

Capital Good Imports, Public Capital, and Productivity Growth

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Abstract

This paper examines the sources for U.S. labor productivity growth over more than three decades. We find that access to lower priced capital good imports played a significant role for gains in labor productivity. In contrast, imported industrial materials did contribute very little to the overall increase in labor productivity although they have become slightly more important since the early '80s. While private capital formation was the most important and consistent component of labor productivity growth, non-military government expenditures on capital goods did not contribute to the observed long-run increase in labor productivity.

1. Introduction

Identifying the main economic forces driving labor productivity growth has long been a fascinating topic in economic research. Identifying the most important factor or factors responsible for productivity gains is a difficult task, and the results can vary substantially from study to study¹. Outside academic circles, the topic is hotly debated as well. Policy-makers in particular are interested in national productivity and its determinants because high labor productivity growth is the key to higher standards of living. Naturally, the slowdown of US productivity in the '70s, the so called “productivity puzzle,” has generated even more interest in determining factors that affect productivity growth. While the rebound in productivity growth since the early '90s has calmed somewhat the worries of politicians, academic research as well as public debate continues to flourish. For example, a newly emerged point of discontent has been the claim by economists and other experts that official U.S. statistics underestimate the true gains in productivity.

Besides the problem of correct measurement, the empirical research on productivity has focused on a number of issues. First, the literature has explored several candidates which may impact productivity, namely private capital expenditures, government infrastructure expenditure, and the price of energy, in particular the price of oil. While the importance of private capital on labor productivity is broadly accepted, the role of public capital has been controversial. On the one hand, several authors find public infrastructure to be important for improvement in productivity. In an influential study, Aschauer [3] finds a positive relation between public capital and private productivity for US data. Munnell [21] observes a positive impact of public capital on labor and total factor productivity. Lynde and Richmond [19] find that 41% of the decline in labor productivity growth was accounted for by the decline in the public capital to labor ratio. Using state-level data for U.S. manufacturing, Morrison and Schwartz [20] present results that indicate the importance of infrastructure investment for productivity growth. On the other hand, Hulten and Schwab [13] and Holtz-Eakin [11] find that public infrastructure spending played essentially no role in affecting private-sector productivity.

¹See Fischer[7], Griliches [8], Jorgenson [16], Boskin[5] for an assessment of energy prices, R&D and taxes as candidates to explain productivity.

Interestingly, none of the above studies considers the effect of international trade as potential candidate in affecting productivity growth. This is rather surprising given the large number of studies both theoretical and empirical that point to an important link between a country's per capita growth rate and various measures of openness to trade. The theoretical trade literature traditionally has made a strong case for openness to raise GDP growth. Freer international trade implies a more efficient allocation of resources in models with perfect competition² and may lead to higher rates of process or product improvements and/or cost reductions due to access to larger markets in models with imperfect competition³. The more recent empirical literature on trade and growth has found some evidence of a link between openness to trade and growth⁴. In particular, a number of studies have shown a strong link between capital good imports and income growth (Lee [18], Huang and Pereira [12]).

The goal of this paper is to bridge the gap between the productivity growth literature and literature on openness and growth by introducing some element of openness into a productivity growth model. To achieve this task, we extend the model developed by Lynde and Richmond [19]. This model has a number of advantages over the competing approaches. First, Lynde and Richmond's approach tests for the non-stationarity of the data and then estimates them appropriately. Tatom [24], [25] shows that the result of Aschauer can be refuted by first-differencing the non-stationary variables. As pointed by out Lynde and Richmond, first-differencing may not be the most efficient way of adjusting for non-stationarity. Instead, they estimate directly the long-run relationship between the non-stationary variables. Second, the estimation techniques employed by Lynde and Richmond are based on a profit function approach. As Vijverberg, Vijverberg, and Gamble [26] have shown, the use of profit functions leads to more efficient estimates than the commonly used production function approach. Third, it has been shown (Phillips and Loretan [23]; Inder [14]) that the Phillips-Hansen fully-modified estimation technique used in Lynde and Richmond is the superior approach within the class of modified OLS estimators.

We introduce the effects of openness to trade into the Lynde and Richmond framework by disaggregating their single intermediate input price index into three separate price indices: one for domestically produced

²For an overview of this literature, see Jones [15], chapt. 1.

³See, for example, Krugman [17], chapt. 20.

⁴See, for example, Harrison [10]

intermediate goods; one for imported industrial materials; and one for imported capital goods. The point is that by opening up a country to international trade, productivity can increase due to cheaper imported intermediate goods both durable (capital) and non-durable (materials).

Our main results are the following. First, we find that for the entire sample period access to cheaper capital good imports had a positive effect on labor productivity growth. In contrast, imported industrial materials did contribute very little to the overall increase in labor productivity although they have become slightly more important since the early '80s. While private capital formation was the most important and consistent component of labor productivity growth, non-military government expenditures on capital goods did not contribute to the observed long-run increase in labor productivity. However, changes in non-military public capital expenditures were able to determine the directional change in labor productivity over shorter periods until the mid 90's

The paper is organized as follows. A brief sketch of the model is presented in section 2. Section 3 explains the data set, while econometric issues are discussed in section 4. Section 5 contains the estimation and inference results, and section 6 contains the productivity measurements. Section 7 concludes the paper.

