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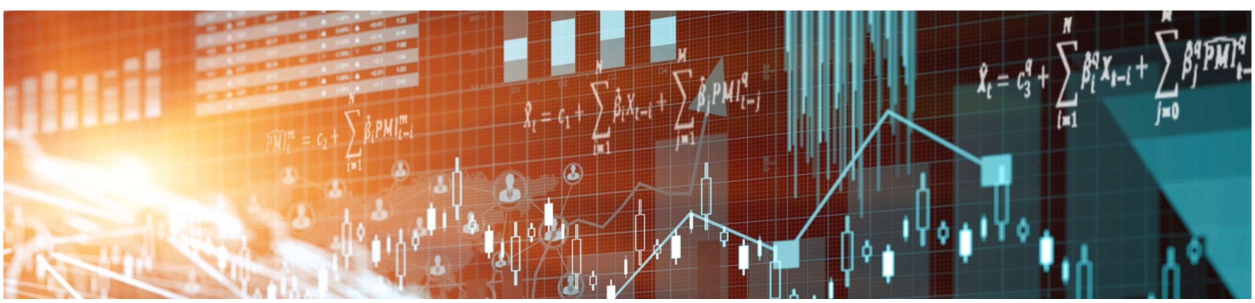
Capital-Goods Imports and US Growth



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Capital-Goods Imports and US Growth

by

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Abstract

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 measures. Investment-specific productivity measures are reflected by the price of capital-goods imports, the price of domestic-equipment investment, and the price of IP products relative to the price of consumption. We use observed prices to solve for optimal investment decisions, and understand the underlying sources of output growth in the U.S. economy. Our findings suggest that the model allocation decisions coming from changes in relative prices explain well the dynamics of investment and U.S. output. Using the model economy, we show that: (i) capital-goods imports have contributed 14 percent to growth in U.S. output per hour since 1975, (ii) capital-goods imports played a small role in the recent weakness in equipment investment, (iii) U.S. output-per-hour growth could have been 18 percent lower without the capital-goods imports technology since 1975, and (iv) in the long run, the implementation of additional tariffs on capital-goods imports would have little impact on the expenditure share of capital-goods imports in equipment investment.

Bank topics: Productivity; Trade integration
JEL codes: E2, F2, F4, O3, O4

Résumé

Les importations de biens d'équipement jouent aujourd'hui un rôle de plus en plus important dans la croissance de l'économie américaine. Pour comprendre ce phénomène, nous construisons un modèle de croissance néoclassique qui intègre les échanges internationaux de biens d'équipement et postule que les agents composent avec une orientation exogène des mesures de la productivité totale des facteurs et de la productivité induite par l'investissement. Le prix relatif des importations de biens d'équipement, le prix relatif de l'investissement en biens d'équipement nationaux, et le prix des produits de propriété intellectuelle par rapport aux prix à la consommation rendent compte des mesures de la productivité induite par l'investissement. Nous utilisons les prix observés pour déterminer les décisions optimales en matière d'investissement et pour comprendre les sources sous-jacentes de la croissance de la production dans l'économie américaine. D'après nos résultats, les décisions de répartition (dans le modèle) qui font suite aux changements de prix relatifs expliquent bien la dynamique de l'investissement et de la production américaine. Le modèle nous permet de conclure que : 1) les importations de biens d'équipement ont compté pour 14 % de la hausse de la production par heure aux États-Unis depuis 1975; 2) les importations de biens d'équipement ont joué un rôle mineur dans la récente faiblesse de l'investissement en biens d'équipement; 3) la croissance de la production par heure aux États-Unis aurait été 18 % plus faible sans l'apport de la technologie héritée des importations de biens d'équipement depuis 1975;

4) à long terme, l'imposition de droits de douane supplémentaires sur les importations de biens d'équipement aurait peu d'effet sur la part des dépenses en importations de biens d'équipement dans l'investissement en matériel.

Sujets : Productivité; Intégration des échanges
Codes JEL : E2, F2, F4, O3, O4

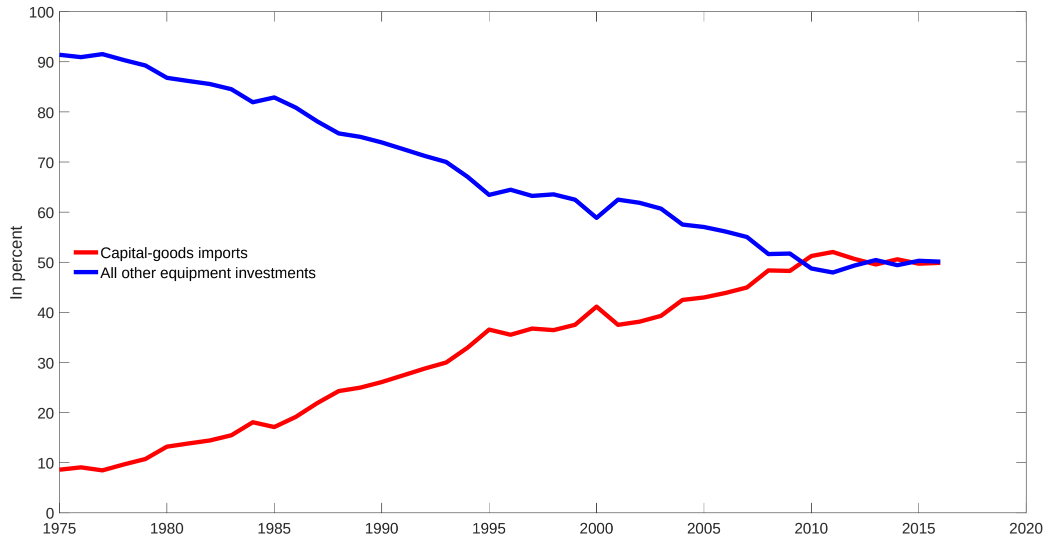
Non-Technical Summary

Over the past 50 years, the U.S. has gone through an enormous expansion in international trade and investment. In this paper, we study the contribution of capital-goods imports to U.S. output growth.

First, we document the contribution of capital-goods imports to growth in U.S. output per hour using a simple growth accounting exercise. From 1975 to 2016, capital-goods imports have contributed 14 percent to growth in U.S. output per hour, while all other equipment investments have contributed 34 percent. This implies that capital-goods imports have explained about one-third of the average annual contribution of equipment investment to U.S. output-per-hour growth since 1975. Put differently, capital-goods imports have increased the level of output per hour by 5.0 percent between 1975 and 2016. In terms of output gains, capital-goods imports have added $830 million in 2016 dollars to the annual level of output by 2016. Summing up the annual contribution of capital-goods imports to U.S. output since 1975, we find that the total payoff is $11.8 trillion in 2016 dollars. Clearly, capital-goods imports have generated significant output gains for the United States. More importantly, we show that capital-goods imports have become an increasing source of growth in equipment investment and in U.S. output. Our analysis also suggests that capital-goods imports played a small role in the recent weakness in equipment investment. Instead, the current weakness in equipment investment can be partly attributed to a lack of productivity growth in domestic-equipment relative to previous expansions.

Second, we build a neoclassical growth model with trade in capital goods to understand the underlying source of capital-goods import growth, and use our model economy to perform two counterfactual experiments and illustrate the importance of capital-goods imports for the U.S. economy. In the first experiment, we ask what growth in U.S. output per hour would be without the capital-goods imports technology. We find that the U.S. economy could have lost up to 18 percent in average annual growth in output per hour since 1975—with an especially severe loss of output-per-hour growth during the 1991 to 2001 expansion. In the second experiment, motivated by the current protectionist environment, we also look at the economic impact of imposing additional trade barriers on capital-goods imports. As a starting point, we show the impact of imposing an additional 20 percent tariff on capital-goods imports starting in 2017. The size of this tariff is reminiscent of The Tariff Act of 1930 (otherwise known as the Smoot-Hawley Tariff). Extrapolating from observed growth trends in prices, hours worked, and working-age population since 1975, we find that imposing an additional 20 percent tariff on capital-goods imports could lead to a 16 percent reduction in U.S. output-per-hour growth over the next 15 years. Our model predicts that this reduction in the U.S. is even larger when we extrapolate from recent growth trends in prices, hours worked, and working-age population observed since the Great Recession.

Figure 1: **Expenditure Shares in U.S. Equipment Investment**



Note: Figure 1 shows the U.S. capital-goods imports expenditure shares of equipment investment since 1975. It shows that capital-goods imports have accounted for an increasing share of the expenditure in U.S. equipment investment over time, from 9 percent in 1975 to 50 percent in 2016.

