cambridge: The MIT Press.

Hertel, Tom (2002) "Applied General Equilibrium Analysis of Agricultural and Resource Policies," in *Handbook of Agricultural Economics*, B. L. Gardner and G. C. Rausser, editors, Amsterdam: Elsevier.

Jones, Ron (1965) "The Structure of Simple General Equilibrium Models," *Journal of Political Economy* 73, 557-72.

Jones, Ron and Stephen Easton (1983) "Factor Intensities and Factor Substitution in General Equilibrium," *Journal of International Economics* 15, 65-99.

Kim, Hyeongwoo (2012) "Generalized Impulse Response Analysis: General or Extreme?" *Auburn Economics Working Paper No. 2012-04*.

Leamer, Edward (1996) “Wage Inequality from International Competition and Technological Change: Theory and Country Experience,” *American Economic Review* 86, 309-14.

Leamer, Edward and James Levinshon (1995) “International Trade Theory: The Evidence,” in *Handbook of International Economics*, Vol. III, ed. by Gene Grossman and Kenneth Rogoff, Amsterdam: Elsevier, 1339-94.

Lerner, Abba (1952) "Factor Prices and International Trade," *Economica* 19, 1-18.

Mokhrari, Manoucher and Farhad Rassekh (1989) “The Tendency Towards Factor Price Equalization Among OECD Countries,” *Review of Economics and Statistics* 71, 636-42.

Mountain, Dean (1986) “Impact of Higher Energy Prices on Wage Rates, Return to Capital, Energy Intensity and Productivity: A Regional Profit Specification,” *Energy Economics* 8, 171-6.

Nassah, Ali Reza, and Elyas Elyasiani (1984) “Energy Price Shocks in the 1970s: Impact on Industrialized Countries.” *Energy Economics* 6, 231-44.

Ng, Serena and Pierre Perron (2001) “Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power,” *Econometrica*, 69, 1519-54.

Ohlin, Bertil (1933) *Interregional and International Trade.* Cambridge*:* Harvard University Press.

O'Rouke, Kevin and Jeffrey Williamson (1992) “Were Heckscher and Ohlin Right? Putting the Factor Price Equalization Theorem back into History,” *NBER Working Paper* 37.

Pesaran, Hashem, and Yongcheol Shin (1996) “Cointegration and Speed of Convergence to Equilibrium,” *Journal of Econometrics*, 71, 117-43.

Pesaran, H. Hashem and Yongcheol Shin (1998) “Generalized Impulse Response Analysis in Linear Multivariate Models, *Economics Letters* 58, 17-29.

Rassekh, Farhad (1992) “The Role of International Trade in the Convergence of Per Capita GDP in the OECD, 1950-1985,” *International Economic Journal* 6, 1-15.

Rassekh, Farhad and Henry Thompson (1997) “Adjustment in General Equilibrium: Some Industrial Evidence,” *Review of International Economics* 5, 20-31.

Rassekh, Farhad and Henry Thompson (1998) “Micro and Macro Convergence: Factor Price Equalization and Per Capita Income,” *Pacific Economic Review*, 3-11.

Ruffin, Roy (1981) “Trade and Factor Movements with Three Factors and Two Goods,” *Economics Letters* 7, 177-82

Samuelson, Paul (1948) “International Trade and the Equalization of Factor Prices,” *Economic Journal* 58, 163-84.

Sims, Chris (1980) “Macroeconomics and Reality,” *Econometrica* 48, 1-48.

Stolper, Wolfgang and Paul Samuelson (1941) “Protection and Real Wages,” *The Review of Economic Studies* 28, 58-73.

Takayama, Akira (1982) “On Theorems of General Competitive Equilibrium of Production and Trade: A Survey of Recent Developments in the Theory of International Trade,” *Keio Economic Studies* 19, 1-38.

Thompson, Henry (1985) “Complementarity in a Simple General Equilibrium Production Model,” C*anadian Journal of Economics* 17, 616-21.

Thompson, Henry (1990) “Simulating a Multifactor General Equilibrium Model of Production,” *International Economic Journal* 4, 21-34

Thompson, Henry (1993) “The Magnification Effect with Three Factors,” *Keio Economic Studies* 30, 57-64

Thompson, Henry (1995) “Factor Intensity versus Factor Substitution in a Specified General Equilibrium Model, *Journal of Economic Integration* 10, 283-97.

Thompson, Henry (2010) “Wages in a Factor Proportions Time Series Model of the US,” *The Journal of International Trade and Economic Development* 19, 241-56.