2. Model

Following Lynde and Richmond [19], public capital, g , is a factor of production freely used by private firms. The three classes of private inputs are capital, k , labor, l , and intermediate inputs, \mathbf{m} . The elements of vector $\mathbf{m} \equiv (m_1, m_2, m_3)'$ are imported capital goods, imported industrial materials, and domestic intermediate goods⁵. We will assume a standard neo-classical production function,

$$q = F(k, l, g, m_1, m_2, m_3, t) \tag{2.1}$$

where q denotes the gross output in real terms and the state of technology is approximated by time, t .

Let p denote the nominal price of output. The input prices, p_k and p_l represent nominal prices of private capital and labor, respectively. Let the price vector of the three classes of intermediate goods be represented

⁵Throughout the paper variables with subscript $i = 1, 2$, and 3 represent imported capital goods, imported industrial materials, and domestic intermediate goods, respectively.

by $\mathbf{p}_m \equiv (p_{m1}, p_{m2}, p_{m3})'$, i.e., the nominal prices of imported capital goods, imported industrial materials, and domestic intermediate inputs, respectively.

Also, let $\boldsymbol{\rho}_m \equiv (\frac{p_{m1}}{p}, \frac{p_{m2}}{p}, \frac{p_{m3}}{p})'$ denote the real price vector of all intermediate goods⁶. As shown in Appendix A, the above production function leads to the following profit function:

$$\pi^* = \pi^*(p, p_k, p_l, g, \boldsymbol{\rho}_m, t) = py^* - p_k k^* - p_l l^* \quad (2.2)$$

Dividing both sides by π^* yields

$$1 = s_y^* - s_k^* - s_l^* \quad (2.3)$$

where $s_y^* = \frac{py^*}{\pi^*}$, $s_k^* = \frac{p_k k^*}{\pi^*}$, and $s_l^* = \frac{p_l l^*}{\pi^*}$ are the shares of output, private capital, and labor in total profit. The profit function is homogeneous of degree one in prices p , p_k , p_l , as can be seen from (2.2). Individual shares are allowed to take values that exceed unity. Indeed, if both s_k^* and s_l^* are positive, s_y^* must be greater than unity⁷.

3. Data

The data used in this study cover the period from '67 to '98. Although for most variables data are available for earlier years, capital good imports and industrial materials imports (both real and nominal) are only available from '67 onwards. Therefore, with the exception of the import variables (and their corresponding profit shares), all unit root test statistics are based on the period from '59 to '98. Ideally, ρ_3 should be comprised of only domestically produced intermediate goods. Unfortunately, such a price index is not available. However, since the fraction of the foreign components in the index is rather small, we consider ρ_3 a fairly good approximation for the true price of domestic intermediate goods. A complete listing of data sources and discussion of variable construction is given in Appendix B.

⁶ Accordingly, $\rho_{mi} = \frac{p_{mi}}{p}$ for $i = 1, 2$, and 3 .

⁷ Alternatively, the shares can be expressed in terms of the price elasticity of profits: $\frac{\partial \ln \pi}{\partial \ln p} = s_y^*$, $\frac{\partial \ln \pi}{\partial \ln p_k} = -s_k^*$, $\frac{\partial \ln \pi}{\partial \ln p_l} = -s_l^*$, and for the intermediate inputs $\frac{\partial \ln \pi}{\partial \ln \rho_m} = \frac{p'_{mi} m_i}{\pi^*} = -s_{mi}^*$, where $i = 1, 2, 3$.

4. Econometric Methodology

The empirical part of this paper consists of the estimation of a system of share functions which are derived from the profit function $\pi^*(p, p_k, p_l, g, \rho_m, t)$. In particular, we approximate 2.2 by a second-degree Taylor expansion around unity⁸. The system of partial derivatives with respect to all relative prices yields a system of six profit share equations⁹. Because of condition 2.3, the share equations for s_y , s_k , and s_l , are not linearly independent, and one of them can be dropped (here s_l). Finally, due to the lack of data for the value of domestic intermediate inputs, we are unable to construct the share of domestic intermediate goods in profits, s_m . We thus estimate the following set of share equations:

$$\begin{aligned} s_y &= \beta_{y0} + \beta_{yy} \ln p + \beta_{yk} \ln p_k + \beta_{yl} \ln p_l + \beta_{ym1} \ln \rho_{m1} \\ &\quad + \beta_{ym2} \ln \rho_{m2} + \beta_{ym3} \ln \rho_{m3} + \beta_{yg} \ln g + \beta_{yt} t + u_y \end{aligned} \quad (4.1)$$

$$\begin{aligned} s_k &= \beta_{k0} + \beta_{ky} \ln p + \beta_{kk} \ln p_k + \beta_{kl} \ln p_l + \beta_{km1} \ln \rho_{m1} \\ &\quad + \beta_{km2} \ln \rho_{m2} + \beta_{km3} \ln \rho_{m3} + \beta_{kg} \ln g + \beta_{kt} t + u_k \end{aligned} \quad (4.2)$$

