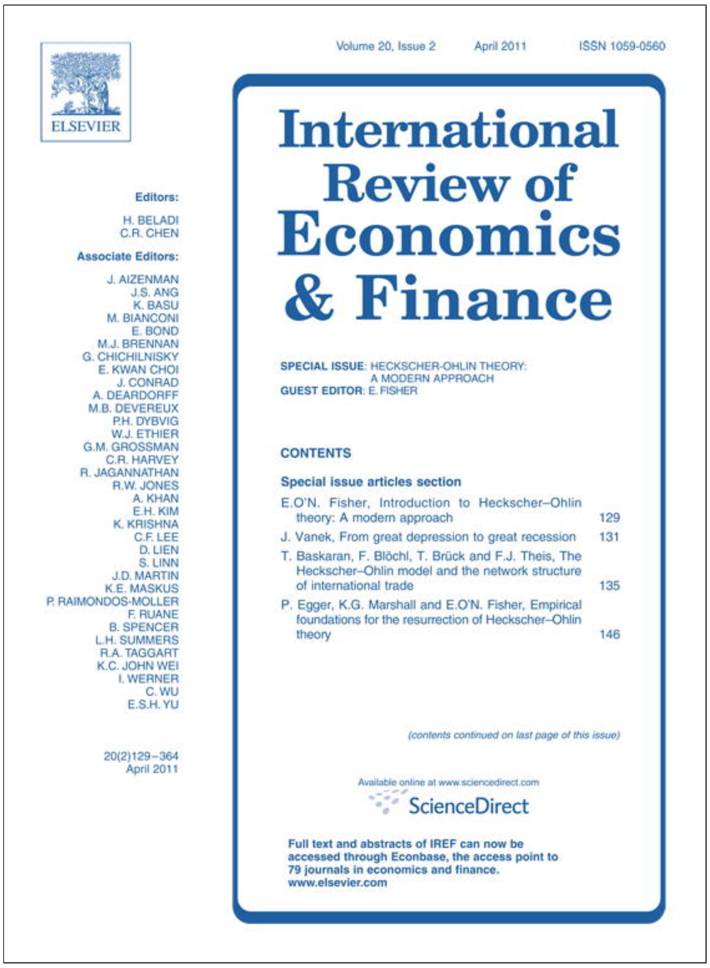

Volume 20, Issue 2 April 2011 ISSN 1059-0560

ELSEVIER

International Review of Economics & Finance

20(2)129–364
April 2011

SPECIAL ISSUE: HECKSCHER-OHLIN THEORY: A MODERN APPROACH
GUEST EDITOR: E. FISHER

CONTENTS

Special issue articles section

(contents continued on last page of this issue)

Available online at www.sciencedirect.com
ScienceDirect

**Full text and abstracts of IREF can now be accessed through Econbase, the access point to 79 journals in economics and finance.
www.elsevier.com**

International Review of Economics and Finance 20 (2011) 185–192

Contents lists available at ScienceDirect

International Review of Economics and Finance

journal homepage: www.elsevier.com/locate/iref

Estimating the Heckscher–Ohlin model: Inverting the inverse matrix

Henry Thompson *

Economics, 202 Comer Hall, Auburn University AL 36849, United States

ARTICLE INFO

Available online 26 November 2010

JEL classification:
F1

Keywords:
Estimation
Heckscher–Ohlin
Stolper–Samuelson

ABSTRACT

This paper estimates the Heckscher–Ohlin model with annual US data from 1949 to 2006 for outputs of manufactures and services with inputs of fixed capital assets and the labor force. Difference equation and error correction regressions provide estimated coefficients for the comparative static system. Tariffs on manufactures primarily raise the capital return in the estimated Stolper–Samuelson results. Factor price equalization does not hold for labor and capital. Inverting the estimated system inverse matrix provides evidence on production. The suggestions are capital biased production of manufactures, strong substitution of capital for labor, and strong labor substitution in manufactures.

Analysis of annual US data from 1949 to 2006 provides some evidence on the Heckscher–Ohlin factor proportions model in the present difference equation and error correction regressions. This paper estimates adjustments in the wage, capital return, and outputs of manufactures and services to changes in factor endowments and product prices. Such a direct approach to estimating the factor proportions model is novel in the empirical trade literature.

The model of Heckscher (1919) and Ohlin (1924) as formalized by Stolper and Samuelson (1941), Samuelson (1953), Jones (1965), and Chipman (1966) provides the foundation of the general equilibrium theory of production and trade. The model assumes homothetic production but the present estimates suggest capital biased manufactures.

Fixed capital assets and the labor force have robust effects on the wage and capital return in the difference equation estimates. For a model consistent with this wage evidence, Thompson (2010) adds energy input. The present paper interprets results as evidence of nonhomothetic production.

Estimated comparative static elasticities relate to fundamental trade theorems with policy implications that include tariffs, subsidies, immigration, and foreign investment. Inverting the matrix of estimated comparative static elasticities reveals evidence on properties of production.

