Stolper-Samuelson Wage Adjustment:
A Time Series Analysis of US Prices and Wages

Henry Thompson

Auburn University

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The comparative static model of production and trade specifies factor prices as functions of exogenous product prices and factor endowments. The Stolper-Samuelson theorem predicts wage adjustment to price changes depends on factor intensity in the model with two factors and two goods. The present paper estimates this comparative static wage adjustment as a time series difference model with the aggregate US wage adjusting to changes in prices of services and manufactures over period 1948 to 2006.

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Contact Information: Economics, 302 Comer Hall, Auburn University, AL 36849, 334-844-2910, fax 5999, *thomph1@auburn.edu*

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The Stolper-Samuelson (1941) theorem considers the effect of a tariff induced change in relative import prices on relative factor prices along the contract curve in the competitive general equilibrium model with two factors and two products. The related comparative static general equilibrium model of production includes the influence of factor intensity and substitution on the direction and size of the factor price adjustments. The applied trade literature looks for indirect evidence on the Stolper-Samuelson theory in wages of production relative to nonproduction workers, gini indices, trade volumes, relative prices of labor intensive products, and other indicators.

The present approach to the Stolper-Samuelson theorem is more direct, estimating the comparative static wage adjustment in a difference equation of the average US wage as a function of prices of manufactures and services in the US from 1948 to 2006. Another example of time series analysis applied to fundamental trade theorems is Rassekh (1992) who examines factor price equalization in terms of wage convergence. The present model assumes two products (manufacturing and services) and two factors (labor and capital). Fixed capital assets and the labor force are exogenous variables in the time series difference equation.

1. The 2x2 Production Model

The main assumptions of the competitive general equilibrium model of production are full employment and competitive pricing as developed by Samuelson (1953), Chipman (1966), Chang (1979), and Ethier (1984). In the present application, outputs of manufacturing and services x_M and x_S are priced competitively with cost minimizing production, and factors of production capital K and labor L are fully employed. Substitution elasticities describe how inputs adjust to changing factor prices in the aggregate economy as developed by Jones and Scheinkman (1976). The comparative static model with endogenous factor price and output adjustments is

$$\begin{pmatrix} \sigma_{LL} & \sigma_{LK} & \theta_{LM} & \theta_{LS} \\ \sigma_{KL} & \sigma_{KK} & \theta_{KM} & \theta_{KS} \\ \lambda_{LM} & \lambda_{KM} & 0 & 0 \\ \lambda_{LS} & \lambda_{KS} & 0 & 0 \end{pmatrix} \begin{pmatrix} dlnw \\ dlnr \\ dlnx_M \\ dlnx_S \end{pmatrix} = \begin{pmatrix} dlnL \\ dlnK \\ dlnp_M \\ dlnp_S \end{pmatrix} . \tag{1}$$

Factor prices are wages w and capital rents r, and product prices are p_M and p_S. Percentage changes stated in terms of differences of natural logs relate directly to the time series difference equation. The first two equations in (1) are derived from full employment of labor and capital, and the last two from competitive pricing of manufacturing and services.

The full employment condition for labor is $L = \Sigma_j a_{Lj} x_j$ where L is the labor force, a_{Lj} is the input of labor per unit of good j, x_j is output of good j, and j represents manufacturing M or services S. This condition is differentiated and converted to elasticity form in the first equation of (1) with factor shares θ_{Lj} in industry revenue allowing for endogenous output adjustments, and substitution elasticities σ_{ik} allowing for factor price adjustments. The second equation in (1) is for capital employment.

Competitive pricing of each product is written $p_j = a_{Lj}w + a_{Kj}r$ and differentiation with the cost minimizing envelope condition leads to the last two equations in (1). Industry shares λ_{ij} represent portions of factor i employed in sector j and allow for endogenous factor price adjustments.