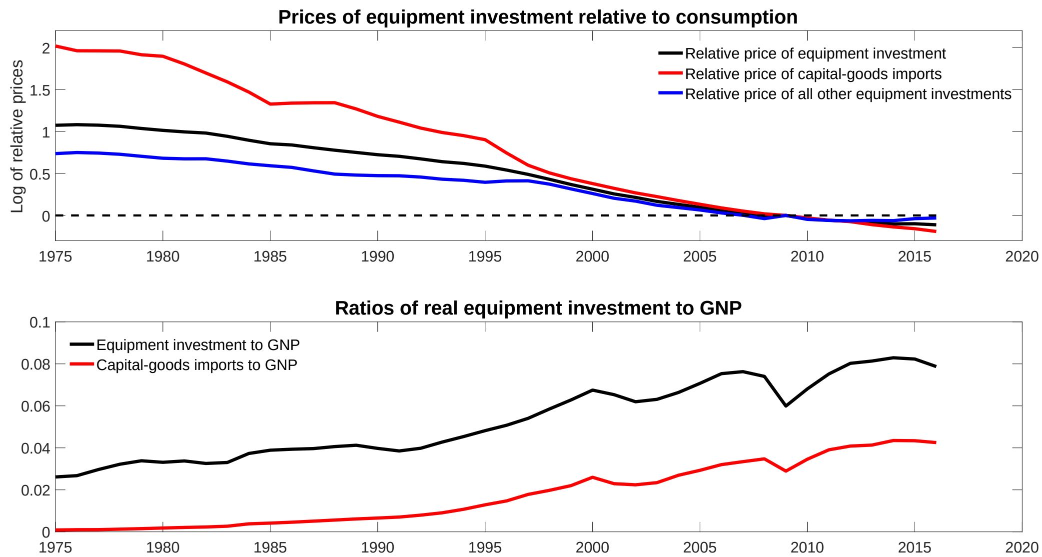
1 Introduction

A significant body of literature has found that technological improvement embodied in new capital goods accounts for a large share of growth in U.S. output per hour. This phenomenon, known as investment-specific productivity, stimulates the growth rate of output per hour by raising the efficiency of equipment in the production of final output. In an influential contribution, Greenwood et al. (1997) explore the role played by investment-specific productivity gains. In their model, gains in investment-specific productivity are reflected in the decline in the price of equipment investment relative to the price of consumption. Using a standard neoclassical growth model, they estimate that investment-specific productivity accounted for nearly 60 percent of U.S. output-per-hour growth 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]

Over the last four decades, the U.S. economy has gone through an enormous expansion in international trade and investment. Figure 1 shows that capital-goods imports have accounted for an increasing share of expenditure in U.S. equipment investment: While accounting for less than 10 percent in 1975, capital-goods imports now account for about 50 percent of U.S. equipment investment expenditure. Figure 2 shows the evolution of prices and quantities for U.S. equipment investment. The upper panel shows that the decline in the price of capital-goods imports has been substantially larger than that of all other categories of equipment investment, while the lower panel shows that capital-goods imports have been the main driver behind the increase in equipment investment. Together, these observations suggest that most of the gains in measured U.S.

[1] Early contributions on the role played by gains in investment-specific productivity in U.S. growth in output per capita include Griliches (1961), Hall (1968), Hall (1971), Gordon (1990), and Hulten (1992). Relatively more recent contributions include those of Cummins and Violante (2002), Whelan (2002b), Fisher (2006), Justiniano and Primiceri (2008), and Samaniego (2010), among others.

Figure 2: **Prices and Quantities Dynamic in U.S. Equipment Investment**



Note: The upper panel of Figure 2 shows the Fisher chain-weighted U.S. price of equipment investment relative to consumption, alongside the U.S. relative price of capital-goods imports, and that of all other U.S. equipment investments. This panel shows that the decline in the price of capital-goods imports has been substantially larger than that of all other investments in equipment. The lower panel shows the ratio of real aggregate equipment investment to gross national product. This panel shows that capital-goods imports have been the main driver behind the increase in equipment investment.

investment-specific productivity (as reflected by the decline in the relative price of equipment investment) have originated from imports of capital goods, and that the decline in the relative price of capital-goods imports has been a driving force behind the increase in the stock of equipment.

In this paper, we consider a neoclassical growth model with trade in capital goods to assess the role played by capital-goods imports in U.S. output growth. The starting point for our analysis is the work of Greenwood et al. (1997). As in that framework, agents face exogenous paths of total-factor productivity (TFP) and investment-specific productivity in equipment. In our setup, however, investment-specific productivity in equipment is jointly determined by the relative price of capital-goods imports and that of domestic-equipment investment through an Armington aggregate. In our analysis, we also control for the quantitative role of investment-specific productivity and technological progress in intellectual property (IP) product, which is reflected by the evolution of the price of IP products relative to the price of consumption. Given these prices, agents make investment decisions in structures, IP products, and equipment, thus including expenditure decisions on capital-goods imports and domestic-equipment investment. We find that the allocation decisions implied by the model and driven by changes in relative prices do a good job at explaining the dynamics of investment expenditure, including the dynamics of capital-goods imports, in U.S. output.

First, we show that capital-goods imports have generated significant gains in output per hour for the United States. More specifically, using a simple growth accounting exercise, we find that capital-goods imports have contributed 14 percent to growth in U.S. output per hour since 1975.[2]

[2]From 1975 to 2016, capital-goods imports have contributed 14 percent to growth in U.S. output per hour, while all other categories of equipment investment have contributed 34 percent. This implies that capital-goods imports have explained about one-third of the average annual contribution of equipment investment

Put differently, capital-goods imports raised the level of output per hour by 5.0 percent between 1975 and 2016. More importantly, we show that capital-goods imports have become an increasingly important source of growth in equipment investment and in U.S. output: Since 2008, the average annual contribution of capital-goods imports to growth in equipment investment rose to as much as 96.6 percent, up from 23.7 percent in the 1980s. In other words, almost all of the growth in equipment investment has been stemming from capital-goods imports as of the last few years. Our analysis also suggests that capital-goods imports played a small role in the recent weakness in equipment investment. Instead, the current weakness in equipment investment can be partly attributed to a lack of investment-specific productivity growth in domestic equipment relative to previous expansions.

We also use our model economy to set up two counterfactual scenarios with the ultimate goal of illustrating the importance of capital-goods imports for the U.S. economy. First, we ask what the U.S. output-per-hour growth would have been without the productivity gains embodied in capital-goods imports. We perform this counterfactual experiment by assuming that agents would have faced an annual growth rate in investment-specific productivity in equipment equal to that of domestic-equipment investment. Within this counterfactual, the model predicts that the U.S. economy would have lost 18 percent in average annual growth in output per hour since 1975—with an especially severe loss of output-per-hour growth during the 1991 to 2001 expansion. This loss in output growth should not come as a surprise: U.S. expenditure shares on capital-goods imports in equipment investment have increased since 1975, while at the same time, capital-goods imports have become cheaper relative to domestic-equipment investment. Without access to capital-goods imports technology, the decline in the relative price of equipment investment would have been less pronounced. In turn, this would have implied a lower growth rate in the stock of equipment, and ultimately a lower growth rate in U.S. output per hour.

Motivated by the current protectionist environment, we also look at the growth implications of imposing additional trade barriers on capital-goods imports. As a starting point, we show the impact of imposing an additional 20 percent tariff on capital-goods imports starting in 2017. The size of this tariff is reminiscent of The Tariff Act of 1930 (otherwise known as the Smoot-Hawley Tariff). Extrapolating from observed growth trends in prices, hours worked, and working-age population since 1975, we find that imposing an additional 20 percent tariff on capital-goods imports could lead to a 16 percent reduction in U.S. output-per-hour growth over the next 15 years—which is about the amount of time that it takes for macroeconomic aggregates to converge to their new balanced-growth path.[3] As expected, the tariff induces an immediate reallocation of equipment investment away from capital-goods imports toward domestic equipment. On impact, the tariff leads to a reduction of about 7 percentage points in the expenditure share on capital-goods imports. The additional tariff, however, does not change the underlying trend: Capital-goods imports would continue to account for a growing share of equipment investment as long as the price of capital-goods imports declines faster than that of domestic-equipment investment. In our example, it takes only five years for the expenditure share on capital-goods imports to return to its pre-tariff level.

to U.S. output-per-hour growth since 1975.

[3] The quantitative effects are specific to the relative price difference between capital-goods imports and domestic-equipment investment that exists when a tariff is implemented. Ultimately, the negative effects of an additional tariff on capital-goods imports are larger the wider the initial wedge in relative prices between capital-goods imports and domestic-equipment investment.

In 2013, the Bureau of Economic Analysis (BEA) expanded its coverage of non-residential fixed investment to include IP products as final investment goods. Although the BEA already included some intangible assets as fixed investment, notably software development, the IP products category groups software with expenditures on research and development, and on entertainment, literary, and artistic originals. In this paper, we model investment as in the National Income and Product Account (NIPA) data by allocating non-residential investment to structures, equipment, and IP products. This implies that we can also account for the contribution of IP products to U.S. output growth. We find that IP products have contributed 26 percent to U.S. output-per-hour growth between 1975 and 2016. Together, equipment and IP products accounted for 73 percent of U.S. output-per-hour growth.[4] We also show that imports of IP products have only marginally contributed to the overall growth in IP products, and ultimately in U.S. output-per-hour growth. In other words, productivity gains in IP products stem from the domestic technology (i.e., investment-specific productivity in domestic IP products), in contrast to gains in the stock of equipment, which mostly stem from capital-goods imports.

The notion that trade in capital goods is an important source of economic growth and fluctuations is not new. As early as the 1960s, Baldwin (1966) argued that trade in capital goods is a crucial component in the dynamic interaction between international trade and economic growth. Later, the literature on international real business cycles, pioneered by Backus et al. (1992) and Baxter and Crucini (1993), generated plausible business cycle dynamics by emphasizing the role of investment dynamics, while Boileau (2002) and Raffo (2010) exploit fluctuations in the price of equipment investment to explain trade in capital goods and other aspects of international economic fluctuations. More recently, Barattieri et al. (2017) show that the decline of investment is a key factor in propagating the recessionary effects of protectionism. Our findings are also related to the large literature on the gains from trade, as well as research on investment prices and economic prosperity. For example, Arkolakis et al. (2012) look at the magnitude of the welfare gains from trade. Jones (1994) examines the relationship between the relative price of equipment investment and economic growth, while Eaton and Kortum (2001), Hsieh and Klenow (2007), and more recently Armenter and Lahiri (2012) and Mutreja et al. (2018) develop theories of economic development based on the relative price of equipment investment. Finally, Karabarbounis and Neiman (2014) demonstrate how the decline of the labor share of output can be explained by the decline in the relative price of equipment investment. In our analysis, we show that most of the decline in the relative price of U.S. equipment investment comes from capital-goods imports, and that this relative price decline has been the driving force behind the increase in the stock of U.S. equipment.