The following section develops a parametric approach to nonhomothetic production consistent with the present empirical results. Following a look at data stationarity, the paper estimates the Heckscher–Ohlin regression. The last section inverts the estimated comparative static matrix to uncover evidence on production characteristics.

1. The Heckscher–Ohlin model with nonhomothetic production

The Heckscher–Ohlin model reviewed by Jones and Neary (1984) is based on technical assumptions of neoclassical, constant returns, homothetic production and the behavioral assumptions of competitive pricing and full employment. Changing factor endowments have no impact on factor prices inside the 2×2 production cone, implying factor price equalization between freely trading countries. Directions of the effects of changing prices on factor prices depend only on factor intensity, and are reciprocal to the effects of endowments on outputs. The production frontier is concave in product prices.

* Tel.: +1 334 844 2910; fax: +1 5999.
E-mail address: thomph1@auburn.edu.

1059-0560/$ – see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.iref.2010.11.007

Competitive pricing implies revenue equals cost,

$$p_j x_j = w a_{Lj} x_j + r a_{Kj} x_j \tag{1}$$

where p_j is the price of product j, x_j is output, w is the wage, r is capital return, and the a_{ij} are cost minimizing inputs of factor $i = L,K$ per unit of product $j = M,S$.

By Shephard's lemma, unit inputs a_{ij} are the first derivatives of the cost function cj(w, r, x_j) with respect to w or r, that is $a_{Lj} = \partial c_j(.)/\partial w$ and $a_{Kj} = \partial c_j(.)/\partial r$. Nonhomothetic production implies unit inputs a_{ij} are sensitive to output x_j as well. In functional notation, $a_{ij} = a_{ij}(w, r, x_j)$. Second derivatives are assumed concave in their own factor prices $\partial a_{ij}/\partial w_i = \partial^2 c_j(.)/\partial w_i^2 < 0$ with positive cross price effects $\partial a_{ij}/\partial w_k = \partial^2 c_j/\partial w_i w_k > 0$.

Differentiate Eq. (1) to find

$$x_j dp_j = \left(\Sigma_i w_i a_{ij} - p_j\right) dx_j + \Sigma_i a_{ij} x_j dw_i + \Sigma_i w_i x_j da_{ij}. \tag{2}$$

Fully differentiating the a_{ij} leads to

$$da_{ij} = \Sigma_k a_{ij}^k dw_k + a_{ij}^j dx_j \tag{3}$$

where $a_{ij}^k \equiv \partial a_{ij}/\partial w_k$ and $a_{ij}^j \equiv \partial a_{ij}/\partial x_j$. Signs and sizes of these two partial derivatives depend on homotheticity and returns to scale. Homothetic constant returns production would imply $a_{ij}^j = 0$ simplifying Eq. (3) to $da_{ij} = \Sigma_k a_{ij}^k dw_k$. Homothetic increasing returns would imply $a_{Lj}^j < 0$ and $a_{Kj}^j < 0$ with proportional changes and a constant capital–labor ratio a_{Kj}/a_{Lj}. Capital biased constant returns production would imply $a_{Kj}^j > 0$ and $a_{Lj}^j < 0$. Increasing returns would imply a negative a_{Kj}^j or a_{Lj}^j.

Nonhomothetic production can be approached with the constant elasticity of substitution CES production function of Arrow, Chenery, Minhas and Solow (1961) developed by Sato (1967), Kmenta (1967), Takayama (1993), and Shimomura (1999). The applied production literature also estimates translog production or cost functions of Christensen, Jorgensen and Lau (1973) and other similar functions. The present approach to nonhomothetic production focuses on the linear relation between output and cost minimizing unit inputs.

The present approach to nonhomothetic production is similar to Horn (1983) who develops the global static model. The present approach assumes the substitution elasticities σ_{ik} are constant in a linear relationship between output and the cost minimized inputs as in Thompson (2003).

Competitive pricing implies cost $\Sigma_i w_i a_{ij}$ equals price p_j reducing Eq. (2) to

$$x_j dp_j = \Sigma_i a_{ij} x_j dw_i + \Sigma_i w_i x_j da_{ij}. \tag{4}$$

Introducing percentage changes as differences of natural logs,

$$d\ln p_j = \Sigma_i \alpha_{ij} d\ln w_i + \alpha_j d\ln x_j \tag{5}$$

where input adjustments are reflected by the α_{ij} and α_j terms. Substitution of input i with respect to the price of input k appears in the term $\alpha_{ij} \equiv \theta_{ij} + \Sigma_k \theta_{kj} \sigma_{ki}^j$ where factor shares are $\theta_{ij} \equiv w_i a_{ij}/p_j$ and factor price substitution elasticities are $\sigma_{ki}^j \equiv (\partial a_{ij}/\partial w_k)(w_k/a_{ij})$. Inputs also adjust with respect to output x_j in the term $\alpha_j \equiv \Sigma_i \theta_{ij} \sigma_{ij}$ with output elasticities $\sigma_{ij} \equiv (\partial a_{ij}/\partial x_j)(x_j/a_{ij})$. Homothetic production simplifies Eq. (5) to $d\ln p_j = \Sigma_i \theta_{ij} d\ln w_i$. The competitive pricing relationship in Eq. (5) leads to the two final equations in the comparative static system (Eq. (8)).