$$\begin{aligned} s_{m1} &= \beta_{m10} + \beta_{m1y} \ln p + \beta_{m1k} \ln p_k + \beta_{m1l} \ln p_l + \beta_{m1m1} \ln \rho_{m1} \\ &\quad + \beta_{m1m2} \ln \rho_{m2} + \beta_{m1m3} \ln \rho_{m3} + \beta_{m1g} \ln g + \beta_{m1t} t + u_{m1} \end{aligned} \quad (4.3)$$

$$\begin{aligned} s_{m2} &= \beta_{m20} + \beta_{m2y} \ln p + \beta_{m2k} \ln p_k + \beta_{m2l} \ln p_l + \beta_{m2m1} \ln \rho_{m1} \\ &\quad + \beta_{m2m2} \ln \rho_{m2} + \beta_{m2m3} \ln \rho_{m3} + \beta_{m2g} \ln g + \beta_{m2t} t + u_{m2} \end{aligned} \quad (4.4)$$

In addition to estimates of the above system, we construct restricted estimates by imposing linear restrictions which correspond to the following homogeneity restrictions on the estimated price parameters:

$$\beta_{yy} + \beta_{yk} + \beta_{yl} = 0 \quad (4.5)$$

$$\beta_{ky} + \beta_{kk} + \beta_{kl} = 0 \quad (4.6)$$

⁸See Chambers [6], Chapter 5, for a detailed discussion of flexible functional forms, in particular, as applied to profit functions.

⁹There is no equation for the share of g in profits because government expenditures are considered external from the standpoint of the firm.

$$\beta_{m1y} + \beta_{m1k} + \beta_{m1l} = 0 \quad (4.7)$$

$$\beta_{m2y} + \beta_{m2k} + \beta_{m2l} = 0 \quad (4.8)$$

These restrictions represent the fact that each share equation is homogeneous of degree zero in prices p , p_k , and p_l if the underlying production function exhibits constant returns to scale in capital and labor. We test the validity of the linear restrictions using suitably modified Wald statistics.

An important concern in time series estimation is the question of whether the variables in the regression equation are stationary. If the variables are non-stationary, simple OLS will yield biased estimates which are inappropriate for inference. In this case an estimation procedure is required that corrects for the non-stationarity of the data. One of the leading procedures that has been used in a number of recent studies is the fully-modified (FM) estimation technique developed by Phillips and Hansen[22]. Monte Carlo studies of cointegrating techniques (Phillips and Loretan [23]; Inder [14]) have shown that FM estimates are superior in terms of their small sample properties within the class of modified OLS estimators. Next, we briefly describe the FM estimator and some of its properties (see Phillips and Hansen [22] and Hansen [9] for details).

Each of the above share equations will be estimated separately by the following system:

$$y_{1t} = Ay_{2t} + Bk_t + u_{1t} \quad (4.9)$$

$$\Delta y_{2t} = C\Delta k_t + u_{2t} \quad (4.10)$$

where the scalar y_{1t} represents the share variable, y_{2t} denotes a vector of public capital and all price variables from equation (4.1) to (4.4), and k_t represents the intercept and deterministic time trend. The coefficient A captures the long-run relationship between y_{1t} and y_{2t} . The deviations from long-run equilibrium are captured by u_{1t} , where $u'_t = (u_{1t} \ u'_{2t})$. For convenience we rewrite (4.9) as

$$y_{1t} = \beta x_t + u_{1t} \quad (5.1a)$$

where $\beta = (A \ B)$ and $x_t = (y'_{2t} \ k'_t)'$. To obtain the fully-modified (bias adjusted) estimate, we construct a heteroskedasticity-autocorrelated consistent (HAC) estimate of the long-run covariance matrix Ω , i.e.,

$$\Omega = \lim_{T \rightarrow \infty} \frac{1}{T} \sum_{t=1}^T \sum_{j=1}^T E(u_j u_t').$$

The long-run covariance can be decomposed as $\Omega = \Sigma + \Gamma + \Gamma'$ where $\Sigma = E(u_0 u_0')$ and $\Gamma = \sum_{t=1}^{\infty} E(u_0 u_t')$. Also, let Λ be equal to $\Sigma + \Gamma$. The estimates $\hat{\Omega}$ and $\hat{\Lambda}$ can be partitioned in conformity with u_t such that

$$\hat{\Omega} = \begin{pmatrix} \hat{\Omega}_{11} & \hat{\Omega}_{12} \\ \hat{\Omega}_{21} & \hat{\Omega}_{22} \end{pmatrix} \text{ and } \hat{\Lambda} = \begin{pmatrix} \hat{\Lambda}_{11} & \hat{\Lambda}_{12} \\ \hat{\Lambda}_{21} & \hat{\Lambda}_{22} \end{pmatrix}.$$