Thompson, Henry (2011) “Estimating the Heckscher-Ohlin model: Inverting the Inverse Matrix,” *International Review of Economics and Finance*, 185-92

Thompson, Henry (2012) “Stolper-Samuelson Time Series: Long Term US Wage Adjustment, *Review of Development Economics*, forthcoming

Tovias, Alfred (1982) “Testing Factor Price Equalization in the EEC," *Journal of Common Market Studies* 20, 375-88.

Table 1. Unit Root Pretests

Variable	Specification	ADF_c	$ADF_{c,t}$
w	Level	-2.277	-2.656
	Differenced	$-5.571^{‡}$	$-5.704^{‡}$
K	Level	-0.990	-1.968
	Differenced	$-4.654^{‡}$	$-4.683^{‡}$
L	Level	-2.218	-1.624
	Differenced	$-2.994^{†}$	$-3.155^{§}$
p_M	Level	5.591	1.028
	Differenced	$-3.178^{†}$	$-7.292^{‡}$
p_S	Level	0.250	-1.235
	Differenced	$-6.869^{‡}$	$-6.895^{‡}$
E	Level	-2.647	-1.535
	Differenced	$-5.537^{‡}$	$-6.166^{‡}$

Note: The number of lags is selected by the general-to-specific rule of Hall (1994) following Ng and Perron (2001). ADF_c and $ADF_{c,t}$ refer the ADF-*t* statistics when an intercept is included and when an intercept and time trend are included. Superscripts § † ‡ indicate the null of unit root is rejected at 10%, 5%, and 1% levels. Asymptotic critical values are from Harris (1992).

Table 2. Contemporaneous Matrix Estimates

$$\varepsilon_t^{ps} = u_t^{ps}$$

$$\varepsilon_t^{pm} = -\underset{(0.398)}{0.022} u_t^{ps} + u_t^{pm}$$

$$\varepsilon_t^{L} = \underset{(0.155)}{0.158} u_t^{ps} - \underset{(0.031)}{0.004} u_t^{pm} + u_t^{L}$$

$$\varepsilon_t^{K} = \underset{(0.493)}{1.056} u_t^{ps} + \underset{(0.162)}{0.292} u_t^{pm} + \underset{(0.607)}{0.413} u_t^{L} + u_t^{K}$$

$$\varepsilon_t^{E} = \underset{(0.661)}{0.508} u_t^{ps} + \underset{(0.283)}{0.590} u_t^{pm} + \underset{(0.958)}{0.385} u_t^{L} + \underset{(0.226)}{0.467} u_t^{K} + u_t^{E}$$

$$\varepsilon_t^{w} = \underset{(0.773)}{0.878} u_t^{ps} + \underset{(0.256)}{0.362} u_t^{pm} - \underset{(1.138)}{1.180} u_t^{L} + \underset{(0.191)}{0.539} u_t^{K} + \underset{(0.095)}{0.709} u_t^{E} + u_t^{w}$$

Note: Standard errors are in parentheses and obtained from 10,000 nonparametric bootstrap simulations.

Table 3. Long Term Effect Estimates

	u_t^S	u_t^M	u_t^L	u_t^K	u_t^E	u_t^w
p_S	0.749*	-0.037	-1.288*	-0.176*	-0.077	0.153
	(0.311)	(0.101)	(0.637)	(0.087)	(0.058)	(0.098)
p_M	0.011	0.949*	0.368	-0.007	-0.156	-0.251
	(0.609)	(0.177)	(1.227)	(0.164)	(0.110)	(0.186)
L	0.156	-0.117	2.772*	0.084	0.046	0.001
	(0.527)	(0.158)	(0.923)	(0.126)	(0.084)	(0.147)
K	2.512*	-0.540	3.446	1.464*	0.520*	-0.499
	(1.270)	(0.464)	(2.943)	(0.401)	(0.259)	(0.443)
E	0.850	0.456	-0.529	0.111	1.107*	-0.637*
	(0.959)	(0.424)	(2.302)	(0.376)	(0.203)	(0.338)
w	1.281	0.322	-5.433*	0.452	0.920*	0.733*
	(1.559)	(0.517)	(2.898)	(0.418)	(0.252)	(0.435)

Note: Standard errors are in parentheses and obtained from 10,000 bootstrap simulations. * indicates that the estimate is significant at the 10% level.