Full employment implies the labor endowment L equals labor demand $\Sigma_j a_{Lj} x_j$. Differentiate to find $dL = \Sigma_j a_{Lj} dx_j + \Sigma_j x_j da_{Lj}$. Expand da_{Lj} and introduce percentage changes to find

$$d\ln L = \Sigma_j \lambda_{Lj} d\ln x_j + \Sigma_j \left(x_j / L\right)\left(\Sigma_k a_{Lj}^k dw_k + a_{Lj}^j dx_j\right) \tag{6}$$

where $\lambda_{Lj} \equiv a_{Lj} x_j / L$ is the industry j share of labor. The second term in Eq. (6) reduces to $\Sigma_k \sigma_{Lk} d\ln w_k + \Sigma_j x_j \lambda_{Lj} d\ln x_j$ where $\sigma_{Lk} \equiv \Sigma_j \lambda_{Lj} a_{Lj}^k$ is the weighted aggregate substitution elasticity between the price of factor k and the cost minimizing unit labor input. The first equation in Eq. (8) is this full employment condition for labor,

$$d\ln L = \Sigma_k \sigma_{Lk} d\ln w_k + \Sigma_j \left(1 + x_j\right) \lambda_{Lj} d\ln x_j. \tag{7}$$

Homothetic production would simplify Eq. (7) to $d\ln L = \Sigma_k \sigma_{Lk} d\ln w_k + \Sigma_j \lambda_{Lj} d\ln x_j$. The similar full employment condition for capital K is the second equation of Eq. (8).

The comparative static factor proportions model with the present specification of nonhomothetic production is

$$\begin{pmatrix} \sigma_{LL} & \sigma_{LK} & (1+x_M)\lambda_{Lm} & (1+x_S)\lambda_{Ls} \\ \sigma_{KL} & \sigma_{KK} & (1+x_M)\lambda_{Km} & (1+x_S)\lambda_{Ks} \\ \alpha_{Lm} & \alpha_{Km} & \alpha_m & 0 \\ \alpha_{Ls} & \alpha_{Ks} & 0 & \alpha_s \end{pmatrix} \begin{pmatrix} d\ln w \\ d\ln r \\ d\ln x_m \\ d\ln x_s \end{pmatrix} = \begin{pmatrix} d\ln L \\ d\ln K \\ d\ln p_m \\ d\ln p_s \end{pmatrix}. \tag{8}$$

With homothetic production the system matrix A would be derived from the Hessian of the constrained neoclassical income maximization. Chang (1979) shows its determinant is positive. With nonhomothetic production, the sign of the determinant depends partly on σ_{ki}^j and σ_{ij} relaxin the concavity condition.

Shephard's lemma $a_{ij} = \partial c_j / \partial w_i$ and Young's theorem imply $\partial a_{ij}/\partial w_k = \partial a_{kj}/\partial w_i$. Neoclassical concavity implies negative own substitution in the terms $\sigma_{LL} < 0$ and $\sigma_{KK} < 0$. Cross price elasticities σ_{LK} and σ_{LK} are positive indicating substitutes with two inputs.

Invert Eq. (8) to find the system of endogenous factor prices and outputs as functions of exogenous endowments and prices,

$$A^{-1} \begin{pmatrix} d\ln L \\ d\ln K \\ d\ln p_m \\ d\ln p_s \end{pmatrix} = \begin{pmatrix} d\ln w \\ d\ln r \\ d\ln x_m \\ d\ln x_s \end{pmatrix}. \tag{9}$$

The following sections estimate the four equations in Eq. (9). The inverse of this estimated A^{-1} matrix reveals evidence on production in the implied system matrix A in Eq. (8).

A fundamental econometric issue is that the parameters in A^{-1} are functions of the endogenous variables. The present regression analysis does not address this potential problem of parameter drift. Consider estimated coefficients of the regressions "average" parameters for the period.

The present model also raises issues of distortion due to aggregation. If the true model has many products, the competitive model with two factors is only invertible under very restrictive conditions on exogenous world prices or in a model with nontraded products. That point aside, estimates with many products could provide different evidence on homotheticity. Bernstein and Weinstein (2002) examine conditions for production with many products, making the point that the minimum number of products equals the number of factors. Fisher and Marshal (in press) utilize the pseudo-inverse to examine invertible general equilibrium models with many products and Leontief technology. Aggregation may suggest nonhomothetic production when disaggregated production functions appear homothetic.

2. Data and stationarity pretests

The wage, labor force, capital stock, and outputs of manufactures and services are from National Income and Product Accounts of the Bureau of Economic Analysis (2009). Price indices are from the Bureau of Labor Statistics (2009). The prime interest rate is from the Federal Reserve (2009).

The average wage w is deflated employee compensation averaged across the labor force L. Prices of manufactures p_m and services p_s are indices relative to the consumer price index. The capital stock K is the deflated stock of net fixed capital assets.