The fully-modified estimator, denoted by $\hat{\beta}^+$, is given by

$$\hat{\beta}^+ = \left(\sum_{t=1}^T (y^+ x_t - (0 \quad \hat{\Lambda}_{21}^+)) \right) \left(\sum_{t=1}^T x_t x_t' \right)^{-1} \quad (4.11)$$

where $y^+ = y_t - \hat{\Omega}_{12} \hat{\Omega}_{22}^{-1} \hat{u}_{2t}$ and $\hat{\Lambda}_{21}^+ = \hat{\Lambda}_{21} - \hat{\Lambda}_{22} \hat{\Omega}_{22}^{-1} \hat{\Omega}_{21}$ (see Appendix C for further details on the fully-modified estimation procedure). The FM estimator has two main advantages. First, it reduces the second order bias of the parameter estimates in finite samples by recognizing the contemporaneous and serial correlation of the regressor. Formally, the bias reduction is achieved through inclusion of $\hat{\Lambda}_{21}^+$ in (4.11). Second, the FM estimator eliminates the possibility of having asymptotic distributions with non-zero means. Inference results thus can be based on standard asymptotic procedures. Formally, the asymptotic normality of the FM estimator is the result of using modified y^+ instead of y in (4.11).

It should be noted that following Lynde and Richmond we include a dummy variable for the year '74 in all estimation equations because of the extreme inflation in the price of capital in that year¹⁰.

¹⁰Vijverberg et al [26] argue against inclusion of a dummy variable for 1974 since such a step would change the estimate of the serial correlation coefficient in their model. In addition, they find that omitting a dummy variable for 1974 would change estimates considerably. In particular, it would remove the significance for $\ln G$. We find that in our model removing the dummy variable for 1974 reduces the statistical significance of almost all variables up to a point where most of them become insignificant in all share equations. Not surprisingly, the adjusted R-square also declines substantially (for example, from .6 to .44 in the unrestricted output share equation). We thus believe that the model with dummy variable is a better specified model even when revised data are used as is the case in our study.

5. Estimation Results

We now present the results of the empirical estimation. We first need to check whether the variables in the model (i.e., s_y , s_k , s_{m1} , s_{m2} , $\ln p$, $\ln p_k$, $\ln p_l$, $\ln \rho_m$, and $\ln g$) are non-stationary. We report the results for the unit root tests in Table 1. In particular, we report the augmented Dickey-Fuller test without and with deterministic trend (ADF1 and ADF2, respectively) as well as the Phillips-Perron test without and with deterministic trend (PP1 and PP2, respectively). The last row in Table 1 contains the critical value of the appropriate distribution at the 5% level.

Table 1: Unit Root Tests (ADF and Phillips-Perron test statistics for lag length 2)

variables	ADF1	ADF2	PP1	PP2
s_y	-3.21*	-2.22	-3.19*	-3.24
s_k	-1.95	-1.97	-1.64	-1.64
s_{m1}	-0.98	-2.32	-2.61	-2.20
s_{m2}	-2.89	-2.84	-2.83	-2.77
$\ln g$	-1.81	-2.96	-1.87	-0.64
$\ln p_y$	-1.79	-0.20	-1.33	-0.43
$\ln p_k$	-1.41	-2.29	-1.08	-1.52
$\ln p_l$	-1.48	-3.38	-1.46	-3.05
$\ln \rho_{m1}$	-1.23	-3.09	0.45	-1.99
$\ln \rho_{m2}$	-2.6	-2.39	-1.95	-1.68
$\ln \rho_{m3}$	-2.12	-1.81	-1.63	-1.27
5% crit. val.	-2.96	-3.60	-2.96	-3.56

*: significant at 5% level

For both ADF1 and PP1, the unit root null hypothesis is tested against the alternative of stationarity, while ADF2 and PP2 test the null of a unit root with drift against the alternative of linear trend stationarity.

Table 2: Fully-Modified Parameter Estimates

	Unrestricted				Restricted			
	s_y	s_k	s_{m1}	s_{m2}	s_y	s_k	s_{m1}	s_{m2}
$\ln p_y$	-1.75* (2.43)	0.38 (0.97)	0.20* (4.39)	-0.05* (1.85)	-2.65* (3.74)	0.10 (0.26)	0.23* (5.13)	-0.04 (1.37)
$\ln p_k$	-0.11* (2.94)	0.59* (28.76)	0.001 (0.41)	-0.02* (12.58)	0.05 (1.43)	0.63* (36.32)	-0.004* (2.15)	0.02* (16.6)
$\ln p_l$	3.20* (4.55)	-0.55 (1.46)	-0.25* (5.55)	0.05* (1.81)	2.61* (3.73)	-0.73* (1.95)	-0.23* (5.12)	0.06* (2.16)
$\ln \rho_{m1}$	-0.32* (3.23)	0.10* (-1.80)	-0.01 (1.24)	0.01* (3.58)	0.16* (2.01)	0.24* (5.68)	-0.02* (4.82)	0.01* (2.07)
$\ln \rho_{m2}$	0.52* (2.25)	0.30* (2.44)	0.050* (3.10)	-0.01 (0.65)	-0.07 (0.31)	0.12 (1.04)	0.07* (4.72)	0.003 (0.37)
$\ln \rho_{m3}$	-0.90 (1.46)	-1.31* (3.91)	-0.13* (-3.24)	0.09* (3.86)	0.91 (1.59)	-0.75* (2.41)	-0.19* (5.18)	0.06* (2.89)
$\ln g$	3.19* (2.39)	-2.29* (3.59)	-.08 (0.96)	-0.35* (7.06)	3.27* (2.45)	-2.57* (3.56)	-0.08 (0.99)	-0.35* (7.08)
1974 Dummy	-0.14 (1.56)	1.24* (25.1)	0.002 (0.33)	-0.03* (8.15)	0.20* (2.51)	1.35* (30.81)	-0.01* (1.93)	-0.03* (10.91)
constant [‡]	-29.01	24.11	1.22	2.61	-29.31	24.01	1.23	2.61
trend [‡]	-0.18	0.05	0.01	0.01	-0.11	0.07	0.01	0.01
adjusted R^2	0.71	0.97	0.99	0.89	0.39	0.97	0.98	0.89
Wald test [§]					65.37	21.08	19.08	10.22