Overall, our results suggest that capital-goods imports, through their effect on the decline in the relative price of equipment investment, have had a significant impact on U.S. output growth. We do not take a stand as to why the relative price of capital-goods imports has declined; neither do we interpret this relative price decline as fully reflecting embedded technological improvements 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), or also the decline in the costs of multinational production that led some countries to specialize in innovation and others in production, as in Arkolakis et al. (2018). The decline could also reflect changing trade patterns, foreign firms' entry, and an increase in the

[4] The joint contribution of equipment and IP products to U.S. output-per-hour growth is similar to what we found in Cavallo and Landry (2010), using data on the equipment and software category from 1967 to 2009.

dispersion of foreign firm characteristics, as in Redding and Weinstein (2017), or also 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 relative price of capital-goods imports is equivalent to technological progress. In particular, it implies an increase in measured productivity gains.[5]

The rest of the paper is organized as follows. In section 2, we present a simple neoclassical growth model and describe how we match the model with the data. In section 3, we perform our growth accounting exercise, document the contribution of capital-goods imports in U.S. output growth, and perform a series of counterfactual experiments. Finally, in section 4 we lay out our conclusions.

2 The Model

2.1 The Economic Environment

We consider an economy with a representative household, a representative firm, and a government. The representative household makes consumption, labor supply, and investment decisions to maximize lifetime utility,

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

given period-t utility function,

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

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

The production of final output y_t requires the services of labor l_t and three types of capital: structures $k_{s,t}$, equipment $k_{e,t}$, and IP products $k_{ip,t}$. Production evolves according to

$$y_t = a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip}} l_t^{1-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{3}$$

where a_t represents TFP, and α_s, α_e, and α_{ip} represent the income shares of structures, equipment, and IP products.

[5]Appendix A shows the origin and composition of U.S. capital-goods imports over time. We choose to remain agnostic about the specific reasons behind the decline in the relative price of capital-goods imports because its cause, the capital-goods imports composition, and the geographical source of U.S. capital-goods imports have changed over the sample period. These reasons lead us to believe that there is more than one simple story to explain the relative price decline in capital-goods imports over this long period of time. Currently, China is the largest source of U.S. capital-goods imports (in part because of its low labor costs), while that role was owned by Japan in the 1980s (in part because of its novel management techniques at that time).

Final output is allocated to consumption, investment in structures $i_{s,t}$, investment in domestically produced-and-purchased equipment $i_{d,t}$ (hereafter domestic-equipment investment), investment in IP products $i_{ip,t}$, and foreign investment in capital-goods exports $i_{x,t}$. Taking consumption as the numeraire, the resource constraint is given by

$$y_t = c_t + i_{s,t} + p_{d,t} i_{d,t} + p_{ip,t} i_{ip,t} + p_{x,t} i_{x,t}, \tag{4}$$

where $p_{d,t}$ represents the prices of domestic-equipment investment, $p_{ip,t}$ represents the prices of investment in IP products, and $p_{x,t}$ represents the price of capital-goods exports.[6] We impose balanced trade to close the model. This is an assumption that greatly simplifies our model, and that is supported in the data by the fact that the nominal trade balance in capital goods has been roughly balanced over the sample period (see Appendix A, Figure A1). This implies that the value of capital-goods imports is equal to the value of capital-goods exports,

$$p_{m,t} i_{m,t} = p_{x,t} i_{x,t}, \tag{5}$$

where $i_{m,t}$ represents capital-goods imports, and $p_{m,t}$ represents its price. After we take the balanced-trade condition (5) into account, the resource constraint becomes

$$y_t = c_t + i_{s,t} + p_{d,t} i_{d,t} + p_{ip,t} i_{ip,t} + p_{m,t} i_{m,t}. \tag{6}$$

The stock of structures evolves according to

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

where δ_s represents the depreciation rate of structures. In contrast, the stocks of equipment and IP products evolve according to

$$k_{e,t+1} = q_{e,t} i_{e,t} + (1 - \delta_e) k_{e,t}, 0 < \delta_e < 1, \tag{8}$$

$$k_{ip,t+1} = q_{ip,t} i_{ip,t} + (1 - \delta_{ip}) k_{ip,t}, 0 < \delta_{ip} < 1, \tag{9}$$

where δ_e represents the depreciation rate of equipment, and δ_{ip} represents the depreciation rate of IP products. The factors $q_{e,t}$ and $q_{ip,t}$ represent investment-specific productivity in equipment and IP products, respectively. These factors determine the amount of new equipment and IP products that can be purchased for one unit of final output. Accordingly, movements in $q_{e,t}$ and $q_{ip,t}$ reflect changes in the state of technology for transforming investment in equipment and IP products into stocks.

To account for capital-goods imports in equipment investment, we model aggregate investment in equipment as an Armington composite according to

$$i_{e,t} = \left(\phi^{1-\rho} i_{d,t}^{\rho} + (1 - \phi)^{1-\rho} i_{m,t}^{\rho} \right)^{\frac{1}{\rho}}, 0 < \phi < 1, \rho < 1, \tag{10}$$

[6] The price of domestic-equipment investment, $p_{d,t}$, is not the same as the price of capital-goods exports, $p_{x,t}$.

where ϕ represents the long-run share of domestic-equipment investment into aggregate investment in equipment, and ρ determines the elasticity of substitution between domestic-equipment investment and capital-goods imports. The goal of the household is to minimize expenditure on equipment such that equation (10) holds. The solution to the minimization problem yields the following optimal investment quantities:

$$i_{d,t} = \phi(\frac{p_{d,t}}{p_{e,t}})^{\frac{-1}{(1-\rho)}} i_{e,t}, \tag{11}$$

$$i_{m,t} = (1-\phi)(\frac{p_{m,t}}{p_{e,t}})^{\frac{-1}{(1-\rho)}} i_{e,t}. \tag{12}$$

Given these optimal choices, the price of aggregate investment in equipment is

$$p_{e,t} = \left(\phi p_{d,t}^{\frac{\rho}{(\rho-1)}} + (1-\phi)p_{m,t}^{\frac{\rho}{(\rho-1)}}\right)^{\frac{\rho-1}{\rho}}. \tag{13}$$

This expression shows that the price of aggregate investment in equipment depends on the price of domestic-equipment investment and that of capital-goods imports. In the aggregate, the investment decisions depend only on the change in the relative price of domestic-equipment investment relative to that of capital-goods imports—in equilibrium, these prices reflect investment-specific productivity in domestic equipment versus that in capital-goods imports.[7]

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

$$g_t = \tau_{l,t} w_t l_t + \tau_{k,t}(r_{s,t}k_{s,t} + r_{e,t}k_{e,t} + r_{ip,t}k_{ip,t}), \tag{14}$$

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

2.2 Matching the Model with the Data

We use annual data that cover the period 1975 to 2016 from the NIPA Tables unless otherwise noted.[8] Since the baskets of investment in equipment and IP products have changed considerably

[7]Once the investment decisions are made, domestic-equipment investment and capital-goods imports are added to the existing stock of equipment. This assumption may seem ad-hoc, but it is consistent with the stock of fixed assets published by the BEA. The published data do not distinguish between the stock of equipment derived from capital-goods imports and the stock of equipment derived from other sources.

[8]The BEA publishes quality adjusted data starting in 1969. We choose to start our analysis in 1975, because this is when the sustained decline in the relative price of capital-goods imports started. Although a reversal in protectionism started after the Second World War, U.S. trade agreements were only substantially expanded starting in the 1970s.

since 1975, the data are Fisher chain-weighted to better track quality improvement over time.[9] Appendix A briefly surveys the literature on the investment-specific productivity measurement, and contains additional information on the data used in this paper.

We deflate all the nominal variables in our analysis with the implicit price deflator for consumption, defined as the ratio between nominal and real consumption. Real consumption is the chain-weighted sum of personal consumption expenditure on nondurables, non-housing services, and government consumption, while nominal consumption is the sum of the corresponding current-dollar measures for these series. We do not include durable consumption in the consumption aggregate to avoid the issue of accounting for quality improvement in consumer durables. Final output is gross national product minus gross housing and business farm products. Because trade occurs only in capital goods, we add net exports (excluding capital goods) to final output.[10] 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.

The series for investment-specific productivity in equipment is the inverse of the relative price of equipment investment in terms of consumption, with this relative price computed as the ratio between the equipment-investment deflator and the consumption deflator. The equipment-investment deflator is the implicit price deflator for aggregate equipment investment, defined as the ratio between nominal and real aggregate equipment investment. Aggregate real equipment investment, in turn, is the chain-weighted sum of private and government non-residential fixed investment in equipment, while nominal equipment investment is the corresponding current-dollar series. The deflator for capital-goods imports is taken directly from the NIPA data. It includes tariffs, insurance, and transportation costs. The deflator for all other investments in equipment (domestic-equipment investment) is the implicit price deflator of the chain-weighted difference between aggregate equipment investment and capital-goods imports. Finally, the IP products investment deflator is the implicit price deflator for IP products investment, defined as the ratio between nominal and real IP products investment. Aggregate real IP products investment, in turn, is the chain-weighted sum of private and government non-residential fixed investment in IP products, while nominal IP products investment is the corresponding current-dollar series.

We construct the series for the stocks of structures, equipment, and IP products using the laws of motion (7), (8), and (9). Starting with an initial value for $k_{s,1975}$, $k_{e,1975}$, and $k_{ip,1975}$, we compute the stock of structures, equipment, and IP products by iterating on the laws of motion using the nominal investment values for $i_{s,t}$, $i_{e,t}$, and $i_{ip,t}$, divided by the consumption deflator. The stocks of equipment and IP products are quality-adjusted using the evolution in the relative price of aggregate equipment and IP products investment, respectively. The initial stock of structures $k_{s,1975}$ is the current-dollar value in 1975 from the BEA Fixed Assets Tables divided by the consumption deflator. The initial stocks of equipment $k_{e,1975}$ and IP products $k_{ip,1975}$ are the current-dollar values in 1975 from the BEA Fixed Assets Tables divided by the consumption deflator, and adjusted using the 1975 investment-specific productivity in equipment and IP products, respectively.