The capital return r is the prime interest rate i minus the expected inflation π^e plus an arbitrary 4% rental fee. Assuming perfect foresight, expected inflation π^e equals the actual inflation π. This derived capital return is relatively volatile with a mean of 7.2%, a standard deviation of 2.8%, a maximum of 15%, and a minimum of 0.2%. The positive r allows direct estimation of elasticities with natural logs of variables as in Eq. (9). Any rental fee would lead to the same regression results. Regressions with naïve π^e equal to last year's inflation rate produce weaker regression estimates.

Fig. 1 shows plots of factor prices and endowments relative to means. The capital return has the highest variation jumping in 1980 with the prime interest rate but then moderating with inflation. The wage grows steadily over the period with some variation. The capital stock grows at a faster rate and with more variation than the labor force.

Fig. 2 shows output and price variables. Manufactures output grows with some variation. Services output growth is higher, steadier, and increasing. The price of manufactures declines over the period with deceleration while the price of services grows steadily. The relative price of services increases about five times while relative services output increases by about half along the expanding production frontier.

Fig. 3 shows percentage changes of factor variables. Changes in endogenous factor prices have much higher variation than changes in exogenous endowments. The change in the capital return has the highest variation by far. The change in the capital stock varies somewhat while the change in the labor force has little variation. Differences in all factor variables appear stationary.

Fig. 4 shows there is higher variation in growth rates of endogenous outputs than exogenous prices. A major assumption of the model is that the US is a price taker, arguably reasonable at the present highly aggregated level. For particular narrowly defined industries, the US may have market power but there is active international competition across aggregated industries. Heavily traded business services are the main component of the service sector. Manufactures output varies considerably, declining on average. In contrast, services output declines only in 1982.

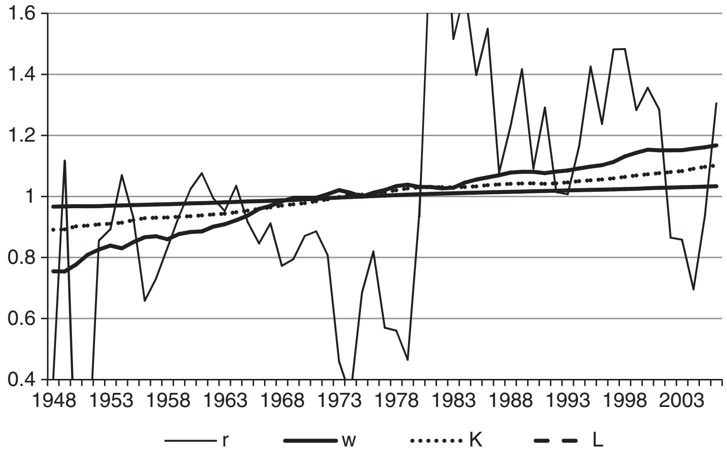

Fig. 1. Factor series.

Stationary pretests determine the order of integration for regression analysis. Pretests with augmented Dickey and Fuller (1979) ADF tests reveal difference stationary series with no evidence of residual correlation. Natural logs of outputs $\ln x_m$ and $\ln x_s$ and the price of services $\ln p_s$ are difference stationary with a single lagged dependent variable. The wage lnw and capital stock lnK are difference stationary with a second lag in ADF(2) tests. The capital return lnr is difference stationary in an ADF(4) test. The price of manufactures $\ln p_m$ is difference stationary with a Perron (1989) structural break in 1975 consistent with the energy crises. The labor force lnL has significant F-tests due to the lagged dependent variable that do not diminish at higher orders but the analysis proceeds.

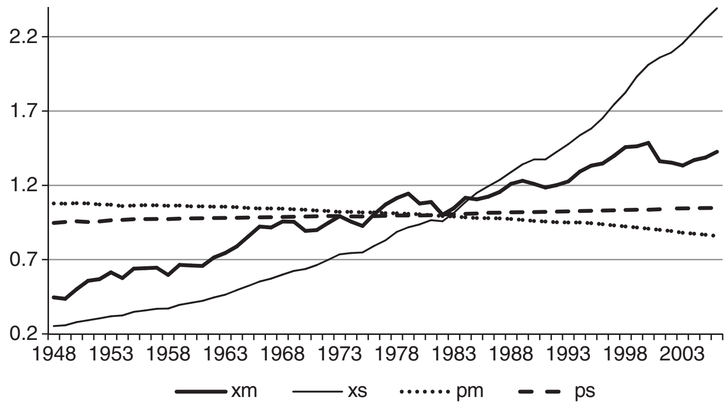

Fig. 2. Output series.