t-statistics in parentheses

† : ADF critical value is 2.99

‡ The t-stats for the intercept and trend term have non-standard asymptotic properties and are thus not reported.

* : significant at 5% level

§ : 5% $\chi^2(1)$ critical value is 3.84

The test results indicate that the variables may indeed be non-stationary¹¹. We thus continue by estimating the share equations (4.1) to (4.4) using the FM estimation procedure for both restricted and unrestricted models. The estimation results are presented in Table 2 and are based on the quadratic spectral kernel

¹¹The only variable that rejects the unit root null is s_y , but only for ADF1 and ADF2. Since both ADF2 and PP2 tests indicate the presence of a unit for s_y , we proceed on the basis that all variables contain a unit root.

with a bandwidth parameter M equal to 1.5 to ensure compatibility between our results and those in the literature, in particular Lynde and Richmond¹².

As the table shows, the majority of parameter estimates are statistically significant at the 5% level. Labor cost and the price of imported capital goods have estimated coefficients that are significant in all but one estimated share equation. The output price index, the price index of private capital, the price index of domestic intermediate goods, government spending and the 1974 dummy variable are all significant in six out of eight equations. Finally, the price index of imported industrial materials is significant in five equations. All Wald test statistics indicate that the imposed homogeneity restrictions can be rejected at the 5% level.

6. Labor Productivity Growth

The empirical estimates of the previous section are an important intermediate step toward the ultimate goal of this paper, which is to decompose labor productivity into its various components and to provide an estimate of the absolute and relative contribution of each component. To that end we log differentiate the value-added function (equation (7.6) in Appendix A) and rearrange terms using the appropriate profit share definitions given in section 2. This leads us to the following equation for the change in labor productivity (here \hat{x} denotes a percentage change in x):

$$\begin{aligned}
(\hat{y} - \hat{L}) &= \frac{s_k^*}{s_y^*}(\hat{k} - \hat{l}) + \frac{1}{s_y^*}(\hat{g} - \hat{l}) + (\lambda - 1) \left(1 + \frac{s_{m1}^* + s_{m2}^* + s_{m3}^*}{s_y^*} \right) \hat{g} \\
&\quad - \left(\frac{s_{m1}^*}{s_y^*} \right) \hat{\rho}_{m1} - \left(\frac{s_{m2}^*}{s_y^*} \right) \hat{\rho}_{m2} - \left(\frac{s_{m3}^*}{s_y^*} \right) \hat{\rho}_{m3} + \frac{1}{y} \frac{\partial H}{\partial t}
\end{aligned} \tag{6.1}$$

There are seven components that contribute to a rise in labor productivity: an increase in the capital-labor ratio (capital intensity); an increase in government spending per worker (public capital intensity); a positive externality effect of higher public expenditures in the case that the production function exhibits increasing returns to scale (i.e. $\lambda > 1$); a decline in the relative price of each of the three intermediate goods¹³ (domestically produced, imported capital and imported industrial materials), and a residual term

¹²Estimation results for other kernel choices are available from the authors upon request.

¹³That the positive influence on productivity is driven by lower prices of intermediate good imports can be seen from the

measuring the impact of (exogenous) technological progress. Due to the lack of data, we are not able to provide an estimate for λ , s_m^* , and $\frac{\partial H}{\partial t}$. We are therefore left with the following four estimable components explaining change in labor productivity:

$$(\hat{y} - \hat{L}) = \frac{\tilde{s}_k^*}{\tilde{s}_y^*}(\hat{k} - \hat{l}) + \frac{1}{\tilde{s}_y^*}(\hat{g} - \hat{l}) - \left(\frac{\tilde{s}_{m1}^*}{\tilde{s}_y^*}\right)\hat{\rho}_{m1} - \left(\frac{\tilde{s}_{m2}^*}{\tilde{s}_y^*}\right)\hat{\rho}_{m2} + \epsilon \quad (6.2)$$