[9] The BEA has implemented several revisions to its methodology in order to account for the rapid rate of innovation in equipment and IP products. Improved hedonic regression techniques and the implementation of the chain-weighted methodology by the BEA are intended to allow equipment and IP products aggregates to better track quality improvement over time.

[10] An alternative measure is to define final output as expenditure, as in equation (6), which gives similar results.

In constructing the stocks of structures, equipment, and IP products, we use depreciation rates sample averages rather than the series to isolate the role of relative price changes in investment decisions.[11] Because of the rapid quality improvement in equipment and IP products, we measure these depreciation rates using the notion of physical depreciation. This notion is different from the one used by the BEA, whose measure is based, instead, on the notion of economic depreciation. As shown by Oliner (1993) and later by Cummins and Violante (2002), with investment measured in efficiency units, one should obtain depreciation rates consistent with the notion of physical depreciation. Therefore, we compute the physical depreciation rate for equipment, $\delta_{e,t}$, and IP products, $\delta_{ip,t}$, as

$$\delta_{e,t} = 1 - (1 - d_{e,t}) \frac{q_{e,t}}{q_{e,t-1}}, \tag{15}$$

$$\delta_{ip,t} = 1 - (1 - d_{ip,t}) \frac{q_{ip,t}}{q_{ip,t-1}}, \tag{16}$$

where $d_{e,t}$ denotes economic depreciation, measured as the ratio between current-cost depreciation and the previous-year current-cost net stock from the BEA Fixed Assets Tables. With regard to structures, the physical depreciation rate, $\delta_{s,t}$, coincides with the economic depreciation rate. Appendix A offers further explanation on the differences between economic and physical depreciation rates, and shows the depreciation rates series and averages.

2.3 Competitive Equilibrium

A competitive equilibrium is a set of prices $p_{e,t}, p_{ip,t}, w_t, r_{s,t}, r_{e,t}, r_{ip,t}$; and allocations $c_t, l_t, i_{s,t}, i_{e,t}, i_{ip,t}$ for the representative household, and $l_t, k_{s,t}, k_{e,t}, k_{ip,t}$ for the firm, such that: (i) given a set of prices, the allocation $c_t, l_t, i_{s,t}, i_{e,t}, i_{ip,t}$ maximizes the representative household's utility, (ii) given a set of prices, the allocation $l_t, k_{s,t}, k_{e,t}, k_{ip,t}$ maximizes firm's profit, and (iii) the resource constraint is satisfied. Appendix B describes the equations of the 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 that determines the number of hours worked,

$$\frac{(1-\theta)}{\theta} c_t = (1 - l_t)(1 - \alpha_s - \alpha_e - \alpha_{ip}) \frac{y_t}{l_t}, \tag{17}$$

and three intertemporal equations that determine the evolution in the stocks of structures, equipment, and IP products,

$$\frac{c_{t+1}}{c_t} = \beta \left((1 - \tau_k) \alpha_s \cdot \frac{y_{t+1}}{k_{s,t+1}} + (1 - \delta_s) \right), \tag{18}$$

[11] The capital stocks and the model's behavior are not significantly different when we use the depreciation rates series instead of their averages.

Table 1: **Baseline Calibration**

Parameter	Description	Value
δ_s	physical depreciation rate of structures	0.025
δ_e	physical depreciation rate of equipment	0.111
δ_{ip}	physical depreciation rate of IP products	0.199
d_e	economic depreciation rate of equipment	0.137
d_{ip}	economic depreciation rate of IP products	0.211
l	ratio of hours worked to non-sleeping hours	0.219
$\alpha_s + \alpha_{ip} + \alpha_e$	capital share of income	0.313
τ_l	tax on labor income	0.251
τ_k	tax on capital income	0.233
ϕ	long-run domestic-to-aggregate equipment-investment ratio	0.517
$\frac{1}{1-\rho}$	elasticity of substitution	2.588

$$\frac{c_{t+1}}{c_t} = \beta \left(q_{e,t}(1-\tau_k)\alpha_e \cdot \frac{y_{t+1}}{k_{e,t+1}} + (1-d_e) \right), \tag{19}$$

$$\frac{c_{t+1}}{c_t} = \beta \left(q_{ip,t}(1-\tau_k)\alpha_{ip} \cdot \frac{y_{t+1}}{k_{ip,t+1}} + (1-d_{ip}) \right). \tag{20}$$

We solve the model by feeding in the exogenous paths of TFP, and observed investment prices as opposed to the balanced-growth path approach used by Greenwood et al. (1997).[12] Solving for an equilibrium path involves choosing a sequence of consumption, hours worked, and investment in structures, equipment, and IP products given the exogenous path of TFP, the price of investment in domestic equipment, the price of capital-goods imports, the price of investment in IP products, hours worked, the working age population, the initial stock of structures, equipment, IP products, 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 1975 and let it run to 2068. From 2017 to 2068, we assume that TFP, the relative price of domestic-equipment investment, the relative price of capital-goods imports, the relative price of IP products investment, hours worked, and the working-age population grow at constant rates equal to their average growth rates between 1975 and 2016.

2.4 Calibration and Estimation of the Model

Table 1 presents the calibrated parameter values. We use sample averages instead of the series to isolate the role of relative price changes in investment decisions. The sample averages for the physical depreciation rates of structures, equipment, and IP products are 0.025, 0.111, and 0.199, while the sample averages for the economic depreciation rates in equipment and IP products are 0.137 and 0.211. We assume that the number of weekly hours available for market work is 100. This implies that the ratio of hours worked to non-sleeping hours is 0.219. We compute an average

[12] Appendix C show some back-of-the-envelope calculations using Greenwood et al.'s (1997) balanced-growth path approach.

effective tax rate on labor of 0.251, an average effective tax rate on capital of 0.233, and an average capital share of income of 0.313, using the methodology suggested by Mendoza et al. (1994) and Gomme and Rupert (2007).

We assume that the long-run ratio of domestic-to-aggregate equipment investment has reached its steady-state level in the base year 2009, which also corresponds to the year when the expenditure shares stabilized (see Figure 1). Therefore, we set ϕ to 0.517. Since the price of aggregate investment in equipment (13) in the model is not of the Fisher chain-weighted form, the elasticity of substitution between domestic-equipment investment and capital-goods imports comes from the solution to

$$P = \min \left(p_{e,t} - \overline{p}_{e,t}(\rho)\right)' W \left(p_{e,t} - \overline{p}_{e,t}(\rho)\right), \tag{21}$$

where W is an identity matrix, $p_{e,t}$ is the Fisher chain-weighted price of aggregate investment in equipment from the data, and $\overline{p}_{e,t}(\rho)$ is the Fisher chain-weighted price of aggregate investment in equipment resulting from the optimal allocations of domestic-equipment investment (11) and capital-goods imports (12), with the corresponding prices taken from the data. Our estimate of ρ is 0.614, which implies an elasticity of substitution between domestic-equipment investment and capital-goods imports of 2.588. The Armington quantities and the resulting Fisher chain-weighted price of aggregate investment in equipment match the data extremely well (see Appendix D, Figure D1). This implies that if the model's investment decisions in aggregate equipment were identical to those observed in the data, the optimal allocations between domestic-equipment investment and capital-goods imports resulting from the Armington 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 five parameters. The estimated parameter values $\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip}$ are the solution to

$$M = \min \left(m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip})\right)' W \left(m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip})\right), \tag{22}$$

where m_t represents a vector of moments from the data, $\widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip})$ 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, equipment-per-hour, and IP products-per-hour ratios over the period 1975 to 2016. We chose these targets because they are the variables we use to perform our growth accounting exercise. Notice that part of the estimation involves calculating TFP given the income shares of structures, equipment, and IP products. We compute TFP as a residual using the production function (3). The stocks of structures, equipment, and IP products comes from the laws of motion (7), (8), and (9), using $k_{s,1975}$, $k_{e,1975}$, and $k_{ip,1975}$ as initial values.

The estimated parameter values are presented in Table 2. The discount factor is 0.955, which implies an average after-tax return on capital of 4.89 percent.[13] The household's share of utility received from consumption relative to the disutility from supplying labor is 0.276. Finally, the structures share of income is 0.138, the equipment share of income is 0.112, and the IP products share of income is 0.064.

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

Table 2: **Estimated Parameters**

Parameter	Description	Value
β	discount factor	0.955
θ	household's share of utility received from consumption	0.276
α_s	structures share in production	0.138
α_e	equipment share in production	0.112
α_{ip}	IP products share in production	0.064
	Wald Statistics, p-value	0.949

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

$$Q = T \cdot (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip}))' \, \widehat{V} \, (m_t - \widehat{m}_t(\beta, \theta, \alpha_s, \alpha_e, \alpha_{ip})) \to \chi^2_{163}, \tag{23}$$

where $\widehat{V}$ is the covariance matrix of the model's paths, and T (equal to 168) is the number of moments matched. With five parameters to estimate, the system is overidentified and the test statistic follows a chi-square distribution with 163 degrees of freedom. Q is equal to 134.70 with an associated cumulative probability value of 0.949. Therefore, we cannot reject the model at any conventional significance level. Appendix D provides additional checks and figures, confirming that the estimated model matches the salient features of the data fairly well, including the model's ability to match the targets above.

3 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 hour in the data and in the model. We also examine the contribution of capital-goods imports to the recent slowdown in aggregate equipment investment. Then, we perform two counterfactual experiments to illustrate the importance of capital-goods imports for the U.S. economy.