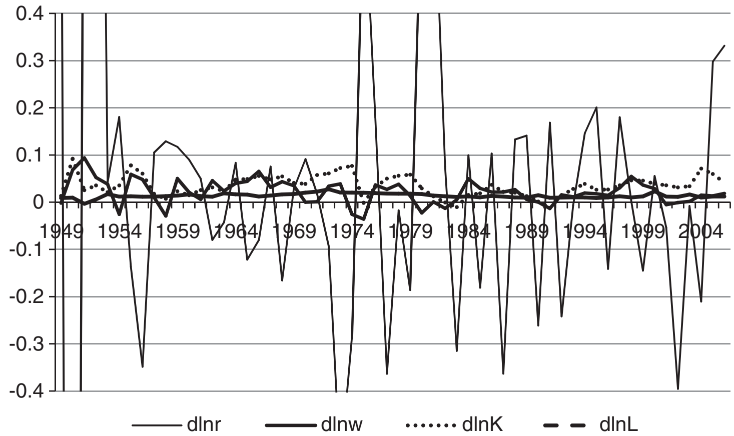

Fig. 3. Factor growth rates.

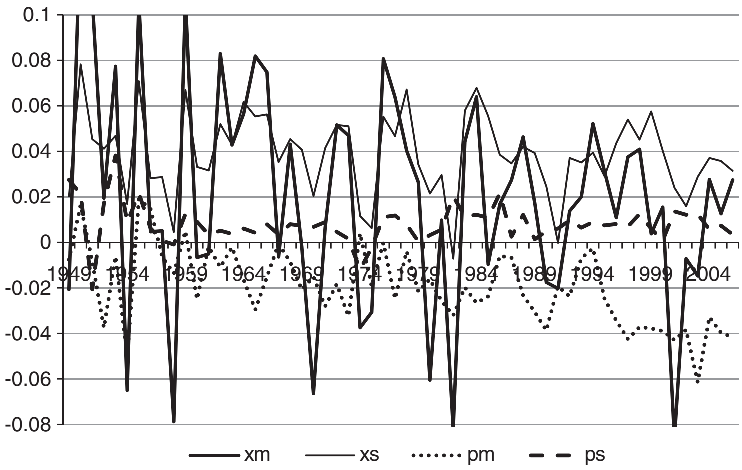

Fig. 4. Output growth rates.

3. Heckscher–Ohlin model regressions

Table 1 reports regressions on factor prices and outputs as functions of factor endowments and prices. There is expected residual correlation in Durbin and Watson (1951) tests as well as ARCH(1) heteroskedasticity but difference equation and error correction regressions prove reliable. The variables in the capital return regression are co-integrated by the Engel and Granger (1987) test, leading to an error correction regression.

The intuitive wage effects of labor and capital endowments in the top row persist in the difference equation estimates. Partial equilibrium economics anticipates these wage results with the effects of changes in supply or marginal productivity. Endowment effects are insignificant for the capital return in the second row.

An increase in the capital stock appears to increase both outputs, especially manufactures. Difference regressions verify these results. Labor force effects on outputs in the difference regressions are different. Elasticities of factor prices with respect to prices are all positive but only the services price elasticity of the wage proves significant in the difference equation regressions.

In the lower right corner of Table 1 both outputs appear sensitive to their own price along the production frontier, an intuitive result that holds in the difference regressions. A higher price of services appears to raise output of manufactures but this result disappears in the difference equation regressions.

Difference equation regressions are in Table 2. The lack of residual correlation and heteroskedasticity suggest changes in fixed capital assets successfully model technological change. Explanatory power is highest in the wage equation and lowest in the capital return equation. A regression with the Perron residual for the price of manufactures produces similar results and is not reported.

An increase in the labor supply strongly lowers the wage while an increase in the capital stock has a strong positive wage impact. An increase in the capital stock lowers the capital return. Labor has no effect on the capital return but a positive effect emerges in the error correction estimate. These results suggest nonhomothetic production.

Table 1
Regression results.

	Constant	lnL	lnK	$\ln p_m$	$\ln p_s$	R^2 DW 1.73 ARCH t EG −3.50
lnw	0.49	−4.91***	2.86***	0.71***	3.37***	.987
(t-stat)	(1.89)	(0.99)	(0.30)	(0.12)	(0.41)	0.54*
						5.29*
						−2.98
lnr	−111	13.2	−8.36	13.6***	50.5***	.311
	(79.8)	(41.3)	(12.4)	(5.19)	(17.3)	1.54*
						2.67*
						−5.98*
$\ln x_m$	−11.6	−5.55	5.86***	2.81***	9.46***	.970
	(1.98)	(4.13)	(1.24)	(0.52)	(1.73)	0.60*
						3.12*
						−3.18
$\ln x_s$	−45.5***	14.8***	1.75***	−0.18	8.74***	.998
	(3.99)	(2.06)	(0.62)	(0.26)	(0.87)	0.60*
						3.88*
						−3.15

* = 10%, ** = 5%, *** = 1%.

Table 2
Difference equation regressions.