where a $(\tilde{})$ indicates an estimated value obtained from the restricted FM regressions presented in Table 2 and ϵ is a residual that measures the combined impact of the omitted components from (6.1). Equation 6.2 extends the analysis of Lynde and Richmond [19] by taking into account the effects of changes in the price of capital good imports and industrial materials imports via ρ_m . The results are reported in Table 3. The first row reports, for the period from '67 to '98, the average annual growth rate of labor productivity as well as the estimated contributions of the four components identified in (6.2): changes in the private and public capital intensity and changes in the relative price of imported capital and industrial materials. The middle section in Table 3 shows the corresponding data broken into two sub-periods ('67-'79, '80-'98), while the bottom section contains the results for a larger number of sub-periods ('67-'73, '74-'79, '80-'89, '90-'93, '94-'98). By choosing different sets of sub-periods, we are able to disentangle the long- from the short-run effects.

For the entire period from '67 to '98, the non-financial corporate sector has seen an average increase in labor productivity of 1.92% per year. Labor productivity growth has been particularly weak between '74 and '79 and relatively strong since 1980. In terms of the components of productivity growth, neither government spending nor industrial materials imports appear to matter much in explaining labor productivity growth between 1967 and 1998. The most important component has been a rise in capital intensity with a relative contribution of 12% over the entire sample period. The other important component is capital good imports which account for 7% of the observed increase in labor productivity.

expression $-\left(\frac{\tilde{s}_{m2}^*}{\tilde{s}_y^*}\right)\hat{\rho}_{m2}$ in equation (6.2). Since the ratio of profit share estimates is always positive the sign of the expression will be negative unless the price of intermediate good imports declines (i.e. a negative value of $\hat{\rho}_{m2}$).

Table 3: Labor Productivity Growth and its Components

period	y/l	Contribution of				residual
		k/l	g/l	ρ_{m1}	ρ_{m2}	
1967-1998	1.92	0.23 (12%)	-0.01 (-0.6%)	0.13 (7%)	0.03 (1.4%)	1.81
1967-1979	1.43	0.16 (11%)	-0.14 (-9%)	0.00 (0%)	-0.1 (-7.2%)	1.52
1980-1998	2.24	0.28 (12.3%)	0.07 (3%)	0.22 (10%)	0.02 (1%)	1.65
1967-1973	1.88	0.21 (11%)	-0.04 (-2%)	-0.03 (-1.5%)	-0.04 (-2.2%)	1.78
1974-1979	0.98	0.11 (11%)	-0.24 (-24.5%)	0.02 (-2%)	-0.17 (-16.9%)	1.25
1980-1989	2.02	0.30 (15%)	0.05 (2.6%)	0.12 (5.7%)	0.01 (3.5%)	1.54
1990-1993	2.31	0.54 (23.2%)	0.82 (35.4%)	0.22 (9.4%)	0.08 (3.5%)	0.66
1994-1998	2.60	0.01 (0.5%)	-0.50 (-19.3%)	0.44 (16.8%)	-0.004 (-0.2%)	2.66

Given the heavy focus on government spending in the labor productivity literature, it is quite ironic that a component that has received very little attention such as capital good imports appears to have played a much more important role for productivity gains than government expenditure per worker.

For the shorter periods, we notice that the contribution of increases in the capital intensity of production is fairly consistent. Except for the 1994-'98 period, capital intensity has been a major component of labor productivity growth, with contribution values ranging from 10% to 23%.

Interestingly, capital good imports have become a more important component of changes in labor productivity over time. While the impact was fairly small or even negative for periods before 1980, capital good imports have since become a major factor behind labor productivity. For the period between 1980

and 1998, the relative contribution of capital goods imports was only slightly behind that of the capital intensity of production (10% versus 12%, respectively). The absolute contribution of capital good imports [represented by the $\hat{\rho}_{m1}$ column] has steadily increased starting with a negative value in the pre-'74 period followed by positive values of .02 and .12 in the two subsequent periods and finally reaching .22 and .44 in the '90s. In relative terms, the contribution of cheaper capital good imports has been rising as well, from -1.5% before '74 to almost 17% between 94 and 98. The impact of price changes in industrial materials imports [represented by the $\hat{\rho}_{m2}$ column] has also changed from being negative in the pre '80 period to a positive value of 0.02 (and a share of 1%) for the '80 to '98 period. It is notable that changes in the price of industrial materials imports had their strongest adverse effect on labor productivity growth (-0.17) in the period from '74 to '79, a result most likely due to the two oil price shocks during that period pushing up production costs of industrial materials in countries with strong trade relations to the U.S. market. The fall in the relative price of $\hat{\rho}_{m1}$ and $\hat{\rho}_{m2}$ could stem from several sources. Prime candidates are the global reduction of trade barriers and a decline in transportation costs. Other sources driving down import prices could be technological progress or increasing returns to scale in the exporting countries.