3.1 Growth Accounting

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

$$\left(\frac{y_t}{l_t}\right) = a_t \cdot \alpha_s \left(\frac{k_{s,t}}{l_t}\right) \cdot \alpha_e \left(\frac{k_{e,t}}{l_t}\right) \cdot \alpha_{ip} \left(\frac{k_{ip,t}}{l_t}\right). \tag{24}$$

Then, we take the natural logarithm of equation (24) and decompose output per hour into three additive factors,

Table 3: **Average Annual Contributions to Growth in U.S. Output per Hour**

	Data					Model				
		Previous 4 expansions					Previous 4 expansions			
	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016
Growth in TFP	0.15	0.30	0.07	0.21	0.45	0.15	0.34	0.07	0.21	0.46
Growth in structures	0.10	0.03	-0.08	0.14	0.14	0.11	0.03	0.05	0.10	0.14
Growth in equipment	0.48	0.34	0.64	0.43	0.27	0.49	0.48	0.72	0.50	0.28
Capital-goods imports	0.14	0.04	0.20	0.16	0.13	0.15	0.02	0.19	0.20	0.14
All other equipment	0.34	0.30	0.44	0.27	0.14	0.34	0.46	0.52	0.30	0.14
Growth in IP products	0.27	0.32	0.36	0.22	0.15	0.25	0.15	0.16	0.20	0.12
IP imports	0.01	0.00	0.01	0.01	0.01					
All other IP products	0.27	0.32	0.36	0.22	0.14					

Note: Table 3 displays the annual average contributions of TFP, structures, equipment, and IP products to growth in U.S. output per hour in the data (Data columns) and in the model economy (Model columns). In the data, the contributions of IP imports to growth in IP products are calculated as in (26). Expansions are from the output troughs to peaks. The deflator for IP imports is taken directly from the NIPA data (charges for the use of intellectual property). The deflator for all other investments in IP products is the implicit price deflator of the chain-weighted difference between aggregate IP products investment and IP imports.

$$\Delta \log \left(\frac{y_t}{l_t}\right) = \Delta \log a_t + \alpha_s \Delta \log \left(\frac{k_{s,t}}{l_t}\right) + \alpha_e \Delta \log \left(\frac{k_{e,t}}{l_t}\right) + \alpha_{ip} \Delta \log \left(\frac{k_{ip,t}}{l_t}\right). \quad (25)$$

This decomposition relates U.S. growth in output per hour to growth in TFP, and to growth in structures per hour, equipment per hour, and IP per hour. We use the real effective shares of capital-goods imports in aggregate investment to obtain the contribution of capital-goods imports to the growth in equipment per hour. We focus on the period $t-1$ shares because it takes one period for aggregate investment in equipment to materialize into stock. In other words, we are looking for the evolution in the accumulation of equipment attributable to capital-goods imports. Because of the properties of the Armington composite (10), this is equivalent to the amount of capital-goods imports that materializes into equipment stock at time t. Under this specification, the real effective shares of capital-goods imports in aggregate investment evolve according to

$$\frac{q_{m,t} i_{m,t}}{q_{i,d} i_{d,t}} = \frac{(1-\phi)}{\phi} \left(\frac{p_{d,t}}{p_{m,t}}\right)^{\frac{\rho}{(1-\rho)}}. \quad (26)$$

Table 3 shows the average annual contributions of TFP, structures per hour, equipment per hour, and IP products per hour to growth in U.S. output per hour in the data. On average, equipment per hour contributed 48 percent to growth in U.S. output per hour between 1975 and 2016, while the growth in structures per hour, and IP products per hour contributed 10 and 27 percent, respectively. The table also breaks down the equipment-per-hour contribution into capital-goods imports and all other equipment investments. This decomposition shows that capital-goods imports alone contributed 14 percent to growth in U.S. output per hour, while all other investment in equipment contributed 34 percent. This implies that capital-goods imports have explained about one-third of the average annual contribution of aggregate equipment investment to U.S. output-per-hour growth since 1975. Put differently, capital-goods imports increased the level of output per hour by 5.0 percent between 1975 and 2016. In terms of output gains, capital-goods imports added $830 million in current dollars ($730 million in 2009 dollars) to the level of output by 2016. Summing up the annual contributions of capital-goods imports to U.S. growth across time, the total payoff from capital-goods imports to U.S. output from 1975 to 2016 is $11.8 trillion in current dollars ($10.4 trillion in 2009 dollars). Clearly, capital-goods imports have generated significant output gains for the United States.

Table 3 decomposes the contribution of IP products per hour to growth in U.S. output per hour into IP imports and all other investments in IP products. This decomposition shows that almost none of the accumulation of IP products comes from IP imports (as reflected by the relative price for the use of foreign IP products). In fact, IP imports have contributed very little to the accumulation of IP products over the years, and consequently to the growth rate in U.S. output per hour. Our analysis below suggests that this is primarily because the measured productivity gains from all other investments in IP products (i.e., domestic-IP products investment) have been far greater than those of imported IP products (see also Figure D5 in Appendix D).

Table 3 also breaks down the average annual contribution of TFP, structures per hour, equipment per hour, and IP products per hour to growth in U.S. output per hour over the past four expansions. This breakdown shows that capital-goods imports have become an increasing source of growth in equipment per hour over time. The contribution of capital-goods imports to growth in equipment per hour increased from 12 percent to 50 percent between the period 1982–1991 and the current expansion. Consequently, capital-goods imports have become an increasing source of growth for the U.S. economy. In fact, capital-goods imports have accounted for somewhere between 13 to 20 percent to U.S. output-per-hour growth since the early 1990s. As we will see below, however, the recent decline in the annual average contribution of capital-goods imports to U.S. output-per-hour growth experienced since the early 2000s comes from a broader decline in the contribution of equipment to growth in U.S. output per hour.

Finally, Table 3 shows the average annual contribution of TFP, structures per hour, equipment per hour, and IP products per hour to growth in U.S. output per hour in our model. As for the results in the data, the table also breaks down the equipment-per-hour contribution into capital-goods imports and all other equipment investments (i.e., domestic-equipment investment). This breakdown shows that the contributions stemming from the model are similar to those in the data over the full sample period and over the past four expansions. Overall, we believe that the model's simple investment decisions coming from changes in relative prices capture well the behavior of capital-goods imports in aggregate investment in equipment, the behavior of the various factors of production, and their dynamics relative to U.S. output.

Explaining the recent slowdown in equipment investment

Non-residential investments, and particularly equipment investment, have been weak since the Great Recession. Panel A of Table 4 shows the average annual growth rates in real non-residential investments over the entire sample period, and over the previous four expansions. This panel confirms that equipment investment has been sluggish since the Great Recession, with an average annual growth rate in equipment investment of 2.2 percent, far below the full sample average of 4.7 percent. The average annual growth rates in structures and IP products investments have also been weaker. These declines in the growth rate of investment in structure, equipment, and IP products, however, appear to have started in the early 2000s. The economic literature provides a plethora of explanations for the decline in non-residential investment, including lower productivity gains, the ageing of the population, secular stagnation, and the long-lasting effects of the Great Recession. In this subsection, we specifically examine the contribution of capital-goods imports to the recent slowdown in aggregate equipment investment.

In our setup, a decline in equipment investment may come from a decline in the growth rate of TFP, a decline in the growth rate of investment-specific productivity in equipment, or from lower growth rates in complementary factors of productions (e.g., structures and IP products).[14] To understand the recent slowdown in equipment investment, Panel B of Table 4 shows the average annual growth rate in productivity measures (i.e., TFP and investment-specific productivity measures). This panel shows that the growth rate of TFP has increased lately. The growth rate of investment-specific productivity in equipment, however, has declined to 1.26 percent during the current expansion—far below the sample average of 2.89 percent. Overall, the table suggests that the decline in equipment investment mainly comes from two sources: first, a lack of investment in structures and IP products, which leads to a decline in the accumulation of the complementary factors of production (structures and IP products); and second, a decline in investment-specific productivity in equipment, which leads to a decline in equipment investment.

Table 4 also breaks down the average annual growth rates in equipment investment into capital-goods imports and all other equipment investments (Panel A), alongside a breakdown in the average annual growth rates of the corresponding productivity measures (Panel B). Panel B shows that while the growth rate in investment-specific productivity in capital-goods imports has slowed down, the growth rate in investment-specific productivity in all other equipment investments has turned negative (this can also be seen through the increase in the relative price of all other equipment investments shown in Figure 1). In line with our premise, this leads to a less pronounced slowdown in capital-goods imports than in all other equipment investment.

Finally, the bottom of Panel A shows the contribution of capital-goods imports to growth in equipment, using the growth rate of chain aggregates proposed by Ehemann et al. (2002) and Whelan (2002a). It confirms that capital-goods imports have been the main driver of equipment investment growth. The average contribution of capital-goods imports to growth in equipment investment has been 64.3 percent since 1975, and has increased from 23.7 percent to 96.6 percent between the 1982–1991 and the 2008–2016 expansions. In other words, almost all of the growth in the stock of U.S. equipment since 2008 came from capital-goods imports.[15] This increasing contribution of capital-goods imports in equipment investment arises for two reasons. First, the growth rate of investment-specific productivity in capital-goods imports has been significantly stronger than that of all other equipment investments. Second, the expenditure share of capital-goods imports in equipment investment has risen over the sample period. This is because capital-goods imports offer more equipment bang for the buck. Overall, our analysis suggests that capital-goods imports

[14]See the first-order conditions that determine the evolution in the stock of equipment, equation (19).

[15]Nevertheless, the expenditure shares in capital-goods imports appear to have stabilized since 2009. This is puzzling: the growth rate of investment-specific productivity in capital-goods imports has been significantly stronger than that of all other equipment investments. Consequently, the expenditure share of capital-goods imports in equipment investment should have risen as predicted by the model (see Appendix D, Figure D4). This phenomenon might be temporary, it might come from a protectionist environment that has emerged in the U.S. over the last few years, or it might be because foreigners are not producing the type of equipment that American firms need.

