

Capital-goods imports, investment-specific technological change and U.S. growth^{*}

Michele Cavallo[†]

Board of Governors of the Federal Reserve System

Anthony Landry[‡]

Federal Reserve Bank of Dallas

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ABSTRACT

Investment-specific technological progress as reflected by the decline in the relative price of U.S. capital goods has substantially contributed to U.S. postwar growth. Imports of capital goods have represented an increasing share of U.S. equipment investment, and their price relative to U.S. capital goods has declined. We examine the quantitative contribution of the decline in the relative price of imports of capital goods to U.S. growth by assessing to what extent this decline can account for the decline in the relative price of capital goods in the U.S. We find that decline in the relative price of imports of capital goods has accounted for nearly 20 percent of U.S. growth during the last forty years.

JEL CLASSIFICATION CODES: E2; F2; F4; O3; O4

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[†]Email: Michele.Cavallo@frb.gov

[‡]Email: Anthony.Landry@dal.frb.org

1 Introduction

In a seminal paper, Greenwood, Hercowitz and Krusell (1997) investigated the role played by technological progress associated with the production of new capital goods in generating postwar U.S. economic growth. The degree of this source of technological progress, namely investment-specific technological progress, is reflected by the decline in the price of equipment investment relative to consumption goods. Using a standard neoclassical model of economic growth, Greenwood, Hercowitz and Krusell estimated that investment-specific technological progress accounted for nearly 60 percent of growth in output per hour in the U.S. during the postwar period.

Over the last forty years, U.S. imports of capital goods have risen as a share of both GDP and of aggregate equipment investment, as illustrated in the upper panel of Figure 1. While accounting for only 5 percent of U.S. aggregate investment in equipment at the beginning of our sample in 1967, imports of capital goods now account for over 40 percent. At the same time, the U.S. terms-of-trade for capital goods has increased, as imports of capital goods have become cheaper relative to both U.S. capital goods and consumption goods. In addition, as shown in the lower panel of Figure 1, the decline in the price of imports of capital goods relative to domestic consumption has been larger than the decline in the relative price of new equipment goods in the aggregate. These observations suggest that a significant portion of the decline in the relative price of equipment investment may actually be accounted for by the decline in the relative price of imports of capital goods.

In this paper, we examine to what extent the decline in the relative price of imports of capital goods contributed to growth in output per hour. For this purpose, we use a small open-economy version of the standard model of economic growth by Greenwood, Hercowitz and Krusell (1997), with international trade both in final and capital goods. We calibrate our small open-economy model using NIPA data to obtain a broad estimate of the contribution of the decline in the relative price of imports of capital goods to growth in output per hours worked over the last forty years. Our

main findings are as follows: First, the decline in the relative price of imports of capital goods has accounted for nearly twenty percent of growth in U.S. output per hours worked. Second, imports of capital goods, and, in particular, the decline in their price has allowed the U.S. economy to grow about 11 percent more rapidly than it would have had under autarky, with no imports of capital goods..

The rest of the paper is organized as follows. Section 2 describes the small open economy model. Section 3 presents the balanced growth path of the model economy. Section 4 describes how we measure relative prices and their respective rates of decline. Section 5 presents the numerical values assigned to the parameters of the balanced growth path. Section 6 examines the quantitative contribution of the decline in the relative price of imports of capital goods to U.S. growth over the last forty years. Section 7 concludes.

2 A small open economy model

This section describes the model economy that we use to measure the contribution of the decline in the relative price of imports of capital goods to growth in output per capita in the U.S. economy during the last forty years. Essentially, we extend the closed-economy growth model developed by Greenwood, Hercowitz and Krusell (1997) to a small open-economy setup with frictionless international trade in both final and capital goods.

In the model by Greenwood, Hercowitz, and Krusell, technological progress can affect growth from two sources: neutral technological progress affects the production of final output given input levels, whereas investment-specific technological progress affects the production of new equipment goods. In their setup, it is the rate of decline in the price of new equipment relative to consumption that reflects the rate of investment-specific technological progress. In fact, increases in the level of investment-specific technology make investment expenditure more productive and reduce the resource cost in terms of output and consumption that is required to obtain one new unit of

equipment.

In our small open economy setup, new equipment is an aggregate of new domestic equipment and imports of final goods. Therefore, the rate of decline in the relative price of new equipment reflects two components: one, the rate of domestic investment-specific technological progress as measured by the rate of decline in the relative price of new domestic equipment; and two, the rate of decline in the relative price of imports of capital goods.

As in Greenwood, Hercowitz and Krusell (1997), there are two types of capital goods, structures and equipment. The set of agents includes a representative households, a representative firm that produces final goods, and a government. Finally, time is discrete and each time period is indexed by the subscript t .

Each period, the representative household receives utility from consuming final goods and derives disutility from supplying labor hours. The representative household's preferences are given by the following utility function:

$$(1) \quad U = \sum_{t=0}^{\infty} \beta^t u(C_t, L_t), \quad 0 < \beta < 1,$$

where β denotes the subjective discount factor, and where C_t and L_t represent, respectively, consumption of final goods and the fraction of hours spent working. The period t utility function is given by:

$$(2) \quad u(C_t, L_t) = \theta \log C_t + (1 - \theta) \log(1 - L_t), \quad 0 < \theta < 1,$$

where θ is a preference parameter.

The technology for producing final goods available to the representative firm is given by the

following Cobb-Douglas production function:

$$(3) \quad Y_t = Z_t K_{s,t}^{\alpha_s} K_{e,t}^{\alpha_e} L_t^{1-\alpha_s-\alpha_e}, \quad 0 < \alpha_s, \alpha_e < 1, \quad \alpha_s + \alpha_e < 1,$$

where Y_t denotes output of final goods, Z_t denotes the level of neutral, total-factor technology, and where $K_{s,t}$ and $K_{e,t}$ represent, respectively, the beginning-of-period stocks of structures and equipment.¹ According to the production function in (3), increases in Z_t represent neutral technological progress.