	Constant	ΔlnL	ΔlnK	$\Delta \ln p_m$	$\Delta \ln p_s$	R^2 DW 1.73 ARCH t
Δlnw	0.01*** (.003)	−9.66*** (2.63)	2.05** (0.46)	0.68** (0.31)	0.44 (0.55)	.414 1.74 −0.53
Δlnr	0.50* (0.30)	−78.4 (209)	−111*** (37.0)	−24.2 (24.8)	−48.8 (43.5)	.219 2.07 0.77
$\Delta \ln x_m$	0.03 (0.02)	−25.7*** (14.4)	7.47*** (2.54)	4.02*** (1.70)	2.75 (2.98)	.279 2.19 −1.08
$\Delta \ln x_s$	0.03*** (0.01)	−4.22 (5.32)	3.31*** (0.94)	0.64 (0.63)	1.77 (1.11)	.261 1.81 1.74*

* = 10%, ** = 5%, *** = 1%.

Manufactures output falls with labor and rises with capital, consistent with labor intensive manufactures. Increased capital, however, also raises services output suggesting nonhomothetic production.

The price of manufactures raises the wage, consistent with labor intensive manufactures. Positive price effects on the capital return emerge in the error correction estimate. The price of manufactures also raises its output along the production frontier in the lower right hand corner of Table 2.

Table 3 reports the error correction model ECM for the capital return. There is a strong error correction process relative to the dynamic equilibrium with slight overshooting consistent with volatility of the capital return. Transitory effects surface for the labor force and price of services. The second row of Table 3 reports derived effects that sum the transitory plus error correction effects through the corresponding significant coefficients in the spurious regression. Error propagation calculations lead to the reported standard errors. These error corrected capital return coefficients enter the estimated system matrix in Eq. (10).

The literature interprets trends or structural breaks in residuals as technological change. The residuals in Fig. 5 are AR(1) stationary with no evidence of residual correlation or heteroskedasticity, consistent with the assumption that fixed capital assets capture technological change. Changes in fixed capital assets evidently capture technological change eliminating the need for a separate technology variable. The capital–labor ratio rises steadily over sample years from 0.74 to 0.86.

Estimates in Tables 3 and 4 lead to the comparative static system in the inverse matrix A^{-1},

$$\begin{pmatrix} -9.66 & 2.05 & 0.68 & 0 \\ 326 & -133 & 13.7 & 191 \\ -25.7 & 7.47 & 4.02 & 0 \\ 0 & 3.31 & 0 & 1.77 \end{pmatrix} \begin{pmatrix} d\ln L \\ d\ln K \\ d\ln p_m \\ d\ln p_s \end{pmatrix} = \begin{pmatrix} d\ln w \\ d\ln r \\ d\ln x_m \\ d\ln x_s \end{pmatrix}. \quad (10)$$

To diminish uncertainty, insignificant coefficients are set to zero in Eq. (10) except for the p_s coefficient for x_s with its p-value of 11%.

Coefficients in Eq. (10) are point estimates of average comparative static effects over the sample period. The coefficients in Eq. (8) vary over time with factor shares and industry shares as well as adjustments in the underlying technology. The stationary differences of the series and successful difference equation regressions suggest these average effects are unbiased.

4. Policy issues in the estimated Heckscher–Ohlin model

Summarizing the results in Eq. (10), effects of the labor force and capital stock on the wage and the capital return are consistent with economic intuition but inconsistent with homothetic production in the 2 × 2 model. There are links between the price of

Table 3
Δlnr error correction model.

	Constant	ΔlnL	ΔlnK	$\Delta \ln p_m$	$\Delta \ln p_s$	Residual	R^2 DW 1.73 ARCH t
Δlnr	−0.16 (0.24)	326* (166)	−133*** (27.6)	−9.89 (18.4)	140*** (42.7)	−1.01*** (0.15)	.581 1.69 gray 0.79
derived	0	326* (4.21)	−133*** (6.77)	13.7*** (1.86)	191*** (25.7)		

* = 10%, ** = 5%, *** = 1%.

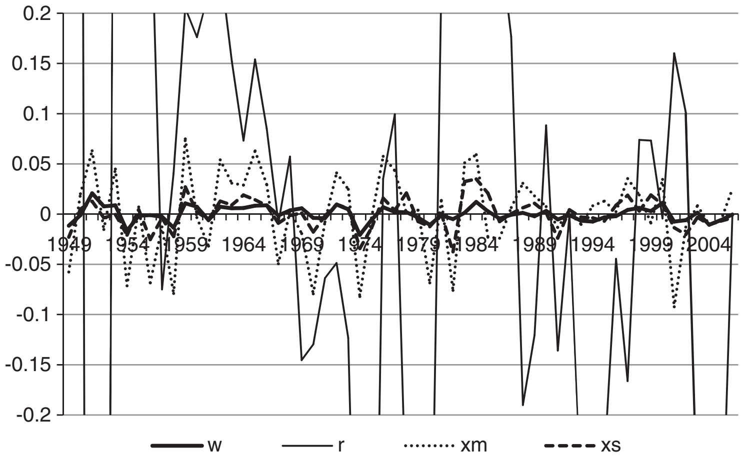

Fig. 5. Regression residuals.

manufactures and the wage, and between both prices and the capital return. Both prices have positive effects on the capital return, again suggesting nonhomothetic production.