Table 4: **Average Annual Growth in Real Non-Residential Investments and in Productivity Measures**

A. Average annual growth in real non-residential investments, in percent

		Previous 4 expansions			
	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016
Structures investment	0.8	0.3	2.5	-0.2	-2.6
Equipment investment	4.7	4.5	7.6	2.8	2.2
Capital-goods imports	11.7	15.4	14.4	4.9	4.2
All other equipment investments	2.2	1.9	4.3	1.4	0.2
IP products investment	5.0	6.5	5.7	2.4	2.3
Average annual contribution to growth in equipment investment from					
Capital-goods imports	64.3	23.7	54.2	67.6	96.6
All other equipment investments	35.7	76.3	45.8	32.4	3.4

B. Average annual growth in productivity measures, in percent

		Previous 4 expansions			
	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016
TFP	0.12	0.28	0.05	0.24	0.49
Investment-specific productivity in equipment	2.89	3.08	4.48	3.84	1.26
Capital-goods imports	5.39	6.50	7.88	4.51	2.62
All other equipment investments	1.87	2.25	2.67	3.37	-0.09
Investment-specific productivity in IP products	1.48	1.54	1.41	2.50	0.78

Note: Table 4 displays the annual average growth in TFP, and investment-specific productivity in equipment and IP products. Investment-specific productivity measures are the inverse of the prices of investments relative to consumption as defined in the text.

played only a small role in the recent disappointing performance of aggregate equipment investment. Instead, the current weakness in equipment investment comes from a lack of investment-specific productivity growth in domestic equipment relative to previous expansions, and in the complementary factors of production. Our analysis also suggests that limiting trade in capital-goods imports could have adverse implications for U.S. output growth. This is what we investigate next.

3.2 Counterfactuals

In this subsection, we use our model economy to perform two counterfactual experiments, and illustrate the importance of capital-goods imports for the U.S. economy. First, we ask what U.S. output-per-hour growth would be without the capital-goods imports technology. Second, motivated by the current protectionist environment, we look at the economic impact of imposing a tariff on capital-goods imports.

U.S. output-per-hour growth without the capital-goods imports technology

What would the U.S. output-per-hour growth have been without the capital-goods imports technology? To answer this question, we assume that the U.S. would have had access to only the technology to produce domestic equipment. That is, we assume that the annual growth rate of investment-specific productivity in aggregate equipment investment would have followed the annual growth rate of investment-specific productivity in domestic-equipment investment. We perform this counterfactual by imposing that $\Delta log\ q_{e,t} = \Delta log\ q_{d,t}$, for $t > 1975$ starting with the same equilibrium conditions as in the baseline economy (i.e., $k_{s,1975}$, $k_{e,1975}$, and $k_{ip,1975}$).[16]

Table 5 shows the average annual growth rate in U.S. output per hour and average annual contributions to growth in U.S. output per hour from growth in TFP, structures per hour, equipment per hour, and IP products per hour when we impose that the annual growth rate of investment-specific productivity in aggregate-equipment investment follows that of domestic-equipment investment. Over the full sample period, the model predicts that the annual average growth in U.S. output per hour would have been 18 percent lower without the capital-goods import technology. The table also breaks down the average annual growth rate in U.S. output per hour, and the average annual contributions to growth in U.S. output per hour from growth in TFP, structures per hour, equipment per hour, and IP products per hour over the past four expansions. This breakdown shows that we could have expected a significant decline in U.S. output-per-hour growth across all four expansions without the capital-goods imports technology, and that the reduction in U.S. output-per-hour growth could have been especially severe during the 1991–2001 expansion.

Why is the decline in the growth rate of U.S. output per hour without the capital-goods imports technology greater than the contribution of capital-goods imports to the growth rate in U.S. output per hour over the sample period (14 percent versus -18 percent)? It is because the decline in the price of equipment investment would have been muted without access to the capital-goods imports technology. In turn, this would have implied a lower growth rate in the stock of equipment. With complementarity between the stock of structures, equipment, and IP products embedded in the production function (3), the growth rate in the stocks of structures and IP products would have been lower. Consequently, growth in U.S. output per hour would have been lower than the contribution of capital-goods imports to growth in U.S. output per hour over the sample period.[17]

Of course, the estimated losses in U.S. output-per-hour growth presented above do not take into account the partial reallocation of the capital-goods imports technology toward U.S. factors of production. Instead, we interpret these estimates as a lower bound on the potential losses of U.S. output-per-hour growth without trade in capital goods. To be clear, some of the growth driving investment-specific productivity in capital-goods imports could have been reallocated to U.S. equipment production, consequently boosting the U.S. output-per-hour growth relative to the scenario without the capital-goods imports technology: for example, the decline in the relative price of capital-goods imports coming from tangible technology improvement embedded in equipment (e.g., a new and more powerful computer chip). Some of the growth driving investment-specific productivity in capital-goods imports, however, would probably have been lost: for example, relative price decline coming from foreign management techniques (e.g., capital-goods imports from

[16] Simply imposing $q_{e,t} = q_{d,t}$ also modifies the initial level in the stock of equipment, as the initial stock of equipment, $k_{e,1975}$, is adjusted using the 1975 investment-specific productivity in equipment measure. This implies that the counterfactual would reflect not only changes in the annual growth rate of investment-specific productivity in equipment investment, but also change in the initial equilibrium conditions.

[17] In other words, more resources would have to be devoted to the accumulation of the stock of equipment, as the decline in the price of equipment investment would have been muted without access to the capital-goods imports technology. This would leave fewer resources to be devoted to the accumulation of the stocks of structures and IP products, and consequently lower growth in U.S. output per hour.

Table 5: **Average Annual Growth and Contributions to Growth in U.S. Output per Hour**, with and without the Capital-Goods Imports (CGM) Technology

	With CGM technology					**Without CGM technology**				
		Previous 4 expansions					Previous 4 expansions			
	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016	1975–2016	1982–1991	1991–2001	2001–2007	2008–2016
Growth in U.S. output per hour	0.76	0.84	0.71	1.18	1.08	0.62	0.73	0.46	1.02	0.94
Difference						-18%	-13%	-35%	-14%	-0.13
Average annual contribution to growth in U.S. output per hour from										
Growth in TFP	0.15	0.34	0.07	0.21	0.46	0.19	0.38	0.11	0.24	0.52
Growth in structures	0.11	0.03	0.05	0.10	0.14	0.12	0.04	0.06	0.05	0.16
Growth in equipment	0.49	0.48	0.72	0.50	0.28	0.40	0.41	0.60	0.50	0.18
Capital-goods imports	0.15	0.02	0.19	0.20	0.14					
All other equipment	0.34	0.46	0.52	0.30	0.14	0.40	0.41	0.60	0.50	0.18
Growth in IP products	0.25	0.15	0.16	0.20	0.12	0.30	0.17	0.23	0.21	0.13

Note: Table 5 displays the annual average growth rate of U.S. output per hour with and without the capital-goods imports technology predicted by the model. It also displays the contributions from TFP, structures, equipment, and IP products to growth in U.S. output per hour.

Japan in the 1980s) or from relatively inexpensive foreign labor supply (e.g., capital-goods imports from China since the 1990s).[18]

Impacts of a tariff on capital-goods imports

Finally, we look at the economic impact of imposing additional trade barriers to the import of capital goods for the U.S. economy.[19] As a starting point, we show the impact of imposing an additional 20 percent tariff on capital-goods imports starting in 2017.[20] The size of this tariff is reminiscent of The Tariff Act of 1930 (otherwise known as the Smoot-Hawley Tariff), which at its peak imposed an average 20 percent charge on imports.[21]

[18]Appendix A shows expenditure shares on capital-goods imports by country of origin since 1989. Today, China is the largest source of U.S. capital-goods imports (in part because of its low labor cost), while that title was owned by Japan in the 1980s (in part because of its novel management techniques).

[19]President Trump's administration has threatened punitive tariffs against a number of partners since its inauguration in January 2017. As well, a key economic-policy feature of President Trump's campaign was to cut corporate taxes. The proposed tax cut was to be combined with a border adjustment tax, which would make export sales deductible from the corporate tax base, while expenditure on imported goods would not be deductible, in contrast with other costs such as wage bills and purchases of domestic intermediates. Therefore, if the border adjustment extends to all imports and exports, it is akin to a combination of a uniform import tariff and an export subsidy on all international trade of the United States. Akin to the counterfactual with a tariff on capital-goods imports, this would introduce a wedge in equation (5), and would change the level of $p_{m,t}$ on impact, but not its growth rate.

[20]This is in addition to the actual tariffs, insurance, and transportation costs already included in the deflator for capital-goods imports. For example, US tariffs on manufactured products (including capital-goods imports) averaged 3.0 percent in 2015.

[21]Because our model displays balanced trade in capital goods, we are implicitly assuming that the value of U.S. capital-goods exports would decrease by the same amount as the value of capital-goods imports. This could be thought of as an act of retaliation by American trading partners, similar to the one experienced by the U.S. following The Tariff Act of 1930.

Table 6: **Average Annual Growth and Contributions to Growth in U.S. Output per Hour**, with (w/) and without (w/o) Tariff on Capital-Goods Imports: Extrapolation from 2017-2032

	Full sample trends		**2008–2016 trends**	
	w/o	w/ 20% tariff	w/o	w/ 20% tariff
Growth in U.S. output per hour, 2017–2032	0.80	0.67	0.55	0.43
Difference, in percent		-16%		-21%
Average annual contribution to growth in U.S. output per hour from				
Growth in TFP	0.14	0.17	0.21	0.27
Growth in structure	0.04	0.03	0.17	0.20
Growth in equipment	0.65	0.61	0.46	0.34
Capital-goods imports	0.55	0.49	0.37	0.28
All other equipment	0.10	0.12	0.08	0.06
Growth in IP products	0.16	0.19	0.16	0.19

Note: Table 6 displays the annual average growth rate of U.S. output per hour with and without a 20 percent tariff on capital-good imports predicted by the model. It also displays the contributions from TFP, structures, equipment, and IP products to growth in U.S. output per hour.