Output of final goods can be allocated between consumption, investment in structures, $I_{s,t}$, investment in domestic equipment, $I_{d,t}$, and exports of final goods, X_t . Taking consumption as the numeraire, the resource constraint for final goods is:

$$(4) \quad Y_t = C_t + I_{s,t} + I_{d,t} + X_t,$$

where output, investment in structures, investment in domestic equipment, and exports of final goods are all denominated in terms of consumption.

The law of motion for the stock of structures is given by:

$$(5) \quad K_{s,t+1} = (1 - \delta_s) K_{s,t} + I_{s,t}, \quad 0 < \delta_s < 1,$$

where $K_{s,t+1}$ denotes the end-of-period stock of structures, and where δ_s denotes its depreciation rate. According to (5), the relative price of structures in terms of consumption is equal to one.

¹As pointed out in Greenwood, Hercowitz and Krusell (1997), and in Gomme and Rupert (2007), within the class of CES production functions, only the Cobb-Douglas case is consistent with the existence of a balanced growth path along which all variables with positive growth rates grow at a constant, but not necessarily common, rate.

The law of motion for the stock of equipment is given by:

$$(6) \quad K_{e,t+1} = (1 - \delta_e) K_{e,t} + I_{e,t}, \quad 0 < \delta_e < 1,$$

where $K_{e,t+1}$ denotes the end-of-period stock of equipment, δ_e its depreciation rate, and $I_{e,t}$ represents the amount of new equipment goods.

The amount of new equipment goods, in turn, is a Cobb-Douglas aggregate of two components, new domestic equipment goods and imports of capital goods:

$$(7) \quad I_{e,t} = \left(\frac{Q_{d,t} I_{d,t}}{\eta} \right)^\eta \left(\frac{I_{m,t}}{1 - \eta} \right)^{1-\eta},$$

where η is a technological parameter that reflects the share of domestic equipment investment in the value of new aggregate equipment measured in terms of consumption, and where $I_{m,t}$ represents the amount of imports of capital goods. In (7), $Q_{d,t}$ denotes the level of domestic investment-specific technology, that is, the amount of new domestic equipment goods that can be obtained with one unit of $I_{d,t}$. Increases in $Q_{d,t}$, therefore, represent domestic investment-specific technological progress. Moreover, the inverse of $Q_{d,t}$ represents the relative price of new domestic equipment in terms of consumption. Therefore, the rate of decline in the relative price of domestic equipment corresponds to the rate of domestic investment-specific technological progress.²

In each period, there is balanced trade, that is, the value of imports of capital goods is equal to the value of exports of final goods:

$$(8) \quad P_{m,t} I_{m,t} = X_t,$$

²As indicated in Gomme and Rupert (2007), the presence of investment-specific technological progress supports the assumption of a Cobb-Douglas aggregator.

where $P_{m,t}$ denotes the relative price of imports of capital goods in terms of consumption.

According to the Cobb-Douglas production function in (7), and to the balanced-trade requirement in (8), the relative price of $I_{e,t}$ in terms of consumption, denoted by $P_{e,t}$, is a geometric mean of the relative prices of new domestic equipment and of imports of capital goods:

$$(9) \quad P_{e,t} = Q_{d,t}^{-\eta} P_{m,t}^{1-\eta}.$$

The definition of $P_{e,t}$ in (9) implies that the rate of decline in the relative price of new aggregate equipment is also a geometric mean of the rates of decline in the relative prices of new domestic equipment and of imports of capital goods.

Finally, a government raises distortionary taxes on labor and capital income, with the tax rates denoted by $\tau_{L,t}$, and $\tau_{K,t}$, respectively. In each period, tax revenues are rebated back to households through lump-sum transfers, T_t , so that the government runs a balanced budget. The budget constraint for the government is therefore:

$$(10) \quad \tau_{L,t} W_t L_t + \tau_{K,t} (R_{s,t} K_{s,t} + R_{e,t} K_{e,t}) = T_t,$$

where W_t , $R_{s,t}$, and $R_{e,t}$ denote, respectively, the real wage, the real return from structures, and the real return from equipment.

Appendix A.1. describes the maximization problems of the representative household and of the representative firm and the resulting competitive equilibrium.

3 Balanced growth path

This section describes the balanced growth path of the model economy from Section 2. Along the balanced growth path, all variables that exhibit a positive growth rate grow at a constant rate.

We denote with g the gross growth rate of output, that is, Y_{t+1}/Y_t , and with γ_Z and γ_{Q_d} the gross growth rates of neutral technology and of domestic investment-specific technology. We also denote with γ_{P_m} the rate of decline in the relative price of imports of capital goods in terms of consumption. Therefore:

$$(11) \quad Z_t = \gamma_Z^t, \quad Q_{d,t} = \gamma_{Q_d}^t, \quad P_{m,t} = \gamma_{P_m}^t, \quad \gamma_Z, \gamma_{Q_d} > 1, \quad 0 < \gamma_{P_m} < 1.$$

The resource constraint (4) implies that, along the balanced growth path, output, consumption, investment in structures, investment in domestic equipment, and exports of final goods all grow at the common rate, g :

$$(12) \quad g = \gamma_C = \gamma_{I_s} = \gamma_{I_d} = \gamma_X.$$

The law of motion for the stock of structures (5) implies that $K_{s,t}$ also grows at the rate g :

$$(13) \quad \gamma_{K_s} = \gamma_{I_s} = g.$$

The balanced-trade requirement (8) implies that imports of capital goods grow at the rate $g\gamma_{P_m}^{-1}$:

$$(14) \quad \gamma_{I_m} = \gamma_X \gamma_{P_m}^{-1} = g\gamma_{P_m}^{-1}.$$

The Cobb-Douglas aggregator (7) implies that the amount of new equipment goods grow at the rate $g\gamma_{Q_d}^\eta \gamma_{P_m}^{-(1-\eta)}$:

$$(15) \quad \gamma_{I_e} = (\gamma_{Q_d} \gamma_{I_d})^\eta (\gamma_{I_m})^{1-\eta} = g\gamma_{Q_d}^\eta \gamma_{P_m}^{-(1-\eta)}.$$