Premultiply (1) by the inverse of the system matrix M in (1) to find

$$\begin{pmatrix} dlnw \\ dlnr \\ dlnx_M \\ dlnx_S \end{pmatrix} = M^{-1} \begin{pmatrix} dlnL \\ dlnK \\ dlnp_M \\ dlnp_S \end{pmatrix} . \tag{2}$$

Solving (2),

$$dlnw = (\lambda_{KS} dlnp_m - \lambda_{KM} dlnp_s)/\lambda . \tag{3}$$

The empirical specification of the wage difference equation is

$$dlnw = \alpha_1 dlnK + \alpha_2 dlnL + \alpha_3 dlnp_M + \alpha_4 dlnp_S . \tag{4}$$

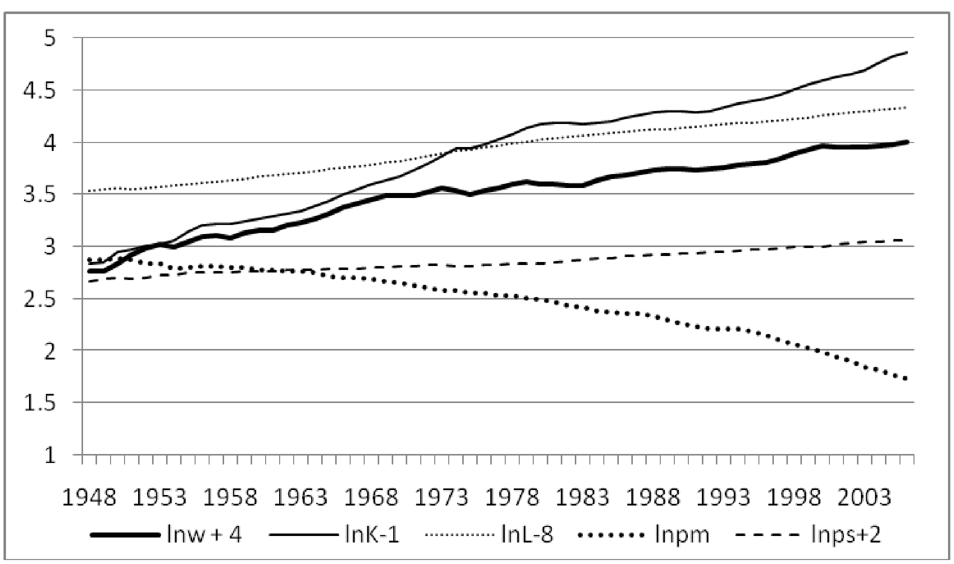
Comparing (3) and (4), theory predicts α_1 and α_2 equal 0 in the estimation of (4), the factor price equalization FPE result. FPE is implied by the zeroes in the null submatrix of the block recursive system matrix in (1) and holds in any model with the same number of factors and prices. If two similar countries trade freely, the equal product prices imply FPE. For a given country as in the present data, small changes in capital or labor endowments have no wage effect due to FPE.

The service sector is labor intensive as shown by Thompson (2007) and the Stolper-Samuelson theorem implies $\alpha_3 < 0$ and $\alpha_4 > 0$ in (4). The magnification effect of Jones (1965) implies percentage wage adjustments flank percentage price changes, implying $\alpha_3 < -1$ and $\alpha_4 > 1$.

2. Stationarity Analysis

The data in Figure 1 from the National Economic Accounts of the Bureau of Economic Analysis (2007) are rescaled as indicated for ease of comparison. The wage w = WL/P is derived as the nominal total employee compensation WL from the national accounts averaged across the labor force L and deflated by the consumer price index P. The wage w has a positive trend over the sixty years.

Figure 1. Data series



The capital stock K is the net stock of fixed capital assets also deflated by the consumer price index, and it generally increases at an increasing rate. The labor force L is the civilian non-institutional population 16 years and older, and it increases at a slower steady rate.

Price indices for manufacturing p_M and services p_S are also deflated by the consumer price index, making them prices of manufactures and services relative to all products. There is a slowly rising price of services and an accelerating decline in the price of manufactures. It is safe to say the 68% decrease in the price of manufactures over the sixty years is due partly to lost import protection and cheap labor intensive imports. The price of services, in stark contrast, increased 59% over the period. The relative price of services p_s/p_m increased almost five times, and the relative output of services increased of 48% according to output indices.

Stationarity tests in Table 1 indicate these series are all nonstationary according to AR(1) autoregressive tests $x = \alpha_0 + \alpha_1 x_{-1} + \varepsilon$ with α_1 plus two times its standard deviation all greater than 1.