Table 4. Variance Decomposition of *k*-Step ahead Forecast Error

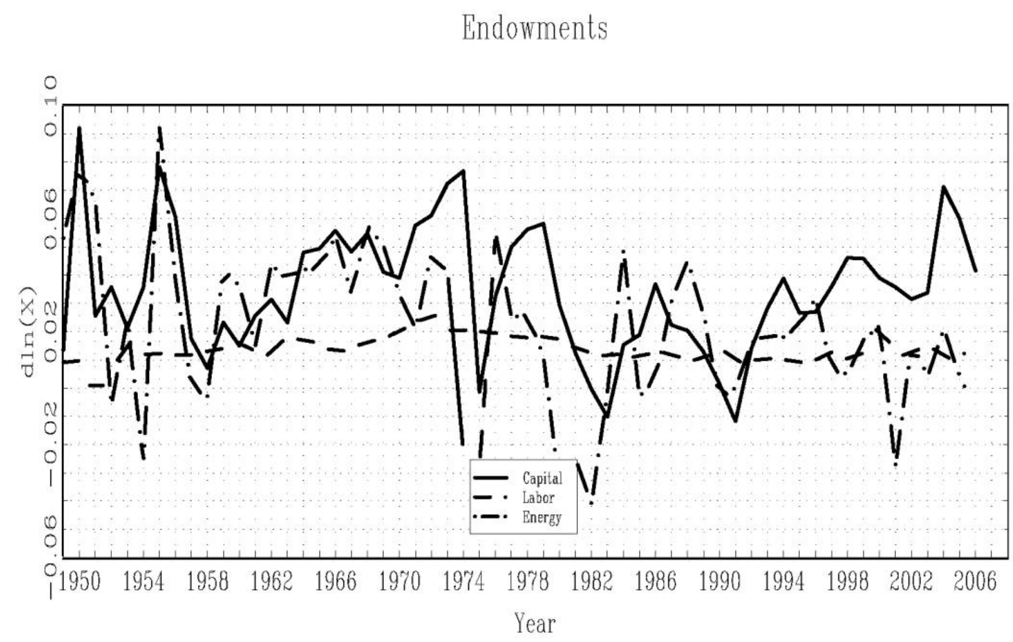
k	p_S	p_M	L	K	E	w
1	0.038	0.044	0.036	0.119	0.437	0.325
	(0.068)	(0.066)	(0.064)	(0.088)	(0.103)	(0.067)
2	0.046	0.016	0.106	0.145	0.534	0.153
	(0.088)	(0.062)	(0.103)	(0.106)	(0.131)	(0.076)
4	0.064	0.007	0.228	0.084	0.536	0.080
	(0.105)	(0.064)	(0.161)	(0.102)	(0.155)	(0.086)
6	0.050	0.013	0.334	0.053	0.455	0.094
	(0.101)	(0.071)	(0.193)	(0.093)	(0.161)	(0.088)
8	0.045	0.018	0.378	0.049	0.415	0.096
	(0.099)	(0.074)	(0.204)	(0.091)	(0.163)	(0.087)
10	0.045	0.018	0.393	0.047	0.404	0.094
	(0.099)	(0.074)	(0.209)	(0.091)	(0.165)	(0.087)

Note: Standard errors are in parentheses and obtained from 10,000 bootstrap simulations.

Figure 1. Data series

Note: Each series is demeaned.