The law of motion for the stock of equipment (6) implies that $K_{e,t}$ grows at the same rate of $I_{e,t}$:

$$(16) \quad \gamma_{K_e} = \gamma_{I_e}.$$

According to the Cobb-Douglas production function (3), the growth rate in output per capita, g , is equal to

$$(17) \quad g = \gamma_Z \gamma_{K_s}^{\alpha_s} \gamma_{K_e}^{\alpha_e}.$$

Therefore, using (12)–(17), g can be computed as follows:

$$(18) \quad g = \gamma_Z^{1/(1-\alpha_s-\alpha_e)} \gamma_{Q_d}^{\alpha_e \eta / (1-\alpha_s-\alpha_e)} \gamma_{P_m}^{-\alpha_e (1-\eta) / (1-\alpha_s-\alpha_e)}.$$

In (18), the term $\gamma_{Q_d}^{\alpha_e \eta / (1-\alpha_s-\alpha_e)} \gamma_{P_m}^{-\alpha_e (1-\eta) / (1-\alpha_s-\alpha_e)}$ represents the contribution to growth in output per capita of the decline in the relative price of new equipment goods in terms of consumption. This term shows that the decline in the relative price of new equipment reflects two components: one, the rate of domestic investment-specific technological progress; and, two, the decline in the relative price of imports of capital goods.

4 Measuring relative prices and their rates of decline

This section describes how we measure the relative prices of aggregate equipment investment, domestic equipment investment, and imports of capital goods in consumption units and their respective rates of decline. We obtain these measures by using forty years of quarterly NIPA, from 1967.Q1 to 2006.Q4.

The first step in our analysis consists of measuring the price variables. We measure the price of consumption with the implicit price deflator for an aggregate of personal consumption in non-

durables and services plus government consumption. We obtain this deflator by dividing the nominal sum of personal consumption in nondurables and services and of government consumption by the corresponding real chain-weighted aggregate computed following the procedure indicated in Whelan (2002). We measure the price of aggregate equipment in a similar way. In particular, we obtain the implicit price deflator for an aggregate of private non-residential fixed investment in equipment and software and government investment in equipment and software by dividing the sum of the corresponding nominal magnitudes by their real chain-weighted aggregate, and we measure the price of aggregate equipment with the resulting deflator. The price of imports of capital goods is simply the corresponding implicit price deflator. Finally, the price of domestic equipment investment is the implicit price deflator for the difference between aggregate equipment investment and imports of capital goods. Similarly to the other price measures, this price deflator is the ratio between the corresponding nominal and real magnitudes. We compute real domestic investment equipment as the chain-weighted subtraction of imports of capital goods from aggregate equipment investment, following, again, the procedure in Whelan (2002).

After obtaining the prices for consumption, aggregate equipment investment, domestic equipment investment, and imports of capital goods, we can measure relative prices. We compute the relative prices of aggregate equipment investment, domestic equipment investment, and imports of capital good in terms of consumption as the ratios between their corresponding implicit price deflators and the implicit price deflator for consumption.

Finally, using these relative prices, we can measure the rates of decline in these relative prices. The rate of decline in the relative price of domestic equipment investment, in particular, measures the rate of domestic investment-specific technological progress. NIPA data indicate that, over the period 1967.Q1 – 2006.Q4, the average rates of decline in the relative prices of aggregate equipment investment, domestic equipment investment, and imports of final goods were 3.00 percent, 2.36

percent, and 4.86 percent, respectively, that is $\gamma_{Q_e} = 1.03$, $\gamma_{Q_d} = 1.0236$, and $\gamma_{P_m} = 1.0486$.

5 Calibration

This section presents the numerical values assigned to the parameters of the balanced growth path. These parameters are such that the balanced growth path is consistent with the corresponding average values for the U.S. economy over the 1967.Q1 – 2006.Q4 period. The model period is one quarter.

As computed in the previous section, the average rates of decline in the relative prices of aggregate equipment, domestic equipment investment, and imports of capital goods, are equal to $\gamma_{Q_e} = 1.03$, $\gamma_{Q_d} = 1.0236$, and $\gamma_{P_m} = 1.0486$, respectively. We obtain the depreciation rates for the stocks of structures and equipment, δ_s and δ_e , following the method of Gomme and Rupert (2007). In particular, in regard to the stock of structures, we compute its depreciation rate as the average of the depreciation of structures in year t divided by the stock of structures at the end of year $t - 1$, with both the depreciation and the stock of structures measured in nominal terms, that is, in current dollars. We apply the same method to compute the depreciation rate for the stock of equipment. We obtain $\delta_s = 0.0251$ and $\delta_e = 0.1495$. As in Greenwood, Hercowitz and Krusell (1997), we set the labor tax rate, $\tau_{L,t}$ equal to 0.4. We set g equal to the average gross growth rate of output per hour measured in consumption units, 0.93 percent, that is $g = 1.0093$. We set L , the fraction of time spent working along the balanced growth path, equal to 0.26, the average fraction of hours worked to total non-sleeping hours. We set the capital share of income, $\alpha_s + \alpha_e$, equal to 33 percent, the ratio of investment in structures to output, I_s/Y , equal to 6.2 percent, and the ratio of investment in equipment to output, I_e/Y , equal to 9.6 percent. Finally, we set the subjective discount factor to 0.94, a value which is consistent with an average after-tax rate of return on capital equal to 7 percent as in Greenwood, Hercowitz and Krusell (1997).