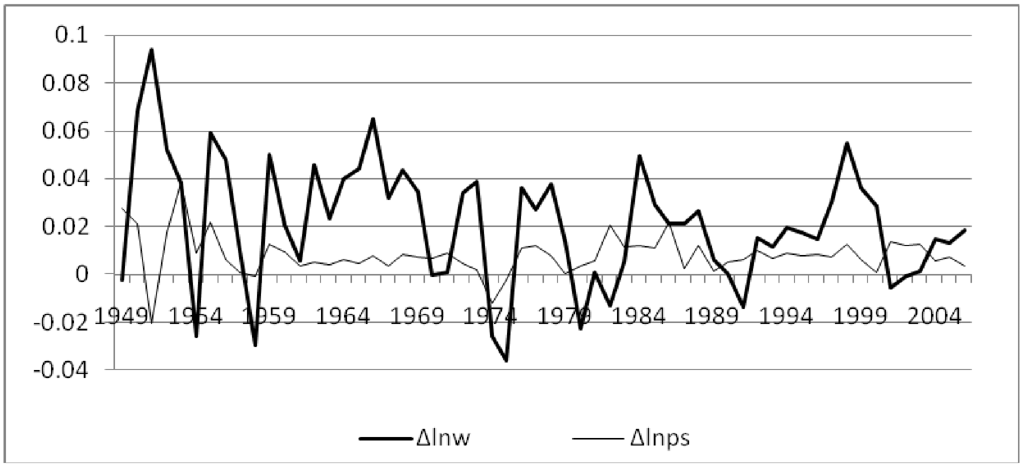
* Table 1 *

Table 2 reports the spurious model estimation between the endogenous wage and exogenous levels of the labor force L, capital stock K, and prices of manufactures p_M and services p_S. The Durbin Watson statistic DW confirms expected autocorrelation. The series are not cointegrated according to the Engle-Granger EG (1987) test.

* Table 2 *

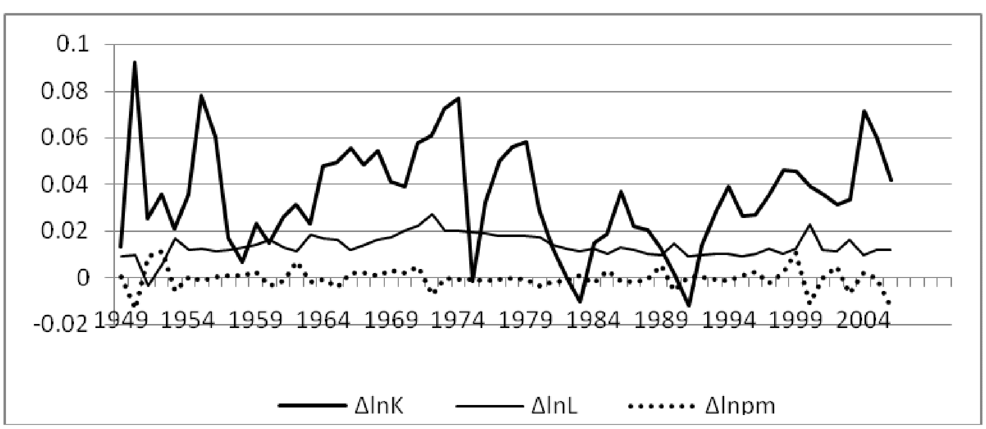
The present focus is on estimation of the difference equation (4). The wage $\Delta \ln w$ and price of services $\Delta \ln p_S$ in Figure 2 are difference stationary by Dickey-Fuller tests with a constant $\Delta x = \alpha_0 + \alpha_1 x_{-1} + \varepsilon$. The α_1 coefficients are insignificant relative to the critical DF statistic -3.78 and F statistics are insignificant relative to the critical $\varphi = 7.06$. There is no evidence of autocorrelation in the residuals according to Durbin-Watson statistics relative to the critical DW = 1.40. There is no heteroskedasticity in the residuals according to autoregressive conditional heteroskedasticity ARCH(1) tests $\varepsilon^2 = \alpha_0 + \alpha_1 \varepsilon^2_{-1} + e$ with $\alpha_1 = 0$. Regressions with $\Delta \ln w$ and $\Delta \ln p_S$ should be reliable.

Figure 2. Difference Stationary



The capital stock ΔlnK in Figure 3 is not difference stationary due to autocorrelation in the residual of Dickey-Fuller tests and ARCH(1) heteroskedasticity in the augmented Dickey-Fuller ADF test reported in Table 2. Differences in the labor force ΔlnL and price of manufactures Δlnp_M are not stationary due to autocorrelation in Dickey-Fuller tests or significant F statistics in φ tests. These series are difference stationary with a 1975 structural break by the Perron (1989) test, consistent with the oil price structural break in US macroeconomic time series. The difference equation regression includes this Perron dummy variable.