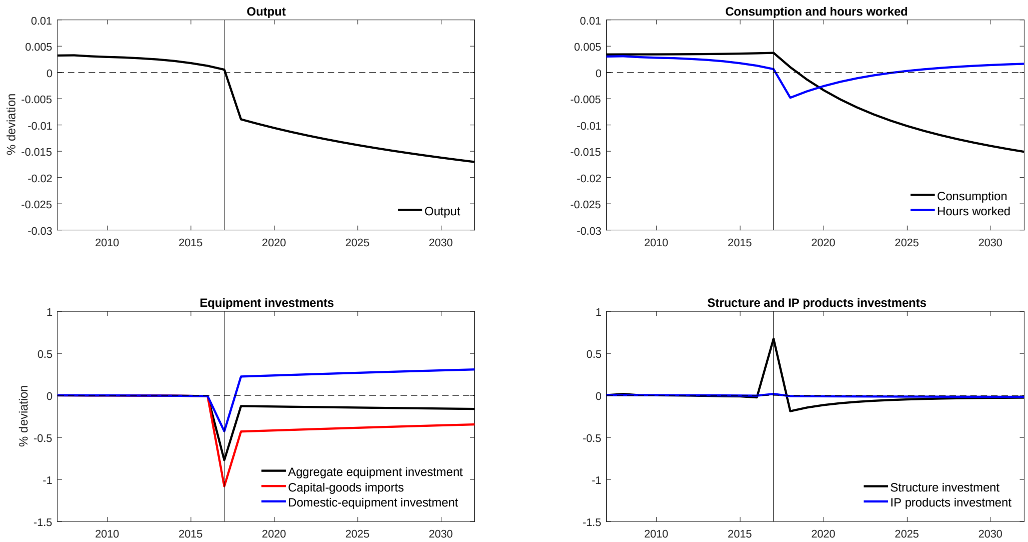
Table 6 shows the average annual growth in U.S. output per hour predicted by our model over the next 15 years, with and without a 20 percent tariff on capital-goods imports. The model predicts that growth in output per hour would drop by 16 percent by 2032, relative to the growth rate of output per hour without a tariff on capital-goods imports. Figure 3 complements Table 6 by showing the path of macroeconomic aggregates following the implementation of a 20 percent tariff in percentage deviation relative to the scenario without a tariff on capital-goods imports.[22] We display the macroeconomic dynamic up to 15 years after the implementation of the tariff because this is how long it takes for the macroeconomic aggregates to converge to the new balanced-growth path.

Here is what happens following the implementation of a 20 percent tariff on capital-goods imports: On impact, the tariff increases the price of capital-goods imports relative to domestic equipment. Consequently, agents reallocate equipment investment away from capital-goods imports toward domestic equipment. The tariff also immediately alters the relative price of investments. The increase in the price of capital-goods imports increases the price of equipment investment relative to the price of structures and IP products investments. In turn, agents reallocate investment away from equipment toward structures and IP products. Once these temporary adjustments following changes in relative prices are completed, structures, equipment, and IP products investments converge to their new balanced-growth paths. In the long run, the greater amount of resources needed to purchase investment goods reduces the accumulation of structures, equipment, and IP products, and ultimately output, hours worked, and consumption.

Figure 4 shows the evolution of the expenditure shares in equipment investment predicted by the model with and without the implementation of a 20 percent tariff on capital-goods im-

[22]We display the path of macroeconomic aggregates in level in Appendix D. The macroeconomic impacts following the implementation of a tariff on capital-goods imports starting on the balanced-growth path are similar to those starting from the 2016 equilibrium conditions. What matters the most for the short-run dynamics of the model is the relative price difference between capital-goods imports and domestic-equipment investment that exists when the tariff is implemented. Ultimately, the pervasive impact of a tariff on macroeconomic aggregates is larger when the relative price difference between capital-goods imports and domestic-equipment investment is larger.

Figure 3: **Dynamics of Macroeconomics Aggregates**



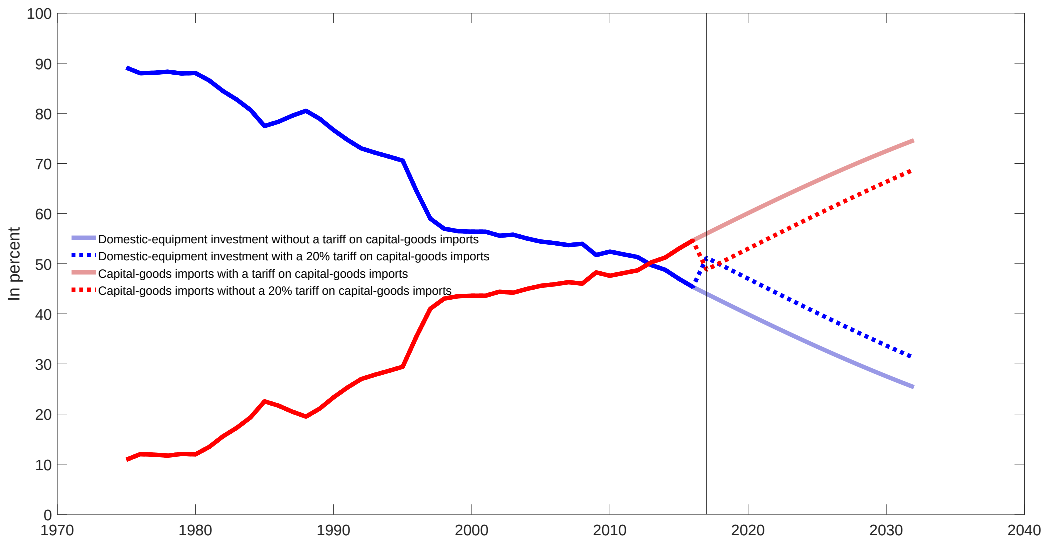
Note: Figure 3 shows the path of macroeconomic aggregates following the implementation of a 20 percent tariff on capital-goods imports in 2017, in percentage deviation relative to the scenario without a tariff on capital-goods imports.

ports in 2017. As discussed above, the implementation of an additional tariff on capital-goods imports leads to an immediate reallocation of equipment investment away from capital-goods imports toward domestic equipment. On impact, a 20 percent tariff leads to a reduction of about 7 percentage points in the expenditure share on capital-goods imports. The tariff, however, does not change the underlying trend: capital-goods imports would still account for a growing share of equipment investment, as long as the relative price of capital-goods imports declines faster than that of domestic-equipment investment. In this example, it takes only five years for the expenditure share on capital-goods imports to come back to its pre-tariff level. Overall, this suggests that imposing a tariff on capital-goods imports reallocates only equipment investment away from capital-goods imports toward domestic-equipment investment in the short run. In the long run, however, a tariff on capital-goods imports does not generate any tangible gains as it leads only to a reduction in the accumulation of structures, equipment, and IP products, and ultimately in U.S. output-per-hour growth.

We know from the previous subsection that the growth rate of investment-specific productivity in equipment has declined substantially over the last few years, far below its 1975 to 2016 average. Because of this slowdown, we also perform this counterfactual by extrapolating our productivity measures, hours worked, and the working age population using their growth rate averages between 2008 and 2016. The results are reported in Table 6. Under this scenario, the model predicts that growth in U.S. output per hour would drop by 21 percent by 2032, relative to the scenario without a tariff on capital-goods imports. This larger drop in output-per-hour growth highlights the economy's reliance on trade in capital goods in an era in which most of the productivity gains come from capital-goods imports.

Of note is that Figure 3 also shows the path of macroeconomic aggregates during the 10 years

Figure 4: **Expenditure Shares in Equipment Investment**



Note: Figure 4 shows the evolution of the expenditure shares in equipment investment predicted by the model with and without the implementation of a 20 percent tariff on capital-goods imports in 2017.

preceding the implementation of a 20 percent tariff. This is because, in our perfect foresight model, the macroeconomic dynamic associated with a tariff on capital-goods imports starts showing up about 10 years before its implementation. More specifically, the model predicts a reduction in investment, output, and hours worked in the years preceding the implementation of the tariff that is not negligible. This shows that the macroeconomic impacts of an anticipated tariff on capital-goods imports show up in macroeconomic aggregates long before its implementation. The macroeconomic dynamic arising before the implementation of an anticipated tariff (as seen in Figure 3) can be thought of as an upper bound for the reduction in investment, output, and hours worked generated by the uncertainty associated with the possibility that a tariff on capital goods may be implemented in the years to come.

4 Conclusion

Over the last four decades, the U.S. has gone through an enormous expansion in international trade and investment, generating large gains in U.S. output growth. In this paper, we show that the bulk of the gains in measured U.S. investment-specific productivity in equipment come from capital-goods imports, and that the relative price decline in capital-goods imports has been a driving force behind the increase in the stock of equipment, and U.S. output growth. To understand this phenomenon, we build a neoclassical growth model with trade in capital goods. In our model, agents face exogenous paths of TFP and investment-specific productivity in equipment and IP products. Investment-specific productivity in equipment is reflected by the relative price of capital-goods imports and that of domestic-equipment investment through an Armington aggregate. We find that the model allocation decisions coming from changes in relative prices explain well the dynamics of investment and U.S. output since 1975.

We use our model economy to perform two counterfactual experiments, and illustrate the importance of capital-goods imports for the U.S. economy. First, we ask what the U.S. output-per-hour growth would have been without the capital-goods imports technology. Our model predicts that the U.S. economy could have lost up to 18 percent in average annual growth in output per hour since 1975. Second, motivated by the current protectionist environment, we look at the economic impact of imposing a tariff on capital-goods imports. Extrapolating from observed trends in prices, population growth, and aggregate hours worked since 1975, our model predicts that imposing an additional 20 percent tariff on capital-goods imports could lead to a 16 percent reduction in U.S. output-per-hour growth over the next 15 years, with a significant drop in output and hours worked arising on impact.