The parameter values that remain to be determined are α_s , α_e , θ , η , and τ_K . These values can be

obtained by solving the nonlinear system of equations that describes the balanced growth path. As standard, before solving the nonlinear system, we transform all the variables that exhibit positive growth rates along the balanced growth path in order to make them stationary. Specifically, we obtain the transformed variables by dividing each of the original variables by their corresponding deterministic trend. For notational simplicity, we denote these transformed detrended variables without a time subscript. These variables are $Y = Y_t/g^t$, $C = C_t/g^t$, $I_s = I_{s,t}/g^t$, $K_s = K_{s,t}/g^t$, $I_d = I_{d,t}/g^t$, $I_e = I_{e,t}/(g\gamma_{Q_e})^t$, $K_e = K_{e,t}/(g\gamma_{Q_e})^t$, $P_e = P_{e,t}/\gamma_{Q_e}^{-t}$, $I_m = I_{m,t}/(g\gamma_{P_m}^{-1})^t$, and $P_m = P_{m,t}/\gamma_{P_m}^{-t}$. The equations characterizing the balanced growth path are obtained from the first-order conditions of the maximization problems of the representative household and of the representative firm described in Appendix A.1., from the laws of motion for the stocks of structures and equipment, (5) and (6), from the resource constraint for output of final goods, and from the Cobb-Douglas production function (7) for new aggregate equipment investment. These equations are the following:

$$(19) \quad \frac{C}{Y} = (1 - \tau_L)(1 - \alpha_s - \alpha_e) \frac{\theta}{1 - \theta} \frac{1 - L}{L};$$

$$(20) \quad 1 = \frac{\beta}{g} \left[(1 - \tau_K) \alpha_s \left(\frac{K_s}{Y} \right)^{-1} + (1 - \delta_s) \right];$$

$$(21) \quad \gamma_{Q_e} = \frac{\beta}{g} \left[(1 - \tau_K) \alpha_e \left(\frac{P_e K_e}{Y} \right)^{-1} + (1 - \delta_e) \right];$$

$$(22) \quad \frac{I_s}{Y} = \frac{K_s}{Y} [g - (1 - \delta_s)];$$

$$(23) \quad \frac{P_e I_e}{Y} = \frac{P_e K_e}{Y} [g\gamma_{Q_e} - (1 - \delta_e)];$$

$$(24) \quad 1 = \frac{C}{Y} + \frac{I_s}{Y} + \frac{P_e I_e}{Y};$$

$$(25) \quad \alpha_s + \alpha_e = 0.33;$$

$$(26) \quad \gamma_{Q_e} = \gamma_{Q_d}^\eta \gamma_{P_m}^{-(1-\eta)}.$$

The first seven equations of this system are similar to those already present in Greenwood, Hercowitz and Krusell (1997). Our system includes an additional equation, (26), that captures the feature that aggregate equipment investment is a composite of domestic equipment investment and imports of capital goods.

The set of equations (20) – (26) represents a system of eight equations in eight unknowns, C/Y , K_s/Y , $P_e K_e/Y$, α_s , α_e , θ , η , and τ_K . The parameter values that we obtain by solving the nonlinear system are $\theta = 0.3262$, $\alpha_e = 0.1419$, $\alpha_s = 0.1881$, $\eta = 0.7433$, and $\tau_K = 0.1013$. The value for η implies a long-run spending share of imports of capital goods equal to 0.2567, which compares fairly well with the mid-range of spending shares of non-residential fixed investment in equipment and software observed in the second half of our sample, as displayed in Figure 2.

6 Shares of contributions to growth

In this section, we examine the quantitative contribution of the decline in the relative price of imports of capital goods to U.S. growth over the last forty years. In order to measure this contribution, we need to measure the rate of neutral technological progress, γ_Z .

First, we start by computing the stock of structures and equipment using the laws of motions (5) and (6). Starting with an initial value for $K_{s,t}$ and $K_{e,t}$, we compute the series for the two stocks of capital by iterating on the corresponding laws of motion using observed values for $I_{s,t}$, $I_{d,t}$, $I_{m,t}$, $Q_{d,t}$, and $P_{m,t}$. As starting values for the capital stocks, we use the stocks of structures and equipments observed at the beginning of the sample period divided by the implicit consumption deflator. Second, we compute the level of neutral technology, Z_t , as the ratio between output and the composite input $K_{s,t}^{\alpha_s} K_{e,t}^{\alpha_e} L_t^{1-\alpha_e-\alpha_s}$, with output also deflated by the implicit deflator for consumption. Having obtained a measure for the level of neutral technology, we can compute γ_Z ,

the rate of neutral technological progress.

Figure 3 plots the series for the level of neutral technology, Z_t , the inverse of the relative price of equipment goods, $Q_{e,t}$, and its components $Q_{d,t}$ and $P_{m,t}^{-1}$. Figure 3 shows that neutral technology and domestic investment-specific technology display modest growth in the first half of our sample and stronger growth in the second half. Over the whole sample, the average growth rate of neutral technology is 0.49 percent while the average growth rate in domestic investment-specific technology is 2.36 percent. The decline in the relative price of imports of capital goods has also increased over the second half of the sample. Over the whole sample, this average rate of decline is 4.86 percent. These numbers imply that the average rate of decline in the relative price of aggregate equipment in terms of consumption is equal to 3 percent.

With our measures of γ_Z , γ_{Q_d} , and γ_{P_m} , we use the balanced growth expression for the growth rate of output per capita, (18), to compute the contribution to growth of neutral technological progress, domestic investment-specific technological progress, and of the decline in the relative price of imports of capital goods. The model predicts an average growth rate in output per hour of 1.35 percent. With no neutral technological progress, that is, with $\gamma_Z = 1$, the model predicts that output per hour would have grown at 0.63 percent. With only neutral technological progress, that is, with $\gamma_{Q_d} = 1$, and $\gamma_{P_m} = 1$, output per hour would have grown at 0.73 percent per year. This implies that, between 1967 and 2006, the decline in the relative price of aggregate equipment contributed about 46 percent to growth in output per hour. With no neutral and domestic investment-specific technological progress, that is, with $\gamma_Z = 1$ and $\gamma_{Q_d} = 1$, the model predicts that output per hour would have grown at 0.26 percent. This implies that the decline in the relative price of imports of capital goods contributed about 19 percent of growth in output per hours and about 41 percent to the decline in the relative price of aggregate equipment.