Figure 2. Differenced Series



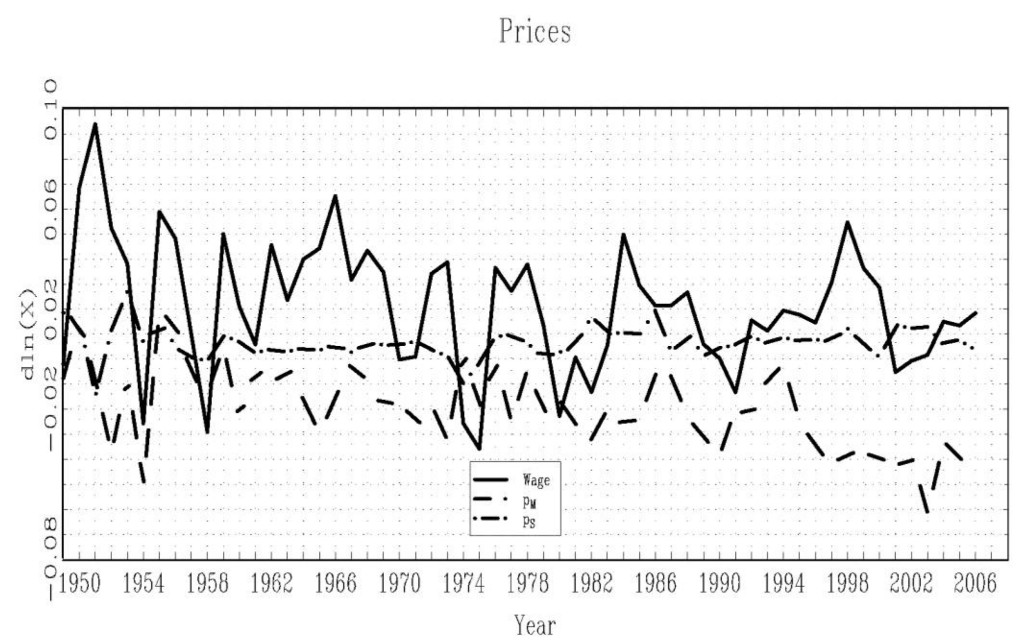
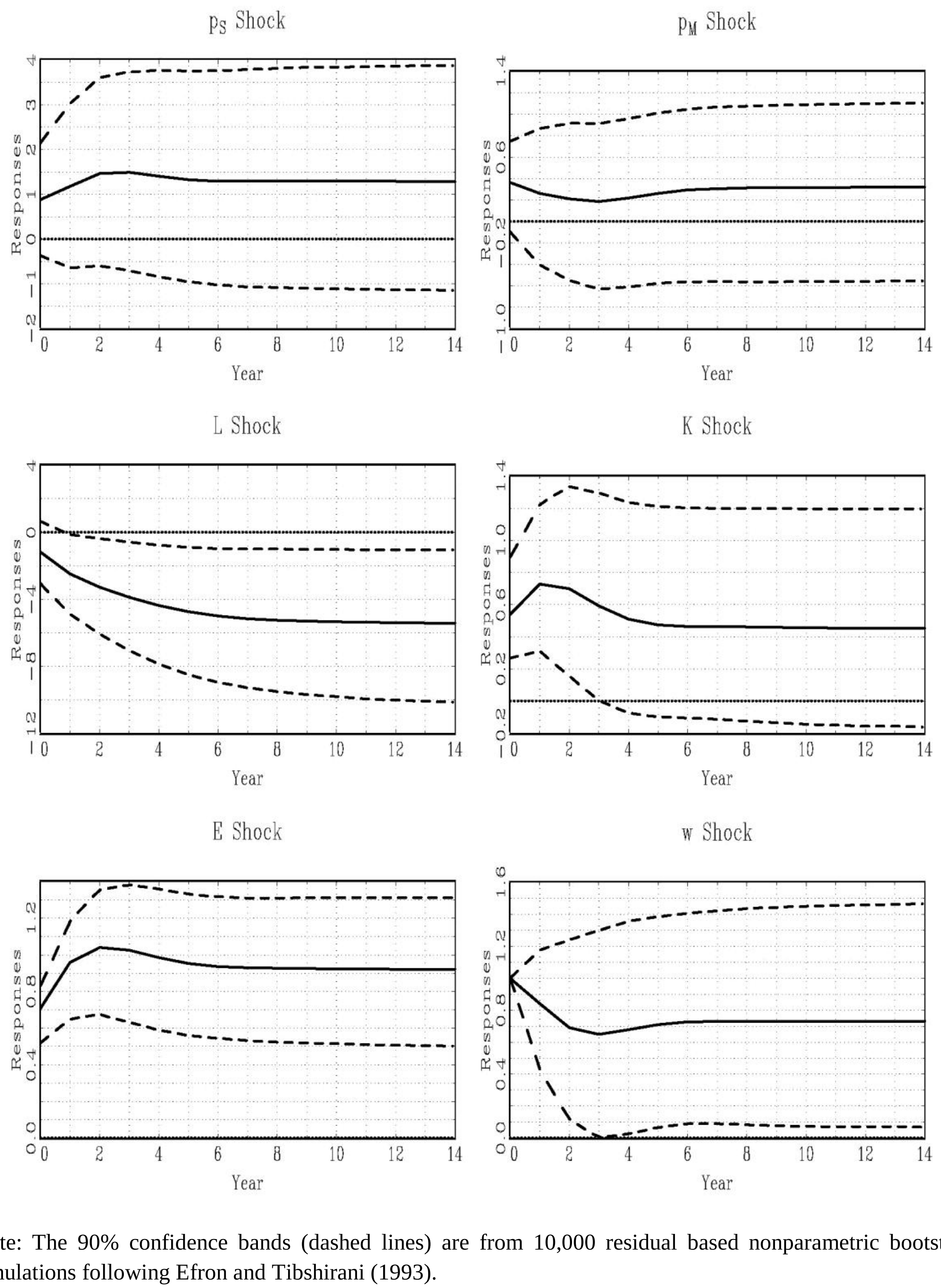


Figure 3. Wage Response Function Estimates



Note: The 90% confidence bands (dashed lines) are from 10,000 residual based nonparametric bootstrap simulations following Efron and Tibshirani (1993).