An increase in the labor force strongly lowers manufactures output but does not affect services output. An increase in the capital stock raises manufactures output more than services. These results are consistent with the nonhomothetic production and weakly suggest capital intensive manufactures.

The elasticity of the manufactures price on its output is consistent with the falling price and output over the period. The mean and standard deviation of the change in the price of manufactures are −2.0% and 0.2% suggesting regular downward adjustment in manufactures output due to its falling price, consistent with high output variability. Capital growth with its 3.5% mean and 0.3% standard deviation supports manufactures. Services output increases with either price, and has an elastic 1.77 own price effect. There are no cross price effects on outputs.

The estimated coefficients in Eq. (10) relate to a number of policy issues. Tariffs raising the price of manufactures by 5% would raise the wage 3.4%. The real wage would rise given that the share of manufactures in consumption is less than 68%. The capital return would increase 13.9% from its mean of 7.2% to 8.2%. Manufactures output would increase 20%.

Limits on immigration would substantially raise the wage. Every 1% decrease in the labor force would raise the wage 9.66%. Immigration accounts for perhaps half of the 1.4% average labor force growth over the sample period. Manufactures output would fall considerably with a limit on immigration, as would the capital return.

Limits on foreign investment lowering the capital stock by 1% would decrease the wage 2.05% and raise the capital return from its 7.2% mean to 10.5%. Outputs would fall by 7.47% in manufactures and 3.31% in services.

5. Inverting the estimated Heckscher-Ohlin inverse matrix

Table 4 reports the inverse of the A^{-1} matrix in Eq. (10) as the system matrix A in Eq. (8). Approximate standard errors computed by the delta method assume 1% variations in the estimated A^{-1} coefficients. Including the insignificant coefficients in Eq. (10) results in very similar coefficients that are insignificant at this level of precision except in the lnr column. Excluding the insignificant coefficients seems reasonable.

Homothetic production would imply a null lower right quadrant. The coefficient $\alpha_m = 0.417$ provides evidence of nonhomothetic production in manufactures. This coefficient is $\alpha_m = \theta_{Lm}\sigma_{Lm} + \theta_{Km}\sigma_{Km}$ where σ_{im} is the elasticity of the unit manufactures input a_{im} with respect manufactures output x_m. Factor shares θ_{Lm} and θ_{Km} sum to one. Given that manufactures is capital intensive, the suggestion is that $\sigma_{Km}>0$ indicating capital bias. For services $\alpha_s = 0.120 = \theta_{Ls}\sigma_{Ls} + \theta_{Ks}\sigma_{Ks}$ suggesting more nearly homothetic production.

Table 4
Inverse coefficient matrix A.

	Δlnw	Δlnr	Δlnx_m	Δlnx_s
ΔlnL	−.231	−.003	.037	.035
	(.012)	(.06^{-6})	(.001)	(.001)
ΔlnK	−.171	−.002	.036	.238
	(.032)	(.65^{-6})	(.001)	(.003)
Δlnp_m	−1.05	.002	.417	−.215
	(1.06)	(4.5^{-6})	(.037)	(.048)
Δlnp_s	.319	.004	−.068	.120
	(.113)	(.28^{-6})	(.004)	(.008)

In the lower left quadrant, manufactures coefficients are $\alpha_{Lm} = -1.05 = \theta_{Lm}(1+\sigma^m_{LL}) + \theta_{Km}\sigma^m_{KL}$ and $\alpha_{Km} = 0.002 = \theta_{Km}(1+\sigma^m_{KK}) + \theta_{Lm}\sigma^m_{LK}$ with substitution elasticities $\sigma^j_{ki} \equiv \partial \ln a_{ij}/\partial \ln w_k$. There are positive cross price substitution terms σ^m_{KL} and σ^m_{LK} with two factors. Suggestions are strong own labor substitution in the negative own elasticity σ^m_{LL} and much weaker own capital substitution in σ^m_{KK}. Cross price substitution σ^m_{KL} of capital with respect to the wage is evidently unable to offset strong own labor substitution in the α_{Lm} term. For services $\alpha_{Ls} = 0.319 = \theta_{Ls}(1+\sigma^s_{LL}) + \theta_{Ks}\sigma^s_{KL}$ suggesting relatively strong substitution of capital with respect to the wage while $\alpha_{Ks} = 0.004 = \theta_{Ks}(1+\sigma^s_{KK}) + \theta_{Ls}\sigma^s_{LK}$ suggests weaker substitution of labor with respect to the capital return.

The upper left quadrant contains the implied aggregate substitution elasticities. The own labor elasticity $\sigma_{LL} = -0.231$ is consistent with implications in the lower half of the A^{-1} matrix as is the nearly zero own capital elasticity σ_{KK}. Capital is a strong substitute for labor when the wage changes while labor is a weak substitute relative to the capital return. Capital does not substitute to any extent for itself.

Summarizing these implications on these revealed properties of production, manufactures production appears capital biased. Own labor substitution appears strong in manufactures, consistent with capital intensive manufactures. Own capital substitution is weak. There appears to be strong capital substitution with respect to the wage but very weak labor substitution with respect to the capital return.