One additional question that we ask is how much different the U.S. growth rate in output per

hour would have been under autarky, with no imports of capital goods. To answer this question, we assume that the series for the relative price of aggregate equipment investment would have followed the series for the relative price of domestic equipment investment, implying the rate of decline in the relative price of aggregate equipment investment would have reflected only domestic investment-specific technological progress, $\gamma_{Q_e} = \gamma_{Q_d}$. Under this scenario, output per hour would have grown at 1.23 percent per year. This estimate indicates that imports of capital goods and, in particular, the decline in their relative price has increased the U.S. growth rate in output per hour by about 11 percent over the period 1967 to 2007. This whole set of estimates indicate that, over the long run, the decline in the relative price of imports of capital goods has had a significant positive impact on growth in U.S. output per hour.

Over the second half of the sample, that is, between 1987.Q1 and 2006.Q4, the average rates of decline in the relative prices of aggregate equipment investment, imports of capital goods and domestic equipment investment were, respectively, 3.99 percent, 6.56 percent and 2.96 percent, whereas the rate of neutral technological progress was equal to 1.16 percent. All of these rates are, therefore, higher than their corresponding values over the whole sample, that is between 1967.Q1 and 2006.Q4. One plausible question is whether the decline in the relative price of imports of capital goods contributed a larger portion to growth during the last 20 years. Our model predicts that, on average, between 1987 and 2006, output per hour grew by 2.62 percent per year. With $\gamma_{Q_e} = \gamma_{Q_d}$, and using (18), the model predicts that output per hour would have grown at 2.38 percent. This implies that the decline in the relative price of imports of capital goods contributed close to 11 percent to growth in output per hour from 1987 to 2006, an estimate similar to those obtained using the whole sample. However, the decline in the relative price of imports of capital goods has contributed a greater portion to the decline in the relative price of aggregate equipment investment. Using (18), this contribution is equal to about 58 percent.

7 Conclusions

Investment-specific technological progress as reflected by the decline in the relative price of U.S. capital goods in terms of consumption has substantially contributed to U.S. postwar growth. Over the last forty years, imports of capital goods have represented an increasing share of U.S. investment in new capital goods, and their price relative to U.S. capital goods has declined. This suggests that a substantial portion of the decline in the relative price of U.S. capital goods may have stemmed from importing cheaper capital goods. Using a small open-economy version of the model in Greenwood, Hercowitz and Krusell (1997), we have examined the quantitative contribution of the decline in the relative price of imports of capital goods to U.S. growth. In particular, we have assessed to what extent the decline in the relative price of imports of capital goods can account for the decline in the relative price of U.S. capital goods. We find that, over the last forty years, the decline in relative price of imports of capital goods has accounted for nearly 20 percent of U.S. output growth, and that imports of capital goods have allowed the U.S. economy to grow 11 percent more rapidly than it would have otherwise had under autarky.

Appendix

A.1. The competitive equilibrium

The problem of the representative household is to choose consumption, C_t , labor supply, L_t , end-of-period stocks of structures and equipment, $K_{s,t}$ and $K_{e,t}$, investment in domestic equipment, $I_{d,t}$, and imports of capital goods to maximize its utility function (1) subject to a budget constraint, to the laws of motion for structures and equipment, (5) and (6), to the Cobb-Douglas production function for new equipment, (7), and to the balanced-trade requirement, (8). The Lagrangian associated with the problem of the representative household is then:

$$\begin{aligned}
 (A1) \quad \mathcal{L} = & \sum_{t=0}^{\infty} \beta^i [\theta \log C_t + (1 - \theta) (1 - L_t)] + \\
 & \sum_{t=0}^{\infty} \beta^i \lambda_t [(1 - \tau_{L,t}) W_t L_t + (1 - \tau_{K,t}) (R_{s,t} K_{s,t} + R_{e,t} K_{e,t}) \\
 & - C_t - K_{s,t+1} + (1 - \delta_s) K_{s,t} - I_{d,t} - P_{m,t} I_{m,t} - T_t] - \\
 & \sum_{t=0}^{\infty} \beta^i \psi_{e,t} \left\{ K_{e,t+1} - (1 - \delta_e) K_{e,t} - \left(\frac{Q_{d,t} I_{d,t}}{\eta} \right)^\eta \left[\frac{I_{m,t}}{(1 - \eta)} \right]^{1-\eta} \right\},
 \end{aligned}$$

where λ_t is the Lagrange multiplier associated with the representative household's budget constraint and $\psi_{e,t}$ is the Lagrange multiplier associated with the law of motion for the stock of equipment.

The set of the household's first-order conditions is as follows. The first-order condition with respect to consumption is:

$$(A2) \quad \frac{\theta}{C_t} = \lambda_t.$$

The first-order condition with respect to labor supply is:

$$(A3) \quad \frac{(1 - \theta)}{1 - L_t} = \lambda_t W_t.$$

The first-order condition with respect to end-of-period structures is:

$$(A4) \quad \frac{\lambda_t}{\beta \lambda_{t+1}} = (1 - \tau_{K,t+1}) R_{s,t+1} + (1 - \delta_s).$$

The first-order condition with respect to end-of-period equipment is:

$$(A5) \quad \frac{\psi_{e,t}}{\beta \psi_{e,t+1}} = (1 - \tau_{K,t+1}) \frac{\lambda_{t+1}}{\psi_{e,t+1}} R_{e,t+1} + (1 - \delta_e).$$

The first-order condition with respect to investment in domestic equipment is:

$$(A6) \quad \lambda_t = \eta \psi_{e,t} \frac{I_{e,t}}{I_{d,t}}.$$

Finally, the first-order condition with imports of capital goods is:

$$(A7) \quad \lambda_t = (1 - \eta) \psi_{e,t} \frac{I_{e,t}}{P_{m,t} I_{m,t}}.$$

Using the first-order conditions (A6) and (A7), it is possible to obtain the value of new aggregate equipment measured in terms of consumption, $P_{e,t} I_{e,t}$:

$$(A8) \quad I_{d,t} + P_{m,t} I_{m,t} = \frac{\psi_{e,t}}{\lambda_t} I_{e,t} = P_{e,t} I_{e,t} = \frac{I_{e,t}}{Q_{e,t}},$$

with

$$(A9) \quad \frac{\psi_{e,t}}{\lambda_t} = P_{e,t} = \frac{1}{Q_{e,t}}.$$

where $P_{e,t}$ is the relative price of aggregate equipment in terms of consumption, that is, the resource

cost of aggregate equipment in terms of consumption, and $Q_{e,t}$ is the inverse of this relative price.

In order to derive the expressions for $Q_{e,t}$ and $P_{e,t}$ we rewrite the first-order conditions (A6) and (A7) as follows:

$$(A10) \quad I_{d,t} = \eta \frac{\psi_{e,t}}{\lambda_t} I_{e,t} = \eta \frac{I_{e,t}}{Q_{e,t}},$$

$$(A11) \quad I_{m,t} = (1 - \eta) \frac{\psi_{e,t}}{\lambda_t} I_{e,t} = (1 - \eta) \frac{I_{e,t}}{P_{m,t} Q_{e,t}}.$$

Using (A10) and (A11) into the production function (7) yields the expressions for $Q_{e,t}$ and $P_{e,t}$:

$$(A12) \quad Q_{e,t} = Q_{d,t}^\eta P_{m,t}^{-(1-\eta)},$$

$$(A13) \quad P_{e,t} = Q_{d,t}^{-\eta} P_{m,t}^{(1-\eta)}.$$

The definitions of $Q_{e,t}$ and $P_{e,t}$ in (A12) and (A13) allow to compute their gross growth rates:

$$(A14) \quad \gamma_{Q_e} = \gamma_{Q_d}^\eta \gamma_{P_m}^{-(1-\eta)},$$

and

$$(A15) \quad \gamma_{P_e} = \gamma_{Q_d}^{-\eta} \gamma_{P_m}^{1-\eta}.$$

Finally, in order to characterize the balanced growth path of the model economy it is useful to compute the gross growth rate of the Lagrange multiplier $\psi_{e,t}$. From (A2) and (A9)

$$\gamma_{\psi_e} = g^{-1} \gamma_{Q_e}^{-1}.$$

The problem of the representative firm is to choose its structures, equipment and labor input levels to maximize its profits given by:

$$(A16) \quad \pi_t = Z_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} - R_{s,t} k_{s,t} - R_{e,t} k_{e,t} - W_t l_t,$$

where lowercase variables $k_{s,t}$, $k_{e,t}$ and l_t denote the representative firm's demand for the services of structures, equipment, and labor, respectively. The first-order condition with respect to structures is

$$(A17) \quad R_{s,t} = \alpha_s \frac{Y_t}{k_{s,t}}.$$

The first-order condition with respect to equipment is:

$$(A18) \quad R_{e,t} = \alpha_e \frac{Y_t}{k_{e,t}}.$$

The first-order condition with respect to labor is

$$(A19) \quad W_t = (1 - \alpha_s - \alpha_e) \frac{Y_t}{l_t}.$$

A competitive equilibrium for this small open economy, as of period t , is a collection of allocations for the representative household, C_t , L_t , $K_{s,t+1}$, $K_{e,t+1}$, $I_{d,t}$, and $I_{m,t}$; for the representative firm, $k_{s,t}$, $k_{e,t}$, and l_t ; and a set of prices $R_{K,s}$, $R_{K,e}$, and W_t such that: (i) taking prices, tax rates, $\tau_{L,t}$, and $\tau_{K,t}$, lump-sum transfers, T_t , levels of neutral and domestic investment-specific technology, Z_t , and $Q_{d,t}$, and the price of imports of capital goods, $P_{m,t}$, as given, the representative household maximizes (A1); (ii) taking prices as given, the representative firm maximizes period t profits given

by (A16); and (iii) all input and good markets clear as follows:

$$(A20) \quad K_{s,t} = k_{s,t},$$

$$(A21) \quad K_{e,t} = k_{e,t},$$

$$(A22) \quad L_t = l_t,$$

$$(A23) \quad Y_t = C_t + I_{s,t} + P_{e,t}I_{e,t},$$

with $I_{e,t}$ given by (7), $P_{e,t}I_{e,t}$ given by (A8), and $P_{e,t}$ given by (A13).

Equations (A20) – (A22) are the market-clearing conditions for structures, equipment, and labor, respectively. Equation (A23) is the resource constraint for output of final goods, after using (A8) into the resource constraint (4). This equation indicates that output of final goods is allocated into consumption, investment in structures, and a aggregate of new equipment goods. The aggregate of new equipment goods, in turn, is the sum of the value of new domestic equipment and of imports of capital goods, as in (A8), all of which are measured in consumption units.

A.2. Data

We obtained our data from the Bureau of Economic Analysis. Data on aggregate series are from NIPA Tables 1.1.3 to 1.1.5, 1.3.3. to 1.3.7, 1.5.3 to 1.5.7, and 1.7.3 to 1.7.7. Data on imports of capital goods are from NIPA Tables 4.2.4 to 4.2.7. Data on investment are from NIPA Tables 5.3.3 to 5.3.7. The series on employment that we use is Total Aggregate Hours: Non-farm Payrolls (SAAR, Bil.Hrs). Finally, the capital stocks and the corresponding depreciations are from the Fixed Assets tables.

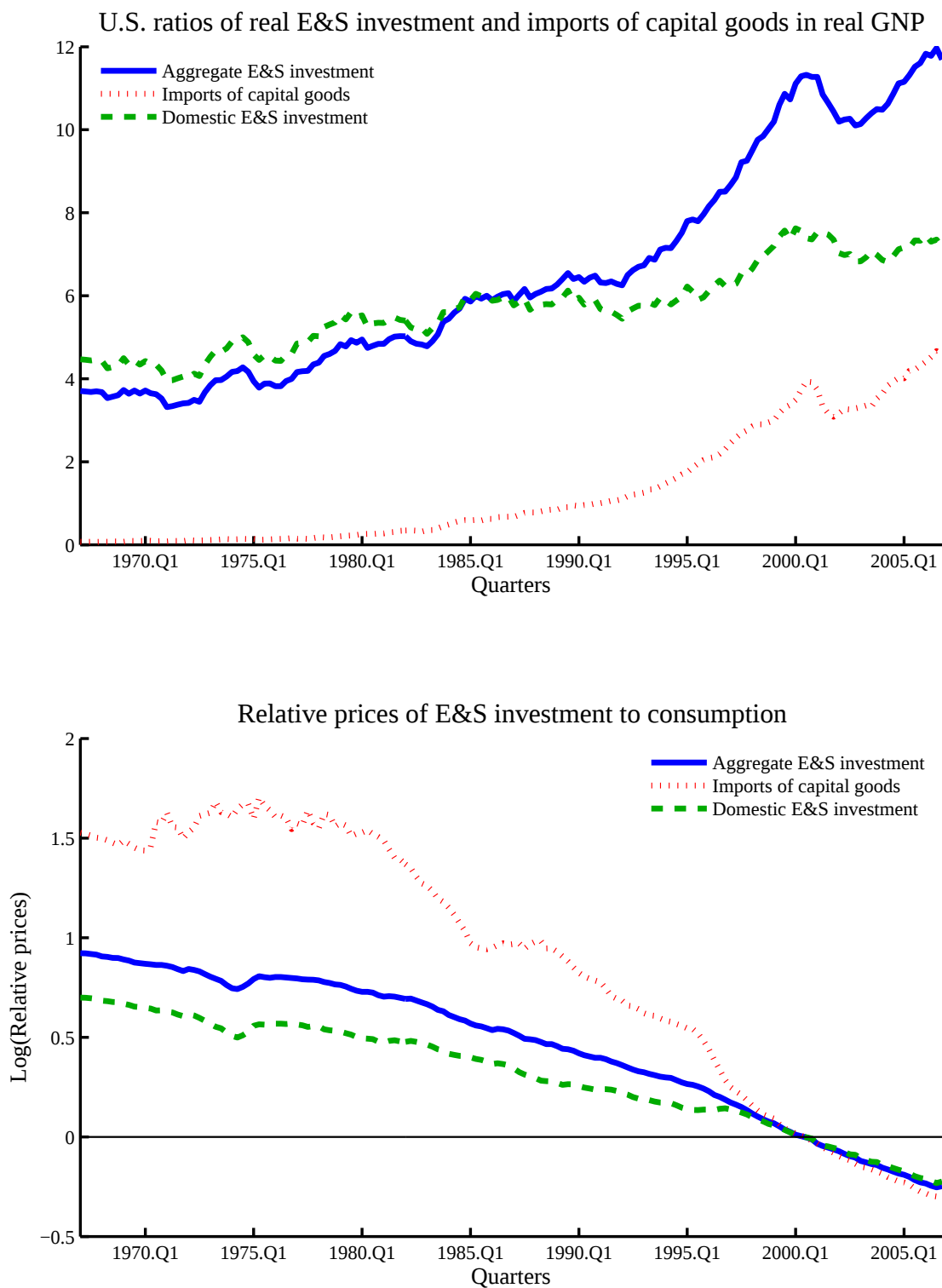
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Greenwood, J., Hercowitz, Z., Krusell, 1997. Long-run implications of investment-specific technological change. *American Economic Review* 87, 342-362.

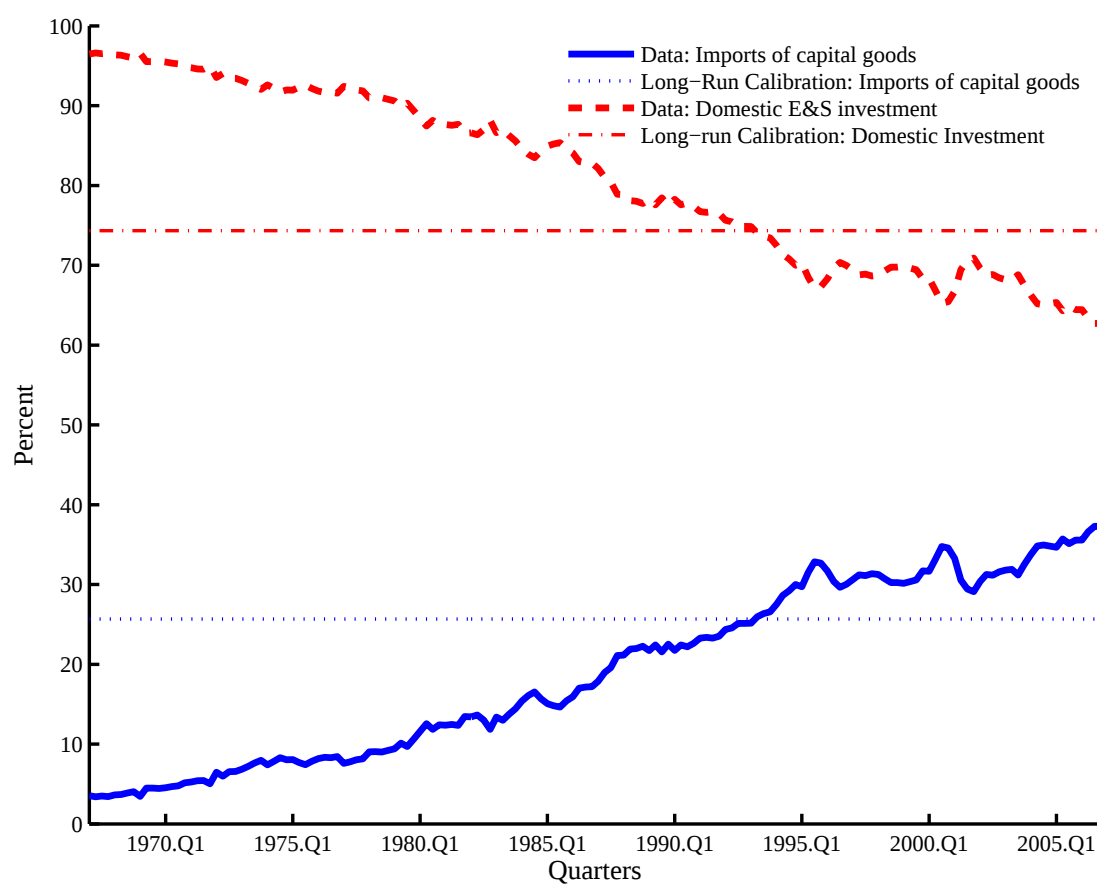
Whelan, K., 2002. A guide to U.S. chain aggregated NIPA data. *Review of Income and Wealth* 48, 217-233.