Figure 3. Difference Stationary with 1975 Perron Structural Break



3. Comparative Static Difference Model

Table 3 reports estimation of the structural model (4) written in differences as

$$\Delta \ln w = \alpha_1 \Delta \ln K + \alpha_2 \Delta \ln L + \alpha_3 \Delta \ln p_M + \alpha_4 \Delta \ln p_S + \alpha_5 \Delta D_{1975} + \varepsilon. \tag{5}$$

Explanatory power is reasonable and there is no positive autocorrelation according to the Durbin-Watson statistic. The structural break has no effect. There is no evidence of heteroskedasticity according to an unreported autorgressive conditional ARCH(1) test.

* Table 3 *

Changes in the price of services p_S have the anticipated positive wage effect with an estimated arc elasticity of 0.65. The mean of $\Delta \ln p_S$ in the sample is 0.008 and the standard deviation is 0.009, implying a range of percentage price changes from 0.017 to -0.001. The implied wage adjustments range from $\Delta \ln w = 0.011$ to -0.001. Over the sample period p_S rose by 59% implying an estimated 38% increase in the wage that accounts for 16% of the actual increase. The magnification effect does not hold since the estimated coefficient is less than one, a result consistent with a model that includes other factors of production.

Changes in the price of manufactures p_M have no wage effect. The decline in the manufacturing output of 28% over the period might explain the lack of a wage effect.

Changes in the labor force L have no wage effect as predicted by the theoretical model but changes in capital K affect the wage. This capital effect is also consistent with a model that includes other factors of production, as well as models with monopolistic pricing and unemployment as developed by Thompson (2003).

Table 3 also reports an estimate of (5) that imposes the lack of capital stock and labor force effects, $\alpha_2 = \alpha_3 = 0$. In this specification, the magnification effect holds for labor intensive services. The 59% increase in the price of services would account for a 90% increase in the wage, 40% of the actual increase. Once again, the price of manufactures has no wage effect.

4. Conclusion

The present empirical results provide some direct support for the factor intensity link between the price of services and the average US wage over a sixty year period. The lack of an effect of the price of manufactures suggests there is no Stolper-Samuelson link between protection and real wages.

Time series analysis offers a largely unexplored opportunity to accumulate evidence on fundamental trade theorems. General equilibrium models with various factors of production (labor skills, capital, natural resources, energy) are known for their lack of qualitative comparative static properties but empirical results would provide parameters for refining theory.

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Table 1. Stationarity Analysis

	AR(1)	DF	DFc	DFt	ADF	Perron 1975
lnw φ DW ARCH(1)	1.02 > 1	9.04	-2.44 5.95 1.68 0.42			
lnK φ DW ARCH(1)	1.01 > 1	11.3	-0.95 0.89 1.13*	-1.24 1.07 1.11*	-1.97 6.21 1.87 2.97*	-1.79 1.97 1.27
lnL φ DW ARCH(1)	1.00 > 1	21.6	-0.23 0.05 0.79*	-0.49 0.20 0.79*	-1.28 11.2*	-2.43 1.87 0.94
$\ln p_s$ φ DW ARCH(1)	1.01 > 1	-5.71*	-0.95 0.91 1.82 0.36			
$\ln p_m$ φ DW ARCH(1)	1.03 > 1	-3.60*	5.59	1.03 15.4*	0.99	-0.48 1.78 0.99
τ_{DF} φ DW 1.40		-2.62	-3.58	-4.15 7.02	-4.15 7.02	τ_{Perron} -3.76

Table 2. Spurious Model

lnw	constant	lnK	lnL	lnp_m	lnp_s	EG τ -4.15
R^2 .982 DW 0.47	10.5*** (4.11)	0.82*** (18.1)	-0.89** (-3.61)	0.39*** (5.18)	2.03*** (7.94)	-2.76 DW 1.57

Table 3. Difference Models

Δlnw	ΔlnK	ΔlnL	Δlnp_m	Δlnp_s	D_{1975}
R^2 .490 DW 1.63 ARCH(1) 0.96	0.68*** (4.85)	-0.64 (-1.34)	0.84 (1.21)	0.65* (1.84)	-.001 (-0.25)
R^2 .217 DW 1.43 ARCH(1) 1.18			0.97 (1.11)	1.33*** (3.37)	.004 (0.68)