Finally, we examine the relationship between government equipment and infrastructure expenditure and labor productivity for the various sub-periods. Table 3 shows that public expenditure can be an important factor in raising or lowering labor productivity. This result is consistent with the findings of Aschauer [3] and Lynde and Richmond [19]. We know that there was a substantial drop in public capital expenditure per worker from the '67-'73 sub-period to the '74-'79 sub-period as well as from the first to the second half of the '90s. As a result, the contribution of government expenditure to labor productivity turned negative in both instances (-24.5% and -19.2%, respectively). While in the first case, labor productivity growth dropped from 1.9 to .98 percent per year, the same is not true for the change in labor productivity between the first and the second half of the '90s. In fact, despite the negative impact of government spending, labor productivity manages to improve even further (from 2.3% to 2.6%). The finding may underscore a simple truth about public capital expenditure in a globalized economy. While government spending patterns used to determine the direction of labor productivity changes in the short run during the '70s and '80s and early '90s, other factors related to the international division of labor - such as capital good imports - play an increasingly

important role for labor productivity gains and are able to offset the adverse impact on productivity caused by a decline in government spending on public capital goods, even in the short run.

7. Summary and Conclusions

This paper provides empirical estimates for some of the key components of labor productivity growth. The main results are as follows. First, we find that access to cheaper capital good imports not only had a positive effect on labor productivity growth for the entire sample period, but has become increasingly important in recent years. In contrast, non-military public capital expenditures (such as government spending on roads, highways, water supply, and airports) did not contribute to labor productivity gains over the sample period. Second, while imported industrial materials played a very limited role in determining labor productivity growth for the entire sample, they have become slightly more important in recent decades. Third, private capital formation is both the most important and most consistent component of labor productivity growth. Finally, fluctuating non-military public capital expenditures were able to determine the directional change in labor productivity over short periods until the mid 90's, but that link appears to be broken since then.

The above results have important policy implications. Most importantly, they suggest that policies aimed at reducing trade barriers, in particular on capital good imports, will stimulate productivity growth both in the short and the long run. Note, however, that barriers to trade are only one element among many in determining the domestic price of capital good imports. As the experience of the '70s has shown, the positive effect of lower trade barriers can be more than offset by the negative impact of higher transportation costs and/or adverse supply shocks in international markets. Regarding public capital expenditure, our results indicate that it too has the ability to raise productivity growth, but the ups and downs of government spending on public capital goods make it an unreliable source of productivity gains in the long run.

Appendix A

In this appendix, we show how the profit function in section 2 can be derived from value-added output given by

$$V = pq - \mathbf{p}'_m \mathbf{m}. \quad (7.1)$$

Dividing both sides by the output price level yields

$$y = q - \boldsymbol{\rho}'_m \mathbf{m}. \quad (7.2)$$

With perfect competition in the intermediate goods markets, factors are paid their marginal value product, so that

$$\frac{\partial F(k, l, g, m_1, m_2, m_3)}{\partial m_i} = \rho_{mi}, \quad i = 1, 2, 3 \quad (7.3)$$

which we can simultaneously solve to obtain the intermediate inputs, \mathbf{m} , expressed as a function of k, l, g, t , and $\boldsymbol{\rho}_m$:

$$\mathbf{m} = \boldsymbol{\phi}(k, l, g, \rho_{m1}, \rho_{m2}, \rho_{m3}, t). \quad (7.4)$$

Substituting (7.4) in (7.2) we obtain the real value-added output y , in terms of $k, l, g, \boldsymbol{\rho}_m$, and t .

$$y = F(k, l, g, \phi_1, \phi_2, \phi_3) - \boldsymbol{\rho}'_m \boldsymbol{\phi}(k, l, g, \rho_{m1}, \rho_{m2}, \rho_{m3}, t) \quad (7.5)$$

or

$$y = H(k, l, g, \rho_{m1}, \rho_{m2}, \rho_{m3}, t). \quad (7.6)$$

Given y we are now able to derive the profit function, π , which we assume to be continuous and twice

differentiable:

$$\max_{y,k,l} \pi = py - p_k k - p_l l \quad (7.7)$$

s.t.

$$y = H(k, l, g, \rho_{m1}, \rho_{m2}, \rho_{m3}, t).$$

Under perfect competition in the product and factor markets, we get the optimized value of k^* , l^* , y^* , as well as π^* , where

$$\pi^* = \pi^*(p, p_k, p_l, g, \rho_m, t) = py^* - p_k k^* - p_l l^*. \quad (7.8)$$

Appendix B

In this appendix, we provide exact variable definitions and data sources and, when needed, explain variable construction. We use the following data in our empirical analysis:

y : (value-added) GDP corporate business non-financial, non-farm sector, in billions of dollars, Source: *Economic Report of the President, 2002. Table B-14.*

$ycon$: (value-added) GDP corporate business non-financial, non-farm sector, in billions of '96 dollars, Source: *Economic Report of the President, 2002. Table B-14.*

k : net stock of fixed non-residential private capital (equipment and structures) in millions of current dollars. Source: unpublished data from BEA¹⁴.