6. Conclusion

Estimating the comparative static Heckscher–Ohlin model is a novel approach to applying and gaining insight into the general equilibrium theory of production and trade. The estimated comparative static coefficients relate to policy issues and technical aspects of production.

Reviewing the present policy implications, tariffs on manufactures would the capital return more than the wage and raise manufactures output. Limits on immigration raise the wage and manufactures output. Limits on foreign investment raise the capital return but lower the wage and manufactures output.

Regarding the implied aspects of production, manufactures production is capital biased. Capital has a weak own price elasticity but is a strong cross price substitute for labor. There is strong own labor substitution especially in manufactures. Labor, however, does not substitute with respect to capital.

For future research, it is possible to estimate various sets of exogenous and endogenous variables reviewed by Thompson (2003), compare results from alternative estimation techniques, estimate systems simultaneously under various restrictions, and compare estimates across countries, time spans, and aggregations. Heckscher–Ohlin theory can be refined in various directions as suggested by estimates. The present estimates suggest renewed attention to the theoretical properties of nonhomothetic production. Such direct estimates increase empirical relevance of the Heckscher–Ohlin model.

Acknowledgements

Thanks to Farhad Rassekh, Sajal Larihi, Charles Sawyer, Cephas Naanwaab, Jennings Byrd, Ermanno Affuso, Eric Fisher, and a referee of this journal for their comments and suggestions.

References

Arrow, K., Chenery, H. B., Minhas, B. S., & Solow, R. (1961). Capital–labor substitution and economic efficiency. *The Review of Economics and Statistics*, *43*, 225−250.
Bernstein, J., & Weinstein, D. (2002). Do endowments predict the location of production? Evidence from national and international data. *Journal of International Economics*, *56*, 55−76.
Bureau of Economic Analysis (2009). *National Economic Accounts*, Department of Commerce webpage, www.bea.gov
Bureau of Labor Statistics (2009). Databases and Tables, webpage, www.bls.gov
Chang, W. (1979). Some theorems of trade and general equilibrium with many goods and factors. *Econometrica*, *47*, 709−726.
Chipman, J. (1966). A survey of the theory of international trade: Part 3, the modern theory. *Econometrica*, *34*, 18−76.
Christensen, L., Jorgensen, D., & Lau, L. (1973). Transcendental logarithmic production frontiers. *The Review of Economics and Statistics*, *55*, 28−45.
Dickey, D., & Fuller, W. (1979). Distribution of the estimates for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*, 427−431.
Durbin, James, & Watson, Geoffrey (1951). Testing for serial correlation in least squares regression, II. *Biometrika*, *38*, 159−179.
Engel, R., & Granger, C. (1987). Cointegration and error-correction: Representation, estimation, and testing. *Econometrica*, *55*, 251−276.
Federal Reserve (2009). Economic Research and Data, webpage, www.federalreserve.gov
Fisher, E., Marshall, K. (in press). The structure of the American economy. *Review of International Economics*.
Heckscher, E. (1919). The effect of foreign trade on the distribution of income. *Ekonomisk Tidskrift*, *11*, 497−512.
Horn, H. (1983). Some implications of non-homotheticity in production in a two-sector general equilibrium model with monopolistic competition. *Journal of International Economics*, *14*, 85−101.
Jones, R. (1965). The structure of simple general equilibrium models. *Journal of Political Economy*, *73*, 57−72.
Jones, R., & Neary, P. (1984). The positive theory of international trade. In R. Jones, & P. Kenen (Eds.), *Handbook of international trade*, *Vol. 1*, Amsterdam: North Holland.
Kmenta, J. (1967). On estimation of the CES production function. *International Economic Review*, *8*, 180−189.
Ohlin, B. (1924). *The Theory of Trade*, translated in H. Flam and J. Flanders, *Heckscher–Ohlin trade theory*, Cambridge: The MIT Press, 1991, 73-214.
Perron, P. (1989). The great crash, the oil shock, and the unit root hypothesis. *Econometrica*, *57*, 1361−1401.
Samuelson, P. (1953). Prices of factors and products in general equilibrium. *Review of Economic Studies*, *21*, 1−20.
Sato, R. (1967). A two-level constant-elasticity-of-substitution production function. *The Review of Economic Studies*, *34*, 201−218.
Shimomura, K. (1999). A simple proof of the Sato proposition on nonhomothetic CES functions. *Economic Theory*, *14*, 501−503.
Stolper, W., & Samuelson, P. (1941). Protection and real wages. *Review of Economic Studies*, *9*, 58−73.
Takayama, A. (1993). *Analytical methods in economics.* Ann Arbor: The University of Michigan Press.
Thompson, H. (2003). Robustness of the Stolper–Samuelson intensity price link. In K. Choi, & J. Harrigan (Eds.), *Handbook of international trade*. London: Blackwell Publishing.
Thompson, H. (2010). Wages in a factor proportions time series model of the US. *Journal of International Trade and Economic Development*, *19*, 241−256.