Our analysis also suggests that capital-goods imports may be significant for short-run economic fluctuations. In closed-economy models, Greenwood et al. (2000), Fisher (2006), and Justiniano et al. (2010) attribute a large fraction of business cycle volatility to fluctuations in the price of equipment, while Justiniano and Primiceri (2008) show that most of the decline in business-cycle volatility observed since the 1980s is driven by the decline in the volatility of innovations to the relative price of investment in equipment. The fact that capital-goods imports contributed two-thirds of the growth of equipment-investment since 1975 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 (2005), and Broda and Weinstein (2006) suggest that the increase in the variety of imports is an important phenomenon to account for. The model considers only the intensive margin of trade in capital goods: it has one type of capital-goods imports which is a perfect substitute for investment in domestic equipment. A natural extension of the model would be to consider the benefit from the extensive margin of capital-goods imports to U.S. output growth.

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A Data

A.1 Measuring Investment-Specific Productivity

Related studies on the role of investment-specific productivity have often used Gordon's (1990) equipment prices series. For example, Hulten (1992) and Greenwood et al. (1997) measure the contribution of investment-specific productivity to U.S. growth using a two-sector model based on Gordon's (1990) prices series. Because this dataset covers only the postwar period until 1983, Hulten's (1992) analysis is limited to that period. Instead, Greenwood et al. (1997) extended Gordon's (1990) prices series 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 prices series 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.[23]

In contrast, Whelan (2002b) uses the official NIPA series to measure the contribution of equipment to U.S. output growth. In 2013, the BEA expanded its coverage of equipment and software into two separate categories—equipment and IP products—to better measure the effects of innovation and intangible assets on the economy. This change was meant to group expenditures on software with expenditures on research and development, and on entertainment, literary, and artistic originals, and to treat this aggregate as final investment goods. In addition, the BEA has implemented several revisions to its methodology in order to account for the rapid rate of innovation in equipment and IP products. Improved hedonic regression techniques and the implementation of the chain-weighted methodology by the BEA are intended to allow equipment and IP products aggregates to better track quality improvement over time. We acknowledge that accurate price measurements are central to our analysis. For our analysis, we choose to use the official NIPA data in part because of the recent classification and updates in the BEA methodology, and because computers, peripherals, and parts have become important drivers behind the growth of capital-goods imports and aggregate investment in equipment.

More recently, Justiniano et al. (2011) and Schmitt-Grohe and Uribe (2011) argued that the inverse of the relative price of equipment (and IP products) investment overstates the relative importance of investment-specific productivity at high-frequency or over the business cycle. As explained by Basu et al. (2013), the price of equipment investment responds slowly to change in investment-specific productivity, often taking up to three quarters for investment-specific shock to impact the price of equipment investment. For example, Wagner (2015) finds that over half of the volatility in the relative price of investment can be attributable to shifts in investment demand over the business cycle, with the rest attributable to investment-specific productivity. As Basu et al. (2013) argue, this could be due to sticky prices or change in relative demand for equipment investment relative to consumption over the business cycle. In this paper, our analysis focuses on growth, and on the low frequency of the data.

[23] In addition, a simple extrapolation of Cummins and Violante's (2002) method to capital-goods imports would be difficult. We would need Gordon's (1990) data on quality adjusted series for capital-goods imports, a classification that is not available in Gordon's study.

A.2 Description of the Data

We use annual data from 1975 to 2016 from the National Income and Product Accounts (NIPA) Tables of the Bureau of Economic Analysis (BEA), unless otherwise noted. We deflate all the nominal variables in our analysis with the implicit price deflator for consumption, defined as the ratio between nominal and real consumption. Real consumption is the chain-weighted sum of personal consumption expenditure on nondurables, non-housing services, and government consumption, while nominal consumption is the sum of the corresponding current-dollar measures for these series (using NIPA Tables 1.5.3–1.5.5). Final output is gross national product minus gross housing and business farm products (using NIPA Tables 1.3.3–1.3.5, and 1.7.3–1.7.5). Because trade occurs only in capital goods, we add net exports (excluding capital goods) to final output (using NIPA Tables 4.3.3–4.3.5). Aggregate real structures, equipment, and IP products investment are the chain-weighted sum of private and government non-residential fixed investment in structures, equipment, and IP products, while nominal structures, equipment, and IP products investment are the corresponding current-dollar series (using NIPA 5.3.3–5.5.5 and 3.9.3–3.9.5). The deflator for capital-goods imports is taken directly from the NIPA data, Table 4.2.4. It includes tariffs, insurance, and transportation costs. The deflator for all other investments in equipment is the implicit price deflator of the chain-weighted difference between aggregate equipment investment and capital-goods imports. The deflator for IP products investment is taken directly from the NIPA data, Table 5.3.4.

The initial current dollar value in the stocks of structures, equipment, and IP products are from the BEA Fixed Assets Tables. The depreciation rates are also taken from the BEA Fixed Assets Tables (Tables 1.1 and 1.3). The employment series is Total Aggregate Hours: Non-Farm Payrolls (SAAR) from the Bureau of Labor Statistics. The population series is the Resident Working Age Population: 15–64 Years from the Census Bureau.

A.3 U.S. Capital-Goods Imports, Composition and Origins

Figure A1 displays the nominal U.S. trade balance for all goods and services, capital-goods imports, and intellectual property products (defined as charges for the use of intellectual property), using NIPA Table 4.2.5. The figure shows that current-dollar trade in capital goods has been roughly balanced since 1975, averaging a surplus of $9.7 billion dollars.

Total non-residential equipment investment includes information processing equipment (which primarily includes computers and peripheral equipment, but also communication equipment, non-medical instruments, medical equipment and instruments, and office and accounting equipment), industrial equipment, transportation equipment, and other equipment (which consists primarily of furniture and fixtures, agricultural machinery, construction machinery, mining and oilfield machinery, service industry machinery, and electrical equipment not elsewhere classified).

Capital-goods imports include civilian aircraft, engines and parts, computers, peripherals and parts, and others. Figure A2 documents the capital-goods imports categories, along with their expenditure shares in capital-goods imports in 1978 and 2016 (SAAR, in current dollars). The data are from the BEA International Transaction Account Data, Expanded Details (Table 1.2 and Table IDS-008). The category capital-goods imports, as defined by the BEA, does not include the imports of automobiles, engines, and parts, or the imports of industrial supplies and material, which are both included in equipment investment. These two categories, however, have relatively little imports content, and their relative prices tend to follow those of aggregate equipment investment. Although the results do not change when we define capital-goods imports so as to include automotive, engines, and parts, and imports of industrial supplies and material, we prefer to use the term all other equipment investment instead of domestic-equipment investment when we discuss results coming from the data.

Figure A3 shows the expenditure shares of capital-goods imports by country of origin. Data on capital-goods imports by country of origin are from the U.S. International Trade Commission, for which each series is an aggregate of NAICS 333–336 (for aggregates before 1997) and SIC 35-37 (for aggregates after 1997). The BEA also publishes data on capital-goods imports (already aggregated as defined in NIPA Table 4.2) by countries of origin in International Transactions, Expanded Detail by Area and Country (Table 1.3) starting in 2003. The aggregated data from the U.S. International Trade Commission tend to follow the BEA series very closely.

A.4 Economic and Physical Depreciation Rates

Because of rapid quality improvements in equipment and IP products, 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 (1993), Gort and Wall (1998), and Whelan (2002b). 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 equipment evolves as

$$\delta_{e,t} = 1 - (1 - d_{e,t}) \frac{p_{e,t-1}}{p_{e,t}}, \tag{A.1}$$

$$\delta_{ip,t} = 1 - (1 - d_{ip,t}) \frac{p_{ip,t-1}}{p_{ip,t}}, \tag{A.2}$$

where $\delta_{e,t}$ and $d_{e,t}$ are physical and economic depreciation rates in equipment, and $\delta_{ip,t}$ and $d_{ip,t}$ are physical and economic depreciation rates in IP products. We compute the economic depreciation rate for structures by dividing the depreciation rate of structures in year t by the stock of structures in year $t-1$, using the BEA Fixed Assets Tables (Tables 1.1 and 1.3). We compute the economic depreciation rates for equipment and IP products similarly. Economic depreciation rates are measured using current-dollar series. Figure A4 displays the physical and economic depreciation rates as well as the average physical depreciation rates of structures, equipment, and IP products.

Figure A1: **Nominal Trade Balances**

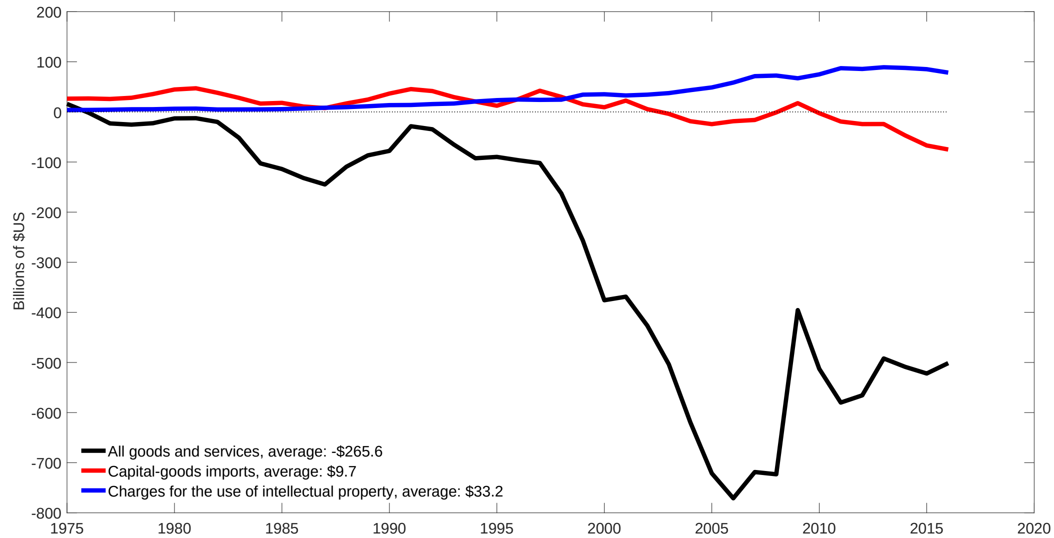