$kcon$: net stock of fixed non-residential private capital (Equipment and Structures) in millions of '96 dollars. Source: unpublished data from BEA.

g : government owned (i.e. federal+state+local) nonmilitary net stock of fixed non-residential capital (equipment and structures) in millions of '96 dollars. Source: unpublished data from BEA.

yl : output per hour of all employees in '96 dollars. Source: *Economic Report of the President, 2002. Table B-14.*

cfc : consumption of fixed capital. (in billions of dollars). Source: *Economic Report of the President, 2002. Table B-13.*

d : depreciation of private capital, defined as $cfc \div k$

i : nominal interest rate on corporate bonds (Moody's Aaa). Source: *Economic Report of the President, 2002. Table B-72.*

q_k : the price index of the capital goods, defined as $k \div kcon$

p_k : the rental price of capital, defined $q_k * (i + d) - (q_k(t) - q_k(t - 1))$

p_l : compensation per hour of all employees in current dollars. Source: *Economic Report of the President, 2002. Table B-14.*

p : price index of output (GDP), defined as $ycurr \div ycon$

¹⁴We thank Michael Glenn of the BEA for providing us with data on equipment and structures.

l : total hours worked, defined as $ycon \div yl$

π : nominal profits, defined as $ycurr - p_k * kcon - p_l * l$

m_1 : imports of capital goods, except automotive, in billions of current dollars. Source: *Economic Report of the President, 2002. Table B-106* and Survey of Current Business '96 issues.

m_192 : imports of capital goods, except automotive, chained '92 dollars. Source: STAT-USA¹⁵.

m_2 : imports of industrial supplies and materials, except petroleum and products, billions of current dollars. Source: STAT-USA.

m_292 : imports of industrial supplies and materials, except petroleum and products, chained '92 dollars. Source: STAT-USA.

p_{mi92} , import price index with base year 92, for $i^{16} = 1, 2$. defined as $m_i \div m_i92$.

p_{mi} : rebase p_{mi92} to year '96, for $i = 1, 2$.

p_{m3} : the producer price of index for intermediate materials, supplies, and components, rebased to '96=100, [by stage of processing]. Source: *Economic Report of the President, 2002. Table B-64*.

ρ_{mi} : real price index of i^{th} good, defined as $p_{mi} \div p$, where $i = 1, 2, 3$.

s_y : output share in profit $ycurr \div \pi$

s_k : capital share in profit $p_k * kcon \div \pi$

s_{m1} : capital goods import share in profit $p_{m1} * m_1 \div \pi$

s_{m2} : intermediate import share in profit $p_{m2} * m_2 \div \pi$

¹⁵National Income and Product Accounts data retrieved from Bureau of Economic Analysis site at <http://www.stat-usa.gov/>

¹⁶Variables with subscript $i = 1, 2$, and 3 represent capital good imports, intermediate materials and supplies imports, and domestic intermediate goods, respectively.

Appendix C

In this appendix, we briefly describe further details of the FM estimation procedure. In particular, we discuss the issues of pre-whitening, kernel choice, and bandwidth selection.

Pre-whitening: OLS estimates of (4.9) and (4.10) yield the residuals \hat{u}_{1t} and \hat{u}_{2t} , respectively. We pre-whiten \hat{u}_t using a low order VAR(1): $\hat{u}_t = \hat{\phi}\hat{u}_{t-1} + \hat{e}_t$. This has the effect of soaking up some, but not all of the serial correlation. Pre-whitening improves the ‘confidence interval coverage,’ as suggested by Andrews and Monahan [2]. Based on the whitened residuals \hat{e}_t we calculate kernel estimators, denoted by $\hat{\Omega}_e$ and $\hat{\Lambda}_e$. These estimators are then used, together with $\hat{\phi}$, to recover the covariance estimators of interest, $\hat{\Omega}$ and $\hat{\Lambda}$.

Kernel choice: There are several kernels to choose from in order to ensure a positive semi-definite HAC estimator $\hat{\Omega}_e$. Andrews [1] finds that compared to the Bartlett and Parzen kernels the quadratic spectral (QS) kernel is superior with respect to the asymptotic truncated mean square criterion. The QS kernel used for the estimation in Table 2 is given by $k(j/M) = k(x) = \frac{25}{12\pi^2 x^2} \left(\frac{\sin(6\pi x/5)}{6\pi x/5} - \cos(6\pi x/5) \right)$.

Bandwidth selection: The estimation results in Table 2 are based on a bandwidth parameter M equal to 1.5. Alternatively, one could use an automatic plug-in bandwidth selection procedure (as recommended by Andrews [1]). The automatic bandwidth parameter that corresponds to the QS kernel is $\hat{M} = 1.3221(\hat{\alpha}(2)T)^{1/5}$ where $\hat{\alpha}(2) = \sum_{a=1}^p \frac{4\hat{\rho}_a^2 \hat{\sigma}_a^2}{(1-\hat{\rho}_a)^6 (1+\hat{\rho}_a)^2} / \sum_{a=1}^p \frac{\hat{\sigma}_a^2}{(1-\hat{\rho}_a)^4}$ (see Andrews [1], section 6).

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