FIGURE 1: COMPONENTS OF EQUIPMENT AND SOFTWARE (E&S) INVESTMENT.



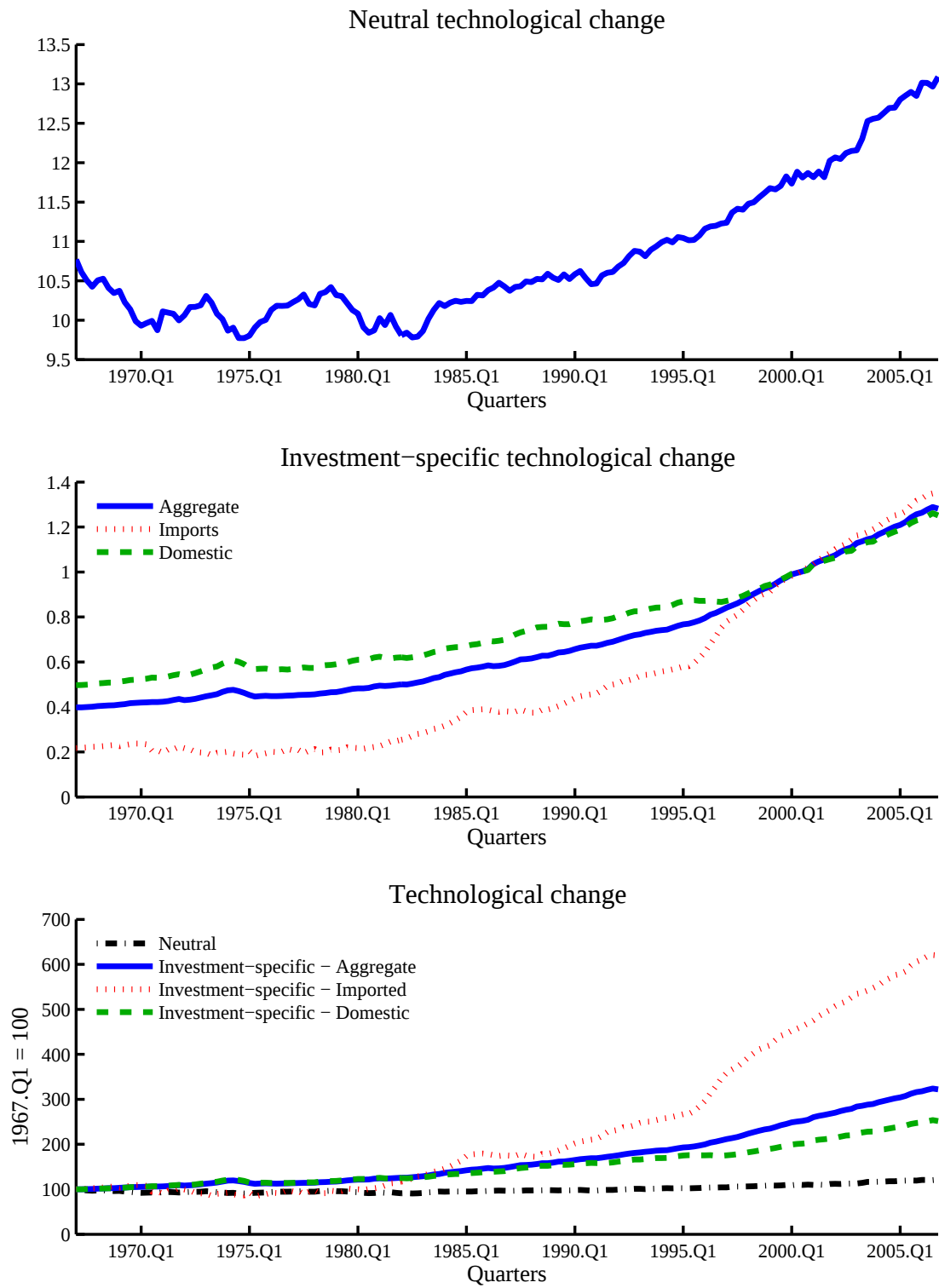
Note:

FIGURE 2: SHARES IN EQUIPMENT AND SOFTWARE (E&S) INVESTMENT



Note:

FIGURE 3: TECHNOLOGICAL CHANGE



Note: