

Capital-Goods Imports, Investment-Specific Productivity, and U.S. Growth*

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Abstract

Over the past 40 years, capital-goods imports have become an increasing source of growth for the U.S. economy. To understand this phenomenon, we build a neoclassical growth model with international trade in capital goods. In our model, agents face exogenous paths of total factor and investment-specific productivity. Investment-specific productivity is reflected by the price of capital-goods imports and the price of investment in domestically-produced equipment and software relative to the price of consumption. We find that the model allocation decisions coming from changes in relative prices explain well the dynamics of capital-goods imports in U.S. output growth. Using the model economy, we show that the U.S. could have lost more than 20 percent of its growth in output per hour without capital-goods imports technology since 1987.

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1 Introduction

In a seminal paper, Greenwood, Hercowitz and Krusell (1997)–(GHK) explore the role played by investment-specific productivity for generating U.S. output growth. In their model, investment-specific productivity is reflected by the decline in the price of investment in equipment and software (E&S) relative to the price of consumption. Using a standard neoclassical growth model, GHK estimated that investment-specific productivity accounted for nearly 60 percent of growth in U.S. output per hour during the postwar period. Their finding has precipitated a growing body of literature on investment-specific productivity as a major source of economic growth and fluctuations.¹ In this context, it is natural to wonder what is behind the decline in the price of investment in E&S.

Over the last 40 years, the price of capital-goods imports has declined relative to the price of investment in domestically-produced and purchased E&S. The upper panel of Figure 1 shows that the decline in the price of capital-goods imports has been substantially larger than the decline in the price of investment in domestically-produced E&S. The lower panel of Figure 1 shows the quantity ratios between capital-goods imports and GNP, and between aggregate investment in E&S and GNP.² It shows that the ratio of capital-goods imports to GNP has increased since 1967. It also suggests that the share of capital-goods imports in aggregate investment in E&S has increased. Together, these observations suggest that the relative price decline in capital-goods imports have been a driving force behind the increase in the stock of E&S.

We study the contribution in the relative price decline of capital-goods imports for U.S. output growth. First, we illustrate the importance of capital-goods imports in U.S. output growth using a simple growth accounting exercise. Since 1967, capital-goods imports have contributed 13.3 percent to growth in U.S. output per hour, while domestically-produced and purchased E&S have contributed 47.9 percent. This implies that capital-goods imports have explained more than 20 percent of the contribution of aggregate investment in E&S to U.S. growth in output per hour. More importantly, capital-goods imports have become an increasing source of growth for the U.S. economy. The contribution of capital-goods to growth in U.S.

¹Early contributions on investment-specific productivity include Griliches (1961), Hall (1968, 1971), Gordon (1990), and Hulten (1992). Recent contributions include Cummins and Violante (2002), Whelan (2002), Fisher (2006), and Justiniano and Primiceri (2008).

²These quantities are quality-adjusted.

output per hour has increased from 5.1 percent from 1967 to 1987 to 26.2 percent from 1997 to 2007.

Second, we build a neoclassical growth model with international trade in capital goods to understand the underlying source of capital-goods imports growth. Our explanation comes from relative price movements between capital-goods imports and domestically-produced and purchased E&S. In our model, agents face exogenous paths of total factor and investment-specific productivity. Investment-specific productivity is reflected by the price of capital-goods imports and the price of investment in domestically-produced E&S relative to the price of consumption. Given these prices, agents make allocation decisions regarding imports of capital goods and expenditure on domestically-produced E&S.

Because of the increasing expenditure share of capital-goods imports in aggregate investment in E&S, we solve the model by feeding in the exogenous paths of total factor and investment-specific productivity as opposed to the balanced growth path approach used by GHK. Overall, the investment decisions coming from changes in relative prices capture well the dynamics of capital-goods imports in aggregate investment in E&S, especially after 1987. Before 1987, the model overpredicts the expenditure share of capital-goods imports in aggregate investment in E&S. These observed movements in expenditure shares may be driven by other factors unexplained by the model such as trade liberalizations and transportation costs. This feature of the model implies that we will focus more extensively on the post 1987 results.

Finally, we perform a series of counterfactual experiments to illustrate the importance of capital-goods imports to the U.S. economy. First, we look at the growth rate in U.S. output per hour without capital-goods import technology. We do this by assuming that agents would only have had access to the domestically-produced and purchased E&S technology. The model predicts that the growth rate in U.S. output per hour would have been roughly similar since 1967. However, the model's predictions look very different over the second half of the sample period. The model predicts that the growth rate of U.S. output per hour would have been 20.2 percent lower since 1987 and 23.4 percent lower since 1997. This should not come as a surprise: U.S. expenditure shares on capital-goods imports in aggregate investment in E&S have increased, while capital-goods imports have become cheaper relative to domestically-produced and purchased E&S. Without access to capital-goods imports technology, the decline in the relative price of investment in E&S would have

been muted, which would have implied a lower growth rate in the accumulation of E&S.

The notion that trade in capital goods is an important source of economic fluctuations is not new. The international real business cycle literature, pioneered by the work of Backus, Kehoe, and Kydland (1992, 1994) and Baxter and Crucini (1993), focuses on the dynamics of investment to generate plausible business cycles. Later, Boileau (1999) and Raffo (2009) exploit movements in the prices of E&S to explain trade in capital goods and other aspects of international economic fluctuations. Our findings are also related to the large literature on investment prices and economic prosperity. For example, Jones (1994) examines the relationship between the relative price of capital-goods and economic growth, while Eaton and Kortum (2001) and Hsieh and Klenow (2007) develop theories of economic growth based on the price of investment in E&S relative to the price of consumption. Here, we address the contribution of trade in capital goods to U.S. growth.

Overall, our results suggest that capital-goods imports through their effect on the decline in the price of aggregate investment in E&S have had a significant impact on U.S. output growth since 1967. We do not interpret the decline in the relative price of capital-goods imports as fully reflecting investment-specific technical change originating from abroad. In part, the decline in the relative price of capital-goods imports may well reflect the creation, reallocation, and integration of global production facilities as in the vertical-specialization model of Yi (2003), as well as lower labor costs in emerging markets, and the reduction of tariffs and transportation costs. Nevertheless, from a U.S. point of view, the decline in the price of capital-goods imports is equivalent to technical change: It implies an increase in measured productivity gains.

The rest of the paper is organized as follows. Section 2 documents the dynamics of U.S. capital-goods since 1967. Section 3 presents our open-economy model. Section 4 describes the model's solution, calibration, and estimation. In Section 5, we perform a growth accounting exercise, discuss the model's performance, and examine the quantitative role of capital-goods imports in U.S. output growth by performing a series of counterfactual experiments. Finally, Section 6 concludes.

2 Empirical Evidence

In this section, we measure the prices of investment in E&S and document the dynamics of U.S. capital-goods imports in aggregate investment in E&S. The annual data are from National Income and Product Accounts (NIPA) and cover the period 1967 to 2007. Since the basket of capital-goods imports has heavily changed since 1967, the data are Fisher chain-weighted to better track quality improvements over time.

2.1 Measuring Prices of Investment in E&S

We infer investment-specific productivity from the ratios of aggregate investment in E&S and the consumption deflators. The consumption deflator is the implicit price deflator for the chain-weighted aggregate of private consumption on nondurables and services and government consumption. We do not include durables consumption in the consumption aggregate to avoid the issue of accounting for quality improvement in consumer durables. The deflator for aggregate investment in E&S is the implicit price deflator for the chained-weighted sum of private and government non-residential fixed investment in E&S. The deflator for capital-goods imports is taken directly from the NIPA data. They include tariffs, insurance, and transportation costs.³ We compute the deflator for domestically-produced and purchased E&S investment as the implicit price deflator of the chain-weighted difference between aggregate investment in E&S and capital-goods imports. Real quantities of aggregate investment in E&S, investment in domestically-produced and purchased E&S, and capital-goods imports are the counterparts of the implicit price deflators described above.

Related studies on the role of investment-specific technical changes have often used Gordon's (1990) E&S prices. For example, Hulten (1992) and GHK measure the contribution of investment-specific productivity to U.S. growth using a two-sector model based on Gordon's E&S prices. Because this dataset only covers the postwar period until 1983, Hulten's analysis is limited to that period. Instead,

³A problem we face is that the capital-goods imports deflator includes intermediate and final use products while the non-residential fixed investment deflator includes only final use products. From the available import matrix 2002-2007, we know that over 60 percent of the expenditures of capital-goods imports went into final use. In computing the deflator of domestically-produced and purchased E&S, we assume that all capital-goods imports go into final use.

GHK extended Gordon's E&S prices to 1992 by applying a constant adjustment factor to the NIPA series. Later, Cummins and Violante (2002) estimated quality bias in the NIPA series and updated Gordon's E&S prices until 2000. They found that the quality bias in the NIPA series is largest for civilian aircrafts, engines, and parts, while the NIPA series for computers, peripherals, and parts is preferable. Importantly, civilian aircrafts, engines, and parts, and computers, peripherals, and parts are two of the three main components of the NIPA capital-goods imports series.

In contrast, Whelan (2002) uses the official NIPA series to measure the contribution of E&S to U.S. output growth. In addition, the Bureau of Economic Analysis (BEA) has implemented several revisions to its methodology in order to account for the rapid rate of innovation in E&S. In particular, hedonic regression techniques and the implementation of chained-weighting methodology by the BEA in the 1990's were intended to allow aggregates to better track quality improvements over time. We acknowledge that accurate price measurements are central to our analysis. For our analysis, we choose to use the official NIPA data because of the recent updates to the BEA methodology and because computers, peripherals, and parts have become an important driver behind the growth of capital-goods imports and aggregate investment in E&S.⁴

2.2 Trends in Capital-Goods Imports

The lower panel of Figure 1 displays the ratios between capital-goods imports and GNP, and between aggregate investment in E&S and GNP. These ratios are based on quality-adjusted quantities of capital-goods imports and aggregate investment in E&S. This panel suggests that the ratio of capital-goods imports to aggregate investment in E&S has increased significantly since 1967. While this ratio can be used to illustrate how capital-goods imports have grown relative to aggregate investment in E&S, it cannot be interpreted as a share. First, the sum of the ratios of chain-weighted aggregates does not equal one, except for the base year. Second, growth in the quantity of capital-goods imports has had a larger impact on the growth of aggregate investment in E&S than it would have had using fixed-weight

⁴In addition, a simple extrapolation of Cummins and Violante's method to capital-goods imports would be difficult. We would need Gordon's data on quality adjusted series for capital-goods imports, a classification that is not available in Gordon's study.

calculation. This is because the price of capital-goods imports has fallen faster than the price of investment in domestic E&S.

We look at two alternative indicators to understand the importance of capital-goods imports in the behavior of aggregate investment in E&S. The first indicator measures the amount of resources allocated to capital-goods imports. Figure 2 displays the expenditure shares of capital-goods imports in aggregate investment in E&S. It shows that capital-goods imports have accounted for an increasing fraction of aggregate expenditure in E&S over the last forty years: While accounting for a mere 3.5 percent in 1967, capital-goods imports have accounted for 37.4 percent of aggregate expenditure in E&S in 2007.

The second indicator captures the contribution of capital-goods imports to growth in aggregate investment in E&S. While we may not be able to add the components of aggregate investment in E&S to obtain its level, we can add the contribution to each of its components to obtain the change in the aggregate.⁵ Table 1 confirms that capital-goods imports have contributed importantly to aggregate investment in E&S. In fact, the average contribution of capital-goods imports to growth in aggregate investment in E&S has been 54 percent over the sample period. In addition, this contribution has increased over time. The contribution of capital-goods imports to growth in aggregate investment in E&S has increased from 11 percent between 1967 and 1987 to 70 percent between 1997 and 2007. The contribution in the latter period had increased for two reasons. First, the price of capital-goods has fallen more rapidly than the price of investment in domestic E&S. Second, the expenditure share of capital-goods imports in aggregate investment in E&S has risen in the second half of the sample.

The capital-goods imports series we use contains information on three categories⁶: civilian aircrafts, engines, and parts; computers, peripherals, and parts; and other. In 2007, the category "other" contained two-thirds of the goods. This category includes electric generating machinery, electric apparatus and parts; oil drilling, mining, and construction machinery; scientific, hospital, and medical equipment and parts; telecommunication equipment; and semiconductors, among others. Nominal imports of computers, peripherals, and parts accounted for 25 percent of capital-goods imports.

⁵See Appendix A for calculation details.

⁶Appendix A describes the category "other" in details.

Table 1 also shows each category’s contribution to the growth in capital-goods imports. From 1967 to 1987, most of growth in capital-goods imports was accounted for by civilian aircrafts, engines, and parts. However, from 1997 to 2007, most of growth in capital-goods imports was accounted for by computers, peripherals, and parts—while civilian aircrafts, engines, and parts ranked last. This surge in the contribution of computers, peripherals, and parts to capital-goods imports growth may be associated with the reduction in tariffs, and the creation and spread of global production in information technology industries as suggested by Feenstra, Reinsdorf, and Slaughter (2008).

3 The Model Economy

The model economy includes a representative household, a representative firm, and a government. The household makes consumption, labor supply, and investment decisions to maximize lifetime utility

$$\sum_{t=0}^{\infty} \beta^t u(c_t, l_t), \quad 0 < \beta < 1, \quad (1)$$

given period t utility function

$$u(c_t, l_t) = \theta \log c_t + (1 - \theta) \log(1 - l_t), \quad 0 < \theta < 1. \quad (2)$$

In these equations, c_t represents consumption of final output, l_t represents labor hours, β is the discount factor, and θ is the household’s share of utility received from consumption.

Each period, final output y_t is produced using a constant-return-to-scale technology with inputs of labor hours l_t and two types of capital, structures $k_{s,t}$ and E&S $k_{e,t}$. The production technology for producing final output is of the Cobb-Douglas form

$$y_t = a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e}, \quad 0 < \alpha_s, \alpha_e < 1, \text{ and } \alpha_s + \alpha_e < 1, \quad (3)$$

where a_t represents total-factor productivity, and α_s and α_e represents the income shares of structures and E&S. Final output is allocated to consumption, investment in structures $i_{s,t}$, investment in domestic E&S $i_{e,t}$, and capital-goods exports $i_{x,t}$. Taking consumption as the numeraire, the resource constraint is given by

$$y_t = c_t + i_{s,t} + p_{d,t} i_{d,t} + p_{x,t} i_{x,t}, \quad (4)$$

where $p_{d,t}$ represents the prices of investment in domestic E&S and $p_{x,t}$ represents the price of capital-goods exports.⁷ We impose balanced trade to close the model. This implies that the value of capital-goods imports is equal to the value of capital-goods exports

$$p_{m,t}i_{m,t} = p_{x,t}i_{x,t}, \quad (5)$$

where $i_{m,t}$ represents capital-goods imports and $p_{m,t}$ represents its price in consumption units. This condition simplifies our model and is supported by the fact that the nominal trade balance in capital goods has been roughly balanced over the sample period as shown in Figure 3. After taking the balanced-trade condition (5) into account, the resource constraint becomes

$$y_t = c_t + i_{s,t} + p_{d,t}i_{d,t} + p_{m,t}i_{m,t}. \quad (6)$$

One new unit of structures costs one unit of final output. The law of motion for the stock of structures is

$$k_{s,t+1} = i_{s,t} + (1 - \delta_s)k_{s,t}, \quad 0 < \delta_s < 1, \quad (7)$$

where δ_s represents the depreciation rate of structures. In contrast, one new unit of equipment costs $p_{e,t}$ units of final output. Therefore, the law of motion for the stock of E&S is

$$k_{e,t+1} = \frac{1}{p_{e,t}}i_{e,t} + (1 - \delta_e)k_{e,t}, \quad 0 < \delta_e < 1, \quad (8)$$

where δ_e represents the depreciation rate of E&S and $1/p_{e,t}$ represents investment-specific productivity. It determines the amount of new E&S that can be purchased for one unit of final output. Accordingly, fluctuations in $1/p_{e,t}$ reflects changes in the current state of technology for transforming investment in E&S into its stock.

We model aggregate investment in E&S as a CES composite:

$$i_{e,t} = \left(\phi^{1-\rho}i_{d,t}^\rho + (1 - \phi)^{1-\rho}i_{m,t}^\rho \right)^{\frac{1}{\rho}}, \quad 0 < \phi < 1, \quad \rho < 1. \quad (9)$$

where ϕ represents the long-run share of investment in domestic E&S into aggregate investment in E&S, and ρ determines the elasticity of substitution between investment in domestic E&S and capital-goods imports. The goal of the household is to

⁷The price of investment in domestic E&S is not the same as the price of capital-goods exports.

minimize expenditure on E&S such that equation (9) holds. The solution to the minimization problem yields the following optimal investment quantities:

$$i_{d,t} = \phi \left(\frac{p_{d,t}}{p_{e,t}} \right)^{\frac{-1}{1-\rho}} i_e, \quad (10)$$

$$i_{m,t} = (1 - \phi) \left(\frac{p_{m,t}}{p_{e,t}} \right)^{\frac{-1}{1-\rho}} i_e. \quad (11)$$

Given these optimal choices, the price of aggregate investment in E&S is

$$p_{e,t} = \left(\phi p_{d,t}^{\frac{\rho}{\rho-1}} + (1 - \phi) p_{m,t}^{\frac{\rho}{\rho-1}} \right)^{\frac{\rho-1}{\rho}}. \quad (12)$$

This expression shows that the price of aggregate investment in E&S depends on the prices of investment in domestic E&S and of capital-goods imports. In the aggregate, the investment decisions depend on the domestic technology to produce E&S and on the measured productivity of capital-goods imports implied by their relative price.⁸

Finally, the government raises taxes on labor at the rate $\tau_{l,t}$ and capital income at the rate $\tau_{k,t}$. It runs a balanced budget each period and tax revenues are rebated to households through a lump-sum transfer g_t . The budget constraint for the government is

$$g_t = \tau_{l,t} w_t l_t + \tau_{k,t} (r_{s,t} k_{s,t} + r_{e,t} k_{e,t}) \quad (13)$$

where w_t represents the real wage, and $r_{s,t}$, and $r_{e,t}$ represents the real rates of return from structures and E&S. Including income taxation is important for the quantitative analysis because of the significant effect that it has on equilibrium capital formation (see Jones (1994)).

4 Matching the Model with the Data

This section presents the solution of the model's competitive equilibrium. It also describes the data, and the calibration and estimation of the parameters.

⁸Once the investment decisions are made, domestic E&S and capital-goods imports are added to the existing E&S stock. This assumption may seem ad-hoc, but it is consistent with the data on the stock of fixed assets from the BEA. The published data do not distinguish between the stock of E&S derived from domestically-produced E&S and the stock of E&S derived from capital-goods imports.

4.1 Computation of a Dynamic Competitive Equilibrium

A competitive equilibrium is a set of prices $\{p_{e,t}, w_t, r_{s,t}, r_{e,t}\}$, and allocations $\{c_t, l_t, i_{s,t}, i_{e,t}\}$ for the household, and $\{l_t, k_{s,t}, k_{e,t}\}$ for the firm such that: (i) Given prices, the allocation $\{c_t, l_t, i_{s,t}, i_{e,t}\}$ maximizes household's utility, (ii) Given prices, the allocation $\{l_t, k_{s,t}, k_{e,t}\}$ maximizes firm's profit, and (iii) The resource constraint (6) is satisfied. Appendix B describes the equations of the resulting competitive equilibrium.

Together with the resource constraint, the household's and the firm's optimality conditions represent a system of equations that can be solved to find the equilibrium of the model economy. This equilibrium is characterized by one intratemporal equation which determines the amount of hours worked,

$$\frac{(1-\theta)}{\theta} c_t = (1-l_t) \cdot (1-\alpha_s - \alpha_e) \cdot \frac{y_t}{l_t}, \quad (14)$$

and two intertemporal equations which determine the evolution in the stocks of structures and E&S,

$$\frac{c_{t+1}}{c_t} = \beta \left(\alpha_s \cdot \frac{y_t}{k_{s,t}} + (1-\delta_s) \right), \quad (15)$$

$$\frac{c_{t+1}}{c_t} = \beta \left(\frac{\alpha_e}{p_{e,t}} \cdot \frac{y_t}{k_{e,t}} + (1-\delta_e) \right). \quad (16)$$

Solving for an equilibrium path involves choosing a sequence of consumption, hours worked, and investment in structures and E&S given the exogenous path of total factor productivity, the price of investment in domestic E&S, the price of capital-goods imports, the working age population, the initial stock of structures and E&S, and the transversality condition. To make the computation of an equilibrium tractable, we assume that the economy converges to its balanced-growth path. We solve the model starting in 1967 and let it run to 2050. From 2008 to 2050, we assume that total factor productivity, the price of investment in domestic E&S, the price of capital-goods imports, hours, and the working-age population grow at constant rates equal to their average growth rates between 1967 and 2007.

4.2 Data

Most of the data comes from NIPA as described in Section 2. Final output is defined as gross national product minus gross housing and business farm products. Because trade only occurs in capital goods, we add net exports (excluding capital

goods) to final output.⁹ The employment series is Total Aggregate Hours: Non-Farm Payrolls (SAAR) from the Bureau of Labor Statistics. The population series is Resident Working Age Population: 15-64 years from the Census Bureau. Appendix A contains additional information on the data.

We construct the stocks of structures and E&S using the laws of motion (7) and (8). Starting with an initial value for $k_{s,1967}$ and $k_{e,1967}$, we compute the stock of structures and E&S by iterating on the laws of motion using observed nominal investment values for $i_{s,t}$ and $i_{e,t}$ divided by the consumption deflator. The stock of E&S is quality-adjusted using the evolution in the price of aggregate investment in E&S. As starting values for the capital stocks, we use the stocks of structures and E&S observed in 1967 from the BEA Fixed Assets tables divided by the consumption deflator.

4.3 Calibration and Estimation

Table 2 presents the calibrated parameter values. We assume that the number of weekly hours available for market work is one hundred. This implies that the ratio of hours worked to non-sleeping hours is 0.217. It also implies that the growth rate of output per hours measured in consumption units is 0.77 percent.

Because of rapid quality improvements in E&S, we use physical depreciation rates in our capital accumulation equations as opposed to economic depreciation rates implied by BEA data. This is suggested by Cummins and Violante (2002) and follows the work of Oliner (1989), Gort and Wall (1998), and Whelan (2002). Economic depreciation measures the change in the value of an asset associated with the aging process and consists of an age and a time effect. Physical depreciation captures the age effect due to wear and tear. The time effect captures obsolescence due to the change in the relative price over time. Since there are no quality improvements in structures, and therefore no change in relative prices, physical depreciation in structures equals economic depreciation. In contrast, the physical depreciation rate in E&S evolves as

$$\delta_{e,t} = 1 - (1 - d_{e,t}) \frac{p_{e,t-1}}{p_{e,t}}, \quad (17)$$

where $\delta_{e,t}$ and $d_{e,t}$ are physical and economic depreciation rates in E&S. We compute the economic depreciation rate in structures by dividing the depreciation rate of

⁹An alternative measure is to define final output as expenditure as in equation (6). This measure gives similar results.

structures in year t by the stock of structures in year $t-1$. We compute the economic depreciation rate in E&S similarly. Economic depreciation rates are measured using current-dollar series. Figure 4 displays the physical and economic depreciation rates as well as the average physical depreciation rates of structures and E&S. The E&S economic depreciation rate trends upward from 13 percent in 1967 to 17 percent in 2008. In contrast, the physical depreciation rate in E&S is trendless at around 12 percent. The volatility in our measure of physical depreciation rate in E&S stems from the volatility in the relative prices of E&S. The average physical depreciation rates of structures and E&S are 2.5 and 12.4 percent. We use these averages to build our measures of capital stocks and to compute the dynamic implications of our model.¹⁰ We choose the averages rather than the series to isolate the role of relative price changes in investment decisions.

We follow Mendoza et al. (1994) and Gomme and Rupert (2007) and compute an average tax rate on labor income of 24.3 percent and an average tax rate on net capital income of 26.9 percent. We also follow Gomme and Rupert (2007) to obtain an average capital income share of 0.285. Also for these cases, we use the series averages to focus on investment decisions.

We assume that the ratio of capital-goods imports in aggregate investment in E&S has reached its steady-state level in the base year 2000. Therefore, we set ϕ to 0.664. This ratio is virtually equivalent to the average share of the last ten years of our data. Since the price of aggregate investment in E&S (12) in the model is not of the Fisher chain-weighted form, the elasticity of substitution between investment in domestic E&S and capital-goods imports comes from the solution to

$$P = \min (p_{e,t} - \bar{p}_{e,t}(\rho))' W (p_{e,t} - \bar{p}_{e,t}(\rho)), \quad (18)$$

where W is an identity matrix, $p_{e,t}$ is the Fisher chain-weighted price of aggregate investment in E&S from the data, and $\bar{p}_{e,t}(\rho)$ is the Fisher chain-weighted price of aggregate investment in E&S resulting from the optimal allocations of investment in domestic E&S (10) and capital-goods imports (11), with the corresponding prices taken from the data. Our estimate of the elasticity of substitution between investment in domestic E&S and capital-goods imports is 1.96. As shown in Figure 5, the CES quantities and the resulting Fisher chain-weighted price of aggregate investment in E&S match the data fairly well. This implies that if the model's investment

¹⁰We did not find any significant difference in capital stocks or in the behavior of the model using the series instead of their averages.

decisions in aggregate E&S were identical to those observed in the data, the optimal allocations resulting from the CES aggregate would be a good approximation to actual investment decisions.

Finally, we use the method of moments to obtain the numerical values of the remaining four parameter. The estimated parameter values $\beta, \theta, \alpha_s, \alpha_e$ are the solution to

$$M = \min (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e))' W (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e)), \quad (19)$$

where m_t represents a vector of moments from the data, $\widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e)$ is the corresponding vector from the model, and W is an identity matrix. The targets are the paths of output per hour, and the structures-per-hour and E&S-per-hour ratios over the period 1967 to 2007. We chose these targets because they are the variables we use to perform our growth accounting exercise. Part of the estimation involves calculating total factor productivity given the income shares of structures and E&S. We compute total factor productivity using the production function (3). The stocks of structures and E&S comes from the laws of motion (7) and (8), using $k_{s,1967}$ and $k_{e,1967}$ as initial values.

The estimated parameter values are presented in Table 3. The discount factor implies an average after tax return on capital of 6 percent.¹¹ The household's share of utility received from consumption relative to the disutility from supplying labor is 0.275. Finally, the structures share of income is 0.162 while the E&S share of income is 0.123. These parameter values are standard in the literature.

Since the system is overidentified, we test the model using a Wald statistic under the hypothesis that the model represents the data generating process. The Wald test statistic is

$$Q = T \cdot (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e))' \widehat{V} (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e)) \rightarrow \chi_{119}^2, \quad (20)$$

where \widehat{V} is the covariance matrix of the model's paths and T is the number of moments matched which is equal to 123. With 4 parameters to estimate, the system is overidentified and the test statistic follows a chi-square distribution with 119 degrees of freedom. Q is equal to 125.3 with an associated probability value of 0.33. Therefore, we cannot reject the model at conventional significance levels.

¹¹The after tax return on capital is g/β where g is the economy average annual growth rate of output per hour.

Figure 6 displays the model's paths of output per hour, and the structures- and E&S-per-hour ratios relative to the data. This figure confirms that the model fits the targets fairly well.

Figure 7 displays our measure of total factor productivity and compares the three measures of productivity: total factor productivity, the technology to produce domestically-purchased E&S, and the productivity implied by the relative price of capital-goods imports. The upper panel shows that total factor productivity displays steady growth throughout the sample periods with large drops during the recessions of 1970, 1975, 1980-1982, and 2001. Over the whole sample, the average annual growth rate of total factor productivity was 0.18 percent. The lower panel compares the three measures of productivity. It shows how rapid was the growth in investment-specific productivities compared to that of total factor productivity. Over the whole sample, the average annual rate of growth in the productivity of domestically-purchased E&S was 2.38, while the average annual rate of growth in the productivity implied by the price of capital-goods imports was 4.71. The average annual rate of growth in the productivity implied by the price of capital-goods imports was even faster after 1980, averaging 7.09 percent.

5 Quantitative Analysis

In this section, we analyze the role of capital-goods imports in U.S. growth. First, we perform a growth accounting exercise to measure the contribution of capital-goods imports to growth in U.S. output per hours using the data. We show that capital-goods imports have become an increasing source of growth for the U.S. economy. Second, we demonstrate how the decrease in the price of capital-goods imports relative to the price of domestically-produced and purchased E&S can explain this fact by using our model economy. Finally, the ability of our model to explain the increasing role of capital-goods imports in U.S. growth enable us to perform a series of counterfactual experiments to illustrate the importance of capital-goods imports for the U.S. economy.

5.1 Growth Accounting

5.1.1 The Data

We perform a growth accounting exercise using the data to measure the contribution of capital-goods imports to growth in U.S. output per hour. First, we rewrite the production function (3) as

$$\frac{y_t}{l_t} = a_t \cdot \left(\frac{k_{s,t}}{l_t}\right)^{\alpha_s} \cdot \left(\frac{k_{e,t}}{l_t}\right)^{\alpha_e}.$$

Then, we take the natural logarithm of equation (??) and decompose output per hour into three additive factors:

$$\log \frac{y_t}{l_t} = \log a_t + \alpha_s \log \left(\frac{k_{s,t}}{l_t}\right) + \alpha_e \log \left(\frac{k_{e,t}}{l_t}\right). \quad (21)$$

This decomposition implies that U.S. growth in output per hour arises from growth in total factor productivity, and in the structure-per-hour and the E&S-per-hour ratios. To obtain the contribution of capital-goods imports, we use the expenditure shares of capital-goods imports in aggregate investment. We focus on the period $t-1$ share because it takes one period for aggregate investment in E&S to materialize into stock. In other words, we are looking for the evolution in the accumulation of E&S attributable to capital-goods imports. Because of the properties of the CES composite (9), this is equivalent to the amount of i_m that materialize into E&S stock at time t .¹²

Table 4 presents the decomposition undertaken in equation (21). It displays the average annual growth rates in output per hour, total factor productivity, structures, domestically-produced and purchased E&S, and capital-goods imports. From 1967 to 2007, the average growth rate in U.S. output per hour was 0.77 percent. Table 5 shows the contributions of each of these components to growth in U.S. output per hour. On average, capital-goods imports contributed 13.3 percent to U.S. output per hour over the period 1967 to 2007, while domestically-produced and purchased E&S have contributed 47.9 percent. This implies that capital-goods imports explained more than one quarter of the average annual contribution of aggregate investment in E&S to U.S. growth in output per hour. Together, capital-goods imports and domestically-produced and purchased E&S accounted for 61.2

¹²From (9), the contribution i_m to the next period stock of E&S is $((1-\phi)^{1-\rho} i_m^\rho)/i_e$ which is equivalent to the expenditure share of capital-goods imports in aggregate investment in E&S $(p_m i_m)/(p_e i_e) = (1-\phi)(p_m/p_e)^{\frac{\rho}{1-\rho}}$.

percent to U.S. output per hour. This estimate is similar to Cummins and Violante (2002), GHK, Whelan (2003) and other studies who found that investment-specific technical change explained around 60 percent to U.S. growth in output per hour in the post-war period.

More importantly, Table 5 shows that capital-goods imports have become an increasing source of growth for the U.S. economy. The contribution of capital-goods imports to U.S. growth in output per hour increased from 5.1 percent from 1967 to 1987 to 26.2 percent from 1997 to 2007. In contrast, the contribution of domestically-produced and purchased E&S to U.S. growth in output per hour increased from 45.7 percent from 1967 to 1987 to 47.9 percent from 1997 to 2007. Therefore, the contribution of capital-goods imports to U.S. growth in output per hour has increase five times over the sample period while the contribution of investment in domestically-produced and purchased E&S has increased by a modest 21 percent.

5.1.2 The Model

In this subsection, we look at the model's ability to match the salient features of the data. First, we look at the dynamics properties of the model. Then, we show the model's ability to replicate the increasing contribution of capital-goods imports to US growth.

The upper panel of Figure 8 presents the ratio of capital-goods imports to output, and the ratio of aggregate investment in E&S to output for the data and the model economy. The model does a good job at capturing the upward trends in the ratios. The lower panel of Figure 8 displays the relative price of aggregate investment in E&S. The model captures the sustained decrease in the relative price of aggregate investment in E&S given the household's optimal investment decisions over investment in domestic E&S and capital-goods imports.

Figure 9 displays the expenditure shares of investment in capital-goods imports and domestically-produced and purchased E&S in aggregate investment in E&S. Overall, simple price movements in the CES aggregate (9) explain well the long-run trend in expenditure shares. However, the model overpredicts the expenditure shares in capital-goods imports from 1967 to 1987. That is, relative price movements don't fully explain the level of expenditure shares in capital-goods imports

observed in the data over the first half of the sample period. These movements in expenditure shares may be driven by other factors unexplained by the model such as trade liberalizations and transportation costs. This characteristic of the model has implications for the model's predictions regarding the contribution of capital-goods imports to U.S. growth and growth rate of output per hour.

Table 4 presents the model's predictions from a decomposition undertaken by equation (21). On average, the model predicts that average growth rate in U.S. output per hour was 0.73 percent. The growth rates of the other components of equation (21) are all close to the data. Table 5 presents the model's predictions regarding the contribution of each of these components to U.S. growth in output per hour. On average, the model predicts that capital-goods imports contributed 15.4 percent to U.S. growth in output per hour from 1967 to 2007. The lower growth rate of U.S. output per hour predicted by the model arises from the large expenditure share of capital-goods imports over the first half of the sample period—relative to the data. The contribution of capital-goods imports to the growth rate of U.S. output per hour is 9.6 percent in the model versus 5.1 percent in the data. Since capital-goods imports were expensive relative to domestically-produced and purchased E&S, the model predicts a lower accumulation of E&S over the first half of the sample period. With less E&S in the production function (3), the model's prediction for output is lower than in the data.

Table 6 illustrates that the growth in aggregate investment in E&S arise mostly from capital-goods imports as in the empirical evidence reported in Section 2. It shows the average annual contributions of capital-goods imports to growth in aggregate investment in E&S. The model underpredicts the average annual contribution of capital-goods imports to aggregate investment in E&S between 1967 and 2007. A closer look at this table reveals that while underpredicting the contribution between 1967 and 1997, the model overpredicts this contribution between 1997 and 2007. Overall, we believe that the model's simple investment decisions coming from changes in relative prices captures well the behavior of capital-goods imports in aggregate investment in E&S and its dynamics relative to output.

5.2 Counterfactuals

In this subsection, we perform a series of counterfactual experiments to illustrate the importance of capital-goods imports for the U.S. economy. First, we look at

the U.S. growth rate in output-per-hour potential without access to the technology embodied in capital-goods imports.

5.2.1 U.S. Growth without Capital-Goods Imports Technology

What would have happened to U.S. output growth without capital-goods imports technology? To answer this question, we assume that the U.S. would only have had access to the technology to produce domestically-produced and purchased E&S. That is, we assume that the relative price of aggregate investment in E&S would have followed the relative price of investment in domestic E&S. We perform this counterfactual by replacing the price of aggregate investment in E&S (12) by $p_e = p_d$.

Table 7 presents the average growth in U.S. output per hour with and without capital-goods imports technology. Over the full sample period, the model predicts that the average growth in U.S. output per hour would have been roughly similar. However, the model's predictions look very different over the second half of the sample period. The model predicts that the growth rate of U.S. output per hour would have been 20.2 percent lower since 1987 and 23.4 percent lower since 1997 without access to the capital-goods imports technology. This should not come as a surprise: U.S. expenditure shares on capital-goods imports in aggregate investment in E&S have increased, while capital-goods imports have become cheaper relative to domestically-produced and purchased E&S. Without access to capital-goods imports technology, the decline in the relative price of investment in E&S would have been muted, which would have implied a lower growth rate in the accumulation of E&S. With complementarities between E&S, structures, and labor implied by the production function (3), U.S. output-per-hour growth would have been lower.¹³

Table 8 shows the contribution to growth in U.S. output per hour without the capital-goods imports technology. The table shows that the contribution of E&S to the growth in U.S. output per hour would have remained at around 60 percent without the capital-goods imports technology.

¹³Over the full sample period, the model predicts that U.S. growth in output per hour would have been 0.4 percent higher without the capital-goods imports technology. This happens because the expenditure shares on capital-goods imports are too high at the beginning of the sample period.

5.3 Robustness Analysis

[TO BE ADDED]

6 Conclusions

Over the past 40 years, capital-goods imports have become an increasing source of growth for the U.S. economy. To understand this phenomenon, we build a neoclassical growth model with international trade in capital goods in which agents face exogenous paths of total factor and investment-specific productivity. Investment-specific productivity is reflected by the price of capital-goods imports and the price of investment in domestically-produced equipment and software relative to the price of consumption. We use observed prices to solve for optimal investment decision and understand the underlying sources of growth in the U.S. economy. We find that the model allocation decisions coming from changes in relative prices explain well the dynamics of capital-goods imports in aggregate investment in E&S, and in U.S. output. Using the model economy, we show that the U.S. could have lost more than 20 percent of its growth in output per hour without capital-goods imports technology since 1987.

The impact of capital-goods imports on the price of E&S may have been significant for short-run economic fluctuations. In closed-economy models, Greenwood, Hercowitz and Krusell (2000) and Fisher (2006) attribute a large fraction of business cycle volatility to fluctuations in the price of E&S. In addition, Justiniano and Primiceri (2008) show that most of the decline in business-cycle volatility observed since the mid-1980's is driven by the decline in the volatility of innovations to the relative price of investment in E&S. The fact that capital-goods imports have contributed more than half to growth in aggregate investment in E&S since 1967 suggests that capital-goods imports might have played an important role in U.S. business cycle volatility.

Another topic of interest would be to understand the nature of the output gains stemming from capital-goods imports. For example, Feenstra (1994), Hummels and Klenow (2006), and Broda and Weinstein (2006) suggest that the increase in the variety of imports is an important phenomenon for which to account for. The model only considers the intensive margin of trade in capital goods: It has one type of capital-goods imports which are a perfect substitute for investment in domestic

E&S. A natural extension of the model would consider the benefit from the extensive margin of capital-goods imports to U.S. growth.

A Data

A.1 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 capital stocks and the corresponding depreciations are from the Fixed Assets tables. The employment series is Total Aggregate Hours: Non-farm Payrolls (SAAR) from the Bureau of Labor Statistics. The population series is Resident Working Age Population: 15-64 years from the Census Bureau.

A.2 Computation of Contributions to Growth

Whelan (2002) shows that the growth rate of a chained aggregate can be expressed as the sum of the contribution of each of its components:

$$\begin{aligned} \frac{\Delta q_t}{q_{t-1}} &= \sum_{i=1}^n \frac{(p_{i,t-1} + p_{i,t}/\Pi_t) \cdot \Delta q_{i,t}}{\left[\sum_{i=1}^n (p_{i,t-1} + p_{i,t}/\Pi_t) \cdot q_{i,t} \right]} \\ &= \sum_{i=1}^n c_{i,t}. \end{aligned} \tag{A1}$$

where q_t represents the quantity of the aggregate, $q_{i,t}$ and $p_{i,t}$ represents the quantity and price of its components, and Π is the growth rate of the aggregate deflator.

To calculate the contribution of a particular category to the change in the aggregate Δq_t , we take the ratio of the component's sum

$$\sum_{t=T_0}^{T_1} c_{i,t} q_{t-1},$$

relative to the aggregate sum

$$\sum_{t=T_0}^{T_1} \sum_{i=1}^n c_{i,t} q_{t-1}$$

over the period T_0 to T_1 .

A.3 Capital-Goods Imports Categories

The table below documents the categories of capital-goods imports and their nominal values in 2007, seasonally-adjusted in million of dollars. The table comes from the NIPA-International Transaction Account Data, Table 2A. 1978 is the earliest year of available disaggregated data.

Table A1:Capital-Goods Imports (except automotive) Categories
Fractions of Nominal Imports (SAAR)

	1978	2007
Electric generating machinery, electric apparatus and parts	9.4	11.4
Oil drilling, mining, and construction machinery	7.1	4.1
Industrial engines, pumps, and compressors	6.0	3.3
Machine tools and metalworking machinery	9.0	2.2
Measuring, testing, and control instruments	2.5	3.3
Other industrial, agricultural, and service industry machinery	27.2	18.5
Computers, peripherals, and parts	5.0	24.6
Semiconductors	9.3	6.8
Telecommunications equipment	8.7	9.7
Other office and business machines	6.2	2.3
Scientific, hospital, and medical equipment and parts	3.6	6.4
Civilian aircraft, engines, and parts	4.4	6.8
Others	1.7	0.6

B The Competitive Equilibrium

A competitive equilibrium is a sequence of prices $\{p_{e,t}, w_t, r_{s,t}, r_{e,t}\}$, allocations $\{c_t, l_t, i_{s,t}, i_{e,t}\}$ for the household and allocations $\{l_t, k_{s,t}, k_{e,t}\}$ for the firm such that: **(i)** Given prices, the allocation $\{c_t, l_t, i_{s,t}, i_{e,t}\}$ maximizes household's utility, **(ii)** Given prices, the allocation $\{l_t, k_{s,t}, k_{e,t}\}$ maximizes firm's profit, and **(iii)** the resource constraint (6) is satisfied.

(i) The household chooses consumption, labor, and investment in structures and E&S to maximize utility

$$\theta \log c_t + (1 - \theta) \log (1 - l_t), \quad (\text{B1})$$

given the budget constraint, law of motions for the stocks of structures and E&S, initial capital stocks, and non-negativity constraints

$$c_t + i_{s,t} + i_{e,t} \leq (1 - \tau_l) w_t l_t + (1 - \tau_k) (r_{s,t} k_{s,t} + r_{e,t} k_{e,t}) + g_t, \quad (\text{B2})$$

$$k_{s,t+1} = i_{s,t} + (1 - \delta_s) k_{s,t}, \quad (\text{B3})$$

$$k_{e,t+1} = q_{e,t} i_{e,t} + (1 - \delta_e) k_{e,t},$$

$$c_t, l_t, k_{s,t}, k_{e,t} \geq 0, \quad l_t \leq 1, \quad (\text{B4})$$

$$k_{s,T_0}, k_{e,T_0} \geq 0, \quad (\text{B5})$$

where $q_{e,t} = 1/p_{e,t}$. Substituting (B3) into (B2), the maximization problem can be represented by the following Lagrangian:

$$L = \max_{c_t, l_t, k_{s,t+1}, k_{e,t+1}} \sum_{t=0}^{\infty} \beta^i [\theta \log c_t + (1 - \theta) \log (1 - l_t)] + \sum_{t=0}^{\infty} \beta^i \lambda_{t+i} \left[(1 - \tau_l) w_t l_t + (1 - \tau_k) (r_{s,t} k_{s,t} + r_{e,t} k_{e,t}) + (1 - \delta_s) k_{s,t} + (1 - \delta_e) \frac{k_{s,t}}{q_{e,t}} + g_t - c_t - k_{s,t+1} - \frac{k_{e,t+1}}{q_{e,t}} \right]. \quad (\text{B6})$$

The first order conditions are:

$$\begin{aligned} c_t &: \frac{\theta}{c_t} - \lambda_t = 0 \\ &: c_t = \frac{\theta}{\lambda_t} \end{aligned} \quad (\text{B7})$$

$$\begin{aligned} l_t &: -\frac{(1 - \theta)}{(1 - l_t)} + \lambda_t (1 - \tau_l) w_t = 0 \\ &: \frac{(1 - \theta)}{\theta} c_t = w_t (1 - \tau_l) (1 - l_t) \end{aligned} \quad (\text{B8})$$

$$\begin{aligned} k_{s,t+1} &: -\lambda_t + \beta \lambda_{t+1} (r_{s,t} + (1 - \delta_s)) = 0 \\ &: \frac{\lambda_t}{\beta \lambda_{t+1}} = (1 - \tau_k) r_{s,t} + (1 - \delta_s) \\ \Rightarrow &: \frac{c_{t+1}}{\beta c_t} = (1 - \tau_k) r_{s,t} + (1 - \delta_s) \end{aligned} \quad (\text{B9})$$

$$\begin{aligned}
k_{e,t+1} &: -\frac{\lambda_t}{q_{e,t}} + \beta\lambda_{t+1} \left(r_{e,t} + (1 - \delta_e) \frac{1}{q_{e,t}} \right) = 0 & (B10) \\
&: \frac{\lambda_t}{\beta\lambda_{t+1}} = (1 - \tau_k) q_{e,t} r_{e,t} + (1 - \delta_e) \\
\Rightarrow &: \frac{c_{t+1}}{\beta c_t} = (1 - \tau_k) q_{e,t} r_{s,t} + (1 - \delta_e)
\end{aligned}$$

(ii) The firm minimizes cost given its production technology

$$\max_{l_t, k_{s,t}, k_{e,t}} \pi_t = a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} - r_{s,t} k_{s,t} - r_{e,t} k_{e,t} - w_t l_t \quad (B11)$$

The first order conditions are:

$$l_t : w_{s,t} = (1 - \alpha_s - \alpha_e) \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} = (1 - \alpha_s - \alpha_e) \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} \quad (B12)$$

$$k_{s,t} : r_{s,t} = \alpha_s \cdot a_t k_{s,t}^{\alpha_s-1} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} \quad (B13)$$

$$k_{e,t} : r_{e,t} = \alpha_e \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e-1} l_t^{1-\alpha_s-\alpha_e} \quad (B14)$$

(iii) The resource constraint (6) is satisfied.

Combining the household's and the firm's optimality conditions, and the resource constraint, we specify a system of equations that can be solved to find the equilibrium of the model. The economy is described by one intratemporal equations which determines the amount of hours worked,

$$\frac{(1 - \theta)}{\theta} c_t = (1 - \tau_l) (1 - l_t) \cdot (1 - \alpha_s - \alpha_e) \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e}, \quad (B15)$$

and two intertemporal equations which determine the evolution of the capital stocks of structures and E&S,

$$\frac{c_{t+1}}{c_t} = \beta \left((1 - \tau_k) \cdot \alpha_s \cdot a_t k_{s,t}^{\alpha_s-1} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} + (1 - \delta_s) \right), \quad (B16)$$

$$\frac{c_{t+1}}{c_t} = \beta \left(q_{e,t} (1 - \tau_k) \left(\alpha_e \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e-1} l_t^{1-\alpha_s-\alpha_e} \right) + (1 - \delta_e) \right). \quad (B17)$$

These correspond to the paper's equations (14) to (16). Using the resource constraint (6) we solve for c_t

$$c_t = a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} l_t^{1-\alpha_s-\alpha_e} - (k_{s,t+1} - (1 - \delta_s) k_{s,t}) - (k_{e,t+1} - (1 - \delta_e) k_{e,t}) / q_{e,t}. \quad (B18)$$

Define $\Phi_t \equiv (k_{s,t+1} - (1 - \delta_s) k_{s,t}) - (k_{e,t+1} - (1 - \delta_e) k_{e,t}) / q_{e,t}$, and rewrite the system of equation as:

$$\frac{(1 - \theta)}{\theta} y_t - \Phi_t = (1 - \tau_l) (1 - l_t) \cdot (1 - \alpha_s - \alpha_e) \cdot \frac{y_t}{l_t}, \quad (B19)$$

$$\frac{y_{t+1} - \Phi_{t+1}}{y_t - \Phi_t} = \beta \left((1 - \tau_k) \cdot \alpha_s \cdot \frac{y_t}{k_{s,t}} + (1 - \delta_s) \right), \quad (\text{B20})$$

$$\frac{y_{t+1} - \Phi_{t+1}}{y_t - \Phi_t} = \beta \left(q_{e,t} (1 - \tau_k) \left(\alpha_e \cdot \frac{y_t}{k_{e,t}} \right) + (1 - \delta_e) \right). \quad (\text{B21})$$

These are the equations we use to solve the model.

C Computation

[TO BE ADDED]

References

- [1] **Backus, D. K., P. J. Kehoe, and F. E. Kydland.** 1992. "International real business cycle." *Journal of Political Economy* 100(4): 745-775.
- [2] **Backus, D. K., P. J. Kehoe, and F. E. Kydland.** 1994. "Dynamics of the trade balance and the terms of trade: the J-curve?" *American Economic Review* 84(1): 84-103.
- [3] **Baxter, M. and M. J. Crucini.** 1993. "Explaining Saving-Investment Correlations." *American Economic Review* 83(3): 416-436.
- [4] **Boileau, M.** 2002. "Trade in capital-goods and investment-specific technical change." *Journal of Economic Dynamics and Control* 26: 963-984.
- [5] **Broda, C., and D. E. Weinstein.** 2006. "Globalization and the gains from variety." *Quarterly Journal of Economics*.
- [6] **Chatterjee, S., and K. Naknoi.** 2009. "The marginal product of capital, capital flows and convergence." Manuscript. Purdue University.
- [7] **Cummins, J. and V. Violante.** 2002. "Investment-specific technical change in the U.S. (1947-2000): measurement and macroeconomic consequences." *Review of Economic Dynamics* 5(2): 243-284.
- [8] **Eaton, J. and S. Kortum.** 2001. "Trade in capital goods." *European Economic Review* 45: 742-755.
- [9] **Feenstra, R. C.** 1994. "New product varieties and the measurements of international prices." *American Economic Review* 81(1): 157-177.
- [10] **Feenstra, R. C., M. B. Reinsdorf, and M. J. Slaughter.** 2008. Effects of terms of trade gains and tariff changes on the measurement of U.S. productivity growth. Manuscript. University of California at Davis.
- [11] **Fisher, J.,** 2006. "The dynamic effects of neutral and investment-specific technology shocks." *Journal of Political Economy* 114(3): 413-641.
- [12] **Gomme, P, and P. Rupert.** 2007. "Theory, measurement and calibration of macroeconomic models." *Journal of Monetary Economics* 54: 460-497.
- [13] **Gordon, R. J.** 1990. The measurement of durable goods prices. University of Chicago Press. Chicago.

- [14] **Gort, M. and R. A. Wall.** 1998. "Obsolescence, input augmentation, and growth accounting." *European Economic Review* 42:1653-1665.
- [15] **Greenwood, J., Hercowitz, Z., and P. Krussel.** 1997. "Long-run implications of investment-specific technological change," *American Economic Review* 87(3): 342-362.
- [16] **Griliches, Z.** 1961. "Hedonic price indexes for automobiles: an econometric analysis of quality change." in *The price statistics of the federal government: review, appraisal and recommendations*, New York, pp. 137-196.
- [17] **Hall, R. E.** 1968. "Technical change and capital from the point of view of the dual." *Review of Economic Studies* 35: 34-46.
- [18] **Hall, R. E.** 1971. "The measurements of quality change from vintage price data." in Z. Griliches ed. *Price index and quality change*, Harvard University Press, pp. 240-271.
- [19] **Hummels, D. and P. J. Klenow.** 2005. "The variety and quality of a nation's exports." *American Economic Review* 95(3): 704-723.
- [20] **Hulten, C. R.** 1992. "Growth accounting when technical change is embodied in capital." *American Economic Review*, 82(4): 964-980.
- [21] **Hsieh, C.-T., and P. J. Klenow.** 2007. "Relative prices and relative prosperity." *American Economic Review* 97(3):562-585.
- [22] **Jones, C. I.** 1994. "Economic growth and the relative price of capital." *Journal of Monetary Economics* 34:359-382.
- [23] **Justiniano, A., and G. E. Primiceri.** 2008. "The time-varying volatility of macroeconomic fluctuations." *American Economic Review* 98(3): 604-641.
- [24] **Oliner, S.,** 1993. "Constant-quality price change, depreciation, and retirement of mainframe computers," in Murray F. Foss, Marilyn E. Mansur, and Allan H. Young, eds., *Price Measurements and Their Uses*. University of Chicago Press.
- [25] **Raffo, A.** 2009. "Technology shocks: novel implications for international business cycles." Manuscript. Board of Governors of the Federal Reserve System.
- [26] **Whelan, K.,** 2002. "A guide to U.S. chain aggregated NIPA data." *Review of Income and Wealth* 48: 217-233.

- [27] **Whelan, K.**, 2002. "Computers, obsolescence, and productivity." *Review of Economics and Statistics* 84(3): 445-461.
- [28] **Whelan, K.**, 2003. "A two-sector approach to modelling U.S. NIPA data." *Journal of Money, Credit and Banking* 35(4): 627-656.
- [29] **Yi, K.-M.**, 2003. "Can vertical specialization explain the growth in world trade?" *Journal of Political Economy* 111(1):52-102.

Table 1: Capital-Goods Imports Contributions to Growth in E&S
(% per annum)

Average contribution to growth in...	1967-1987	1987-1997	1997-2007	1967-2007
Aggregate investment in E&S from...				
Capital-goods imports	11.0	63.6	70.2	54.0
Capital-goods imports from...				
Civilian aircraft, engines, and parts	65.7	23.9	27.5	27.5
Computer, peripherals, and parts	3.0	37.3	53.4	41.5
Other	31.3	38.9	27.1	31.1

Table 2: Baseline Calibration

Parameter	Description	Value
l	Ratio of hour worked to non-sleeping hours	0.217
$\alpha_s + \alpha_e$	Capital share of income	0.285
δ_s	Structures annual depreciation rate	0.025
δ_e	E&S annual depreciation rate	0.124
τ_l	Tax rate on labor income	0.243
τ_k	Tax rate on capital income	0.269
ϕ	Long-run domestic-to-total investment in E&S ratio	0.664
$\frac{1}{1-\rho}$	Elasticity of subst. between domestic and imported investment in E&S	1.964

Table 3: Estimated Parameters

Parameter	Description	Value
θ	Household's share of utility received from consumption	0.275
β	Discount factor	0.951
α_s	Structures share of income	0.162
α_e	E&S share of income	0.123

Table 4: Growth in U.S. Output per Hour

(% per annum)

Average growth in...	1967-1987		1987-1997		1997-2007		1967-2007	
	Data	Model	Data	Model	Data	Model	Data	Model
Output per hour	0.74	0.62	0.74	0.88	0.85	0.80	0.77	0.73
Total factor productivity	0.18	0.18	0.35	0.34	0.00	0.01	0.18	0.18
Structures	0.19	0.11	-0.04	0.05	0.16	0.16	0.12	0.11
Domestic E&S	0.34	0.27	0.32	0.37	0.47	0.42	0.37	0.33
Capital-goods imports	0.04	0.06	0.11	0.12	0.22	0.22	0.10	0.11

Table 5: Contribution to Growth in U.S. Output per Hour

(% per annum)

Average contribution to growth in output per hour from...	1967-1987		1987-1997		1997-2007		1967-2007	
	Data	Model	Data	Model	Data	Model	Data	Model
Growth in total factor productivity	24.1	29.1	46.9	39.3	0.6	0.6	23.1	24.3
Growth in structures	25.0	18.0	-5.7	5.4	18.3	20.1	15.8	14.8
Growth in domestic E&S	45.7	43.4	44.1	42.0	55.1	52.5	47.9	45.5
Growth in capital-goods imports	5.1	9.6	14.7	13.3	26.2	26.8	13.3	15.4

Table 6: Capital-Goods Imports Contributions to Growth in E&S

(% per annum)

	1967-1987		1987-1997		1997-2007		1967-2007	
Average contribution to growth in agg. investment in E&S from...	Data	Model	Data	Model	Data	Model	Data	Model
Capital-goods imports	11.0	0.03	0.64	0.54	0.70	0.79	0.54	0.47

Note: Data from Table 1

Table 7: Average Growth in U.S. Output per Hour
 (% per annum)

Average growth in output per hour since...	1967	1987	1997
with capital-goods imports technology	0.73	0.84	0.80
without capital-goods imports technology	0.73	0.67	0.62
Difference (%)	0.4	-20.2	-23.4

**Table 8: Contribution to Growth in U.S. Output per Hour without
the Capital-Goods Imports Technology**
(% per annum)

Average contribution to growth in output per hour from...	1967-1987	1987-1997	1997-2007	1967-2007
Growth in total factor productivity	22.7	47.5	0.8	24.2
Growth in structures	19.0	9.9	14.3	15.7
Growth in domestic E&S	58.3	42.6	84.9	60.1

Relative Prices of Non-residential Fixed Investment in E&S to Consumption

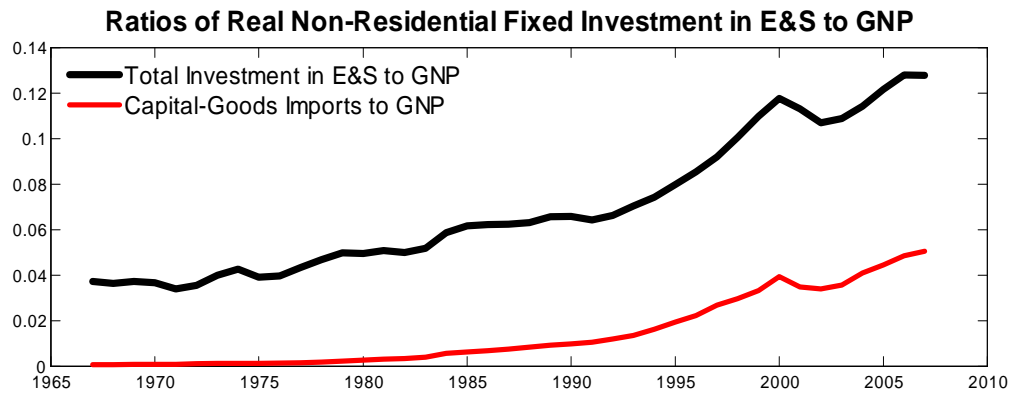
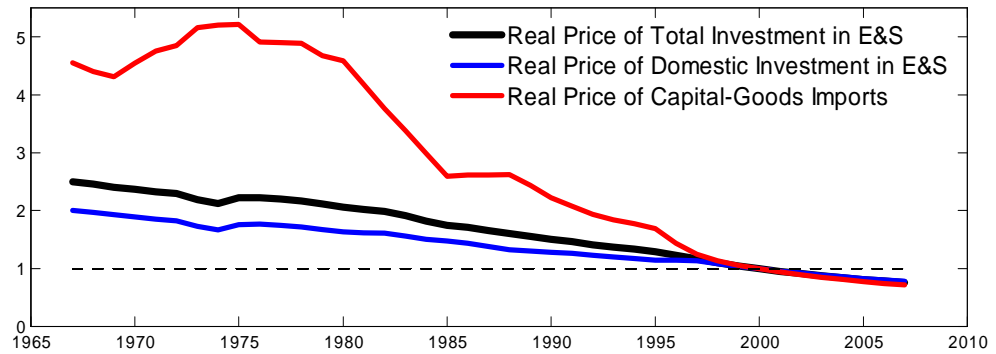


Figure 1: Relative quantities and relative prices of non-residential fixed investment in E&S

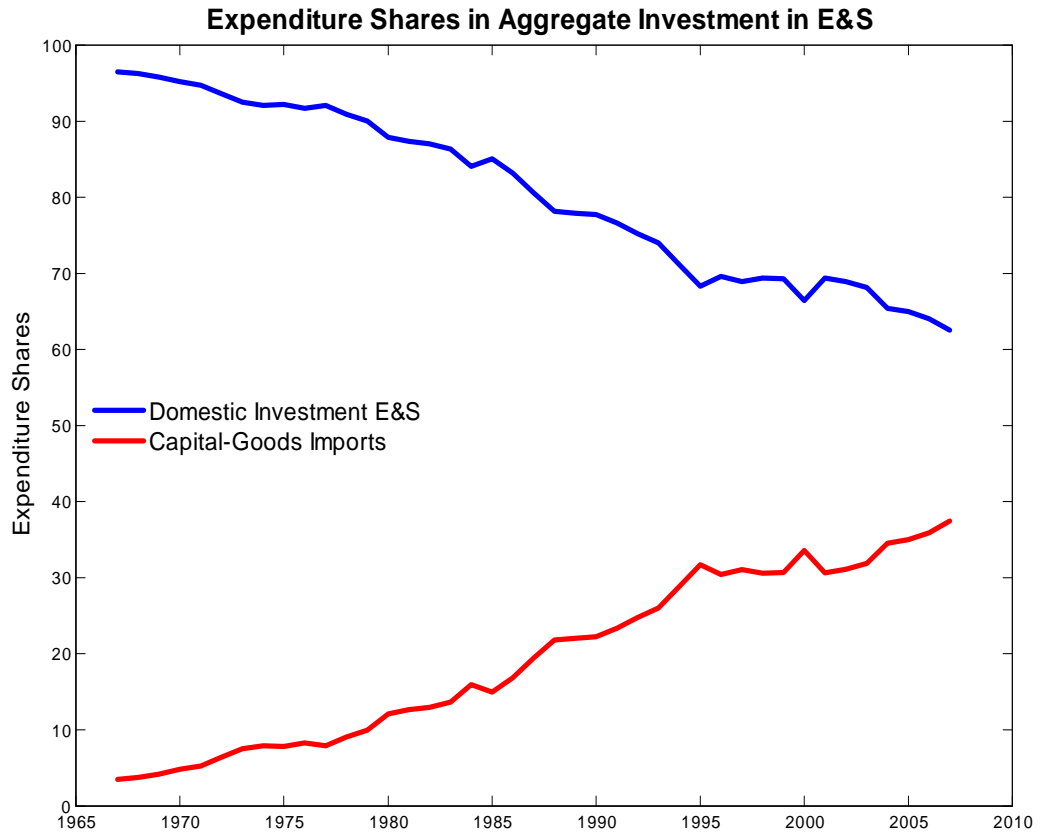


Figure 2: Expenditure shares of investment in domestic E&S and capital-goods imports in aggregate investment in E&S.

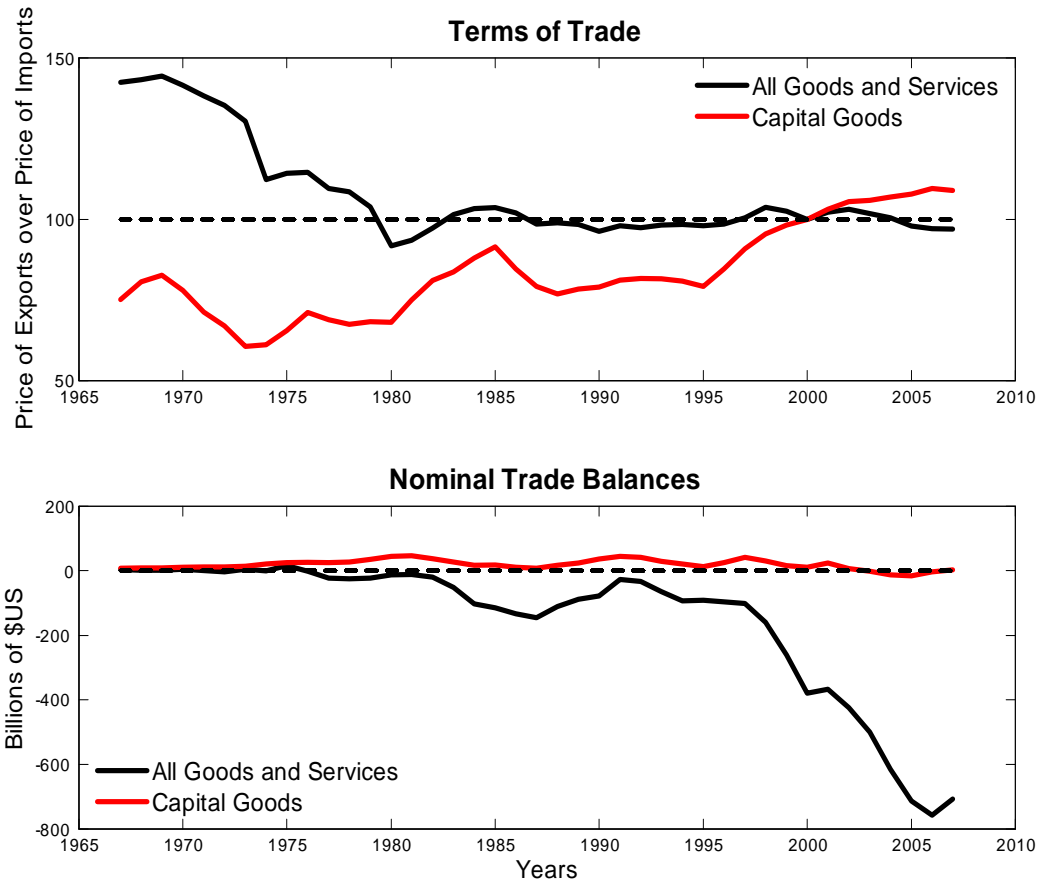


Figure 3: Terms of trades and nominal trade balances

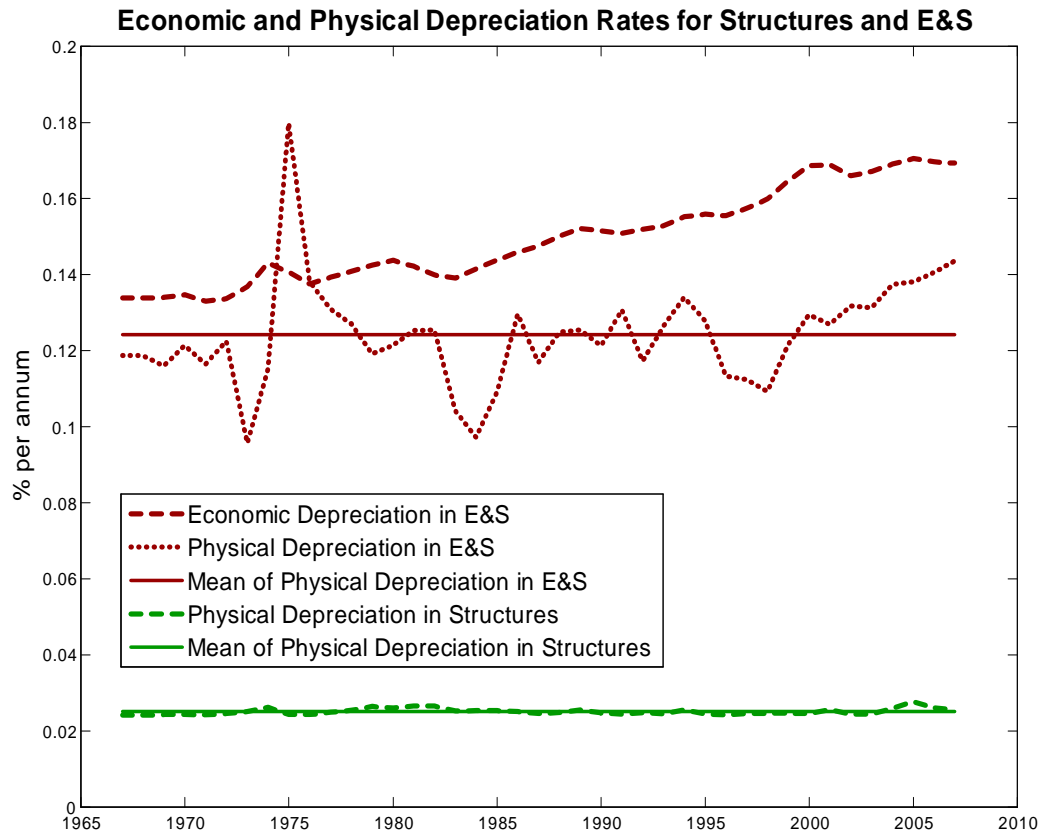


Figure 4: Economic and physical depreciation rates in structures and E&S

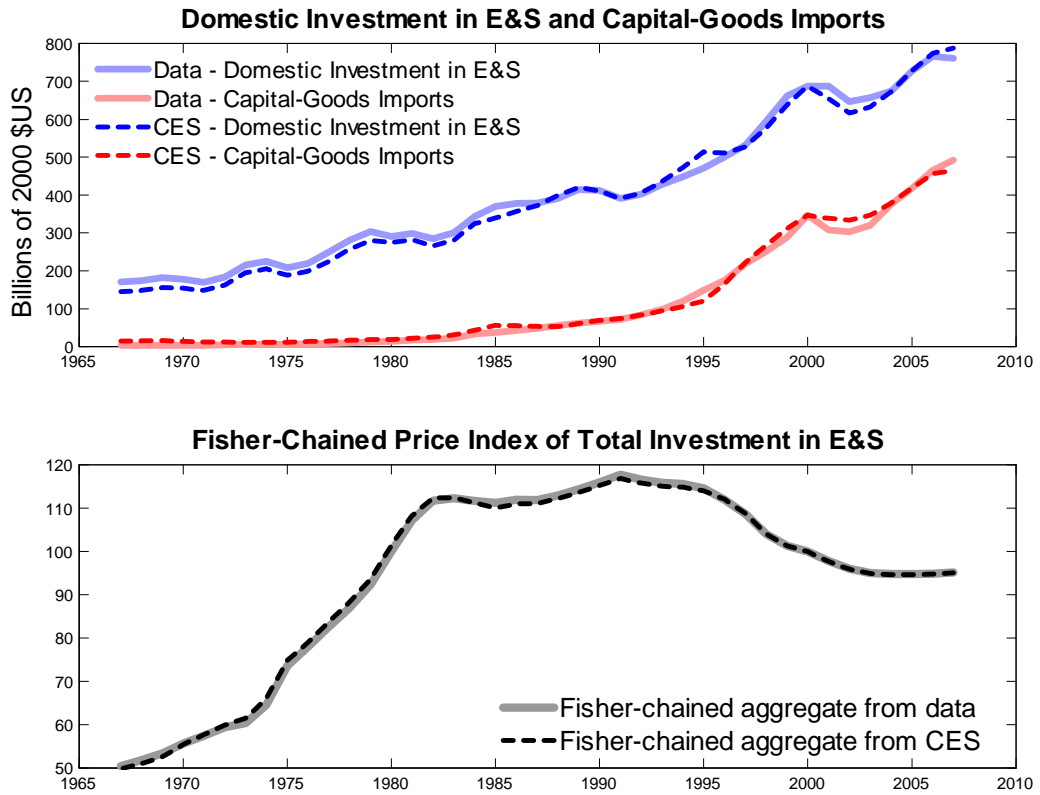


Figure 5: Data vs CES: Quantities of investment in domestic E&S and capital-goods imports, and the price of aggregate investment in E&S.

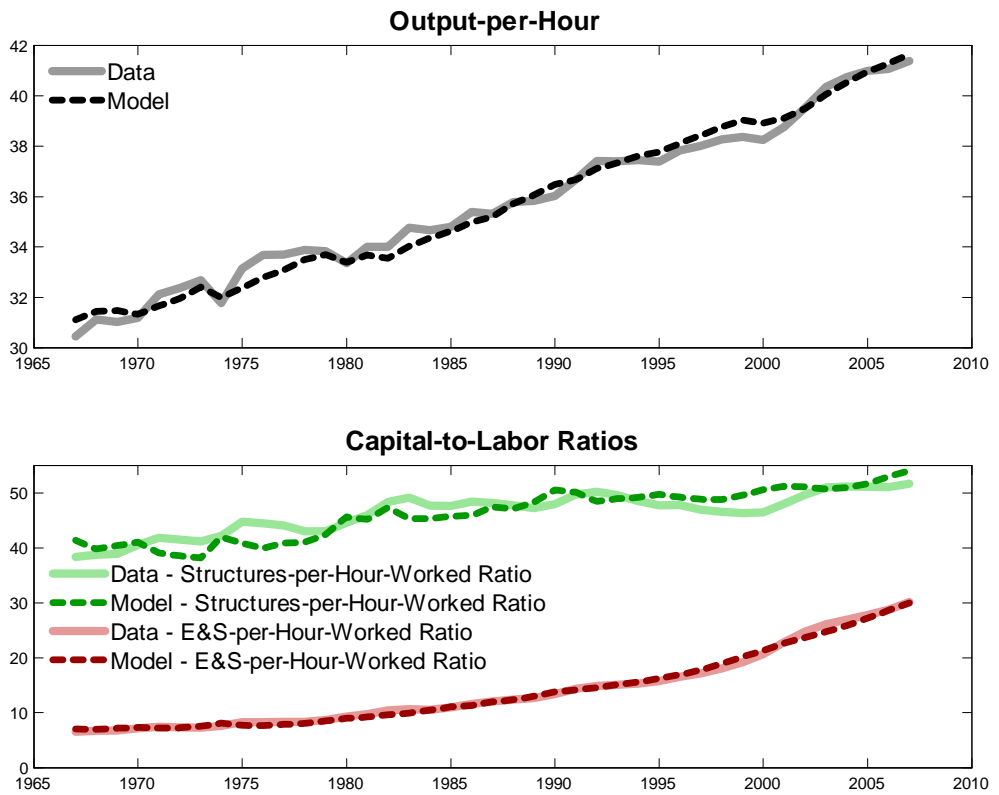


Figure 6: Data vs Model–Estimation targets

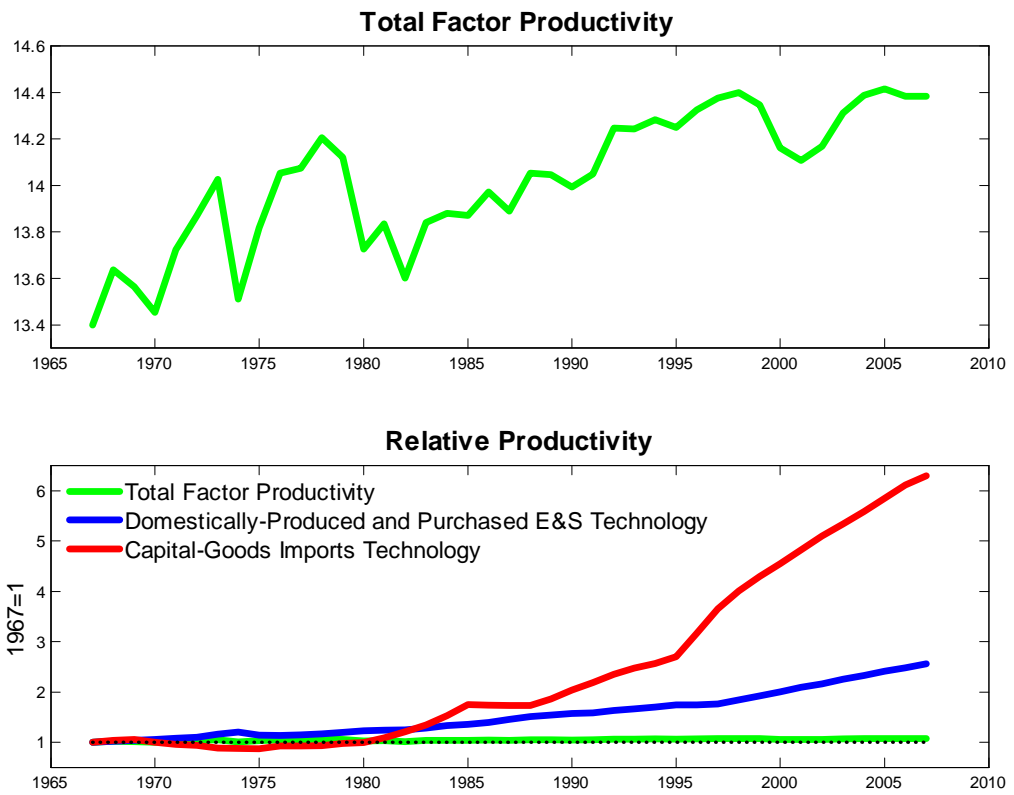


Figure 7: Productivity measures

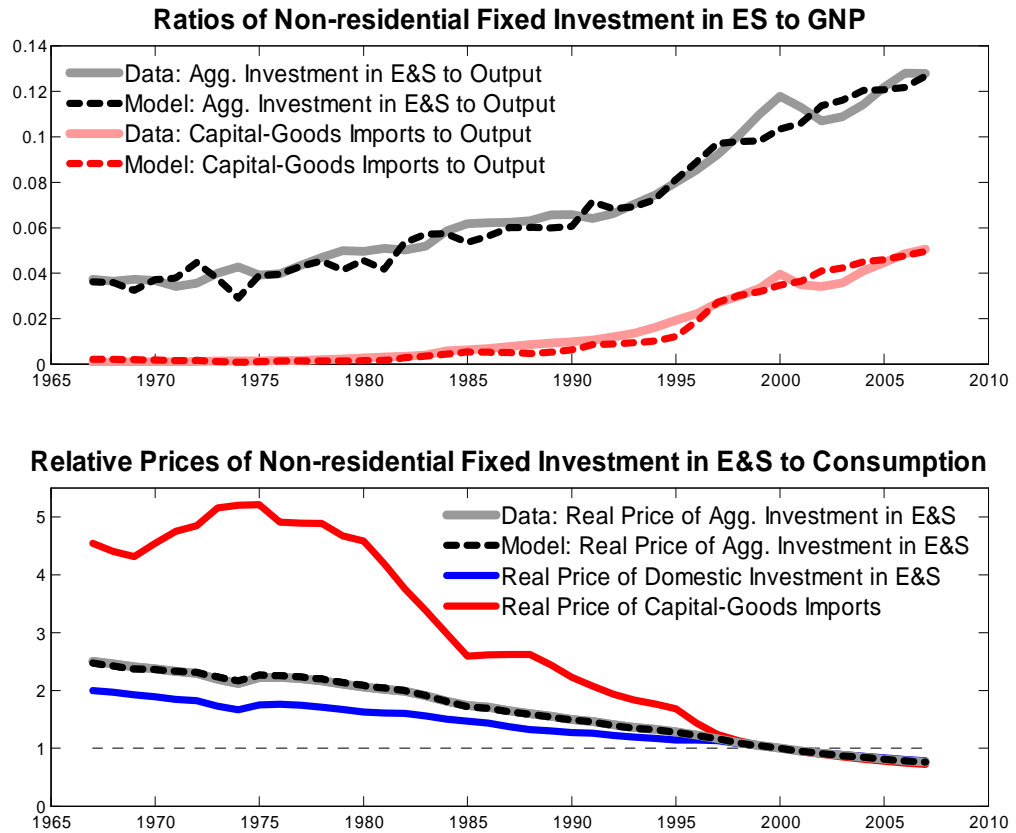


Figure 8: Data vs Model: Relative quantities and relative prices of investments in E&S

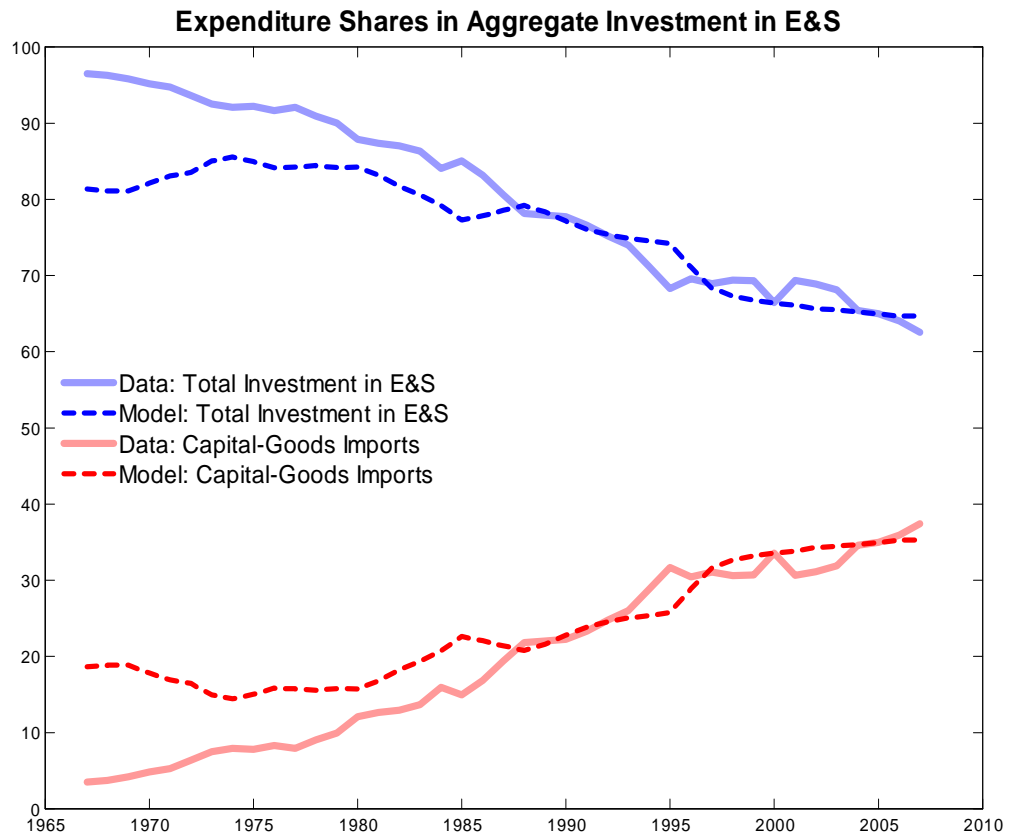


Figure 9: Expenditure shares of investment in domestic E&S and capital-goods imports in aggregate investment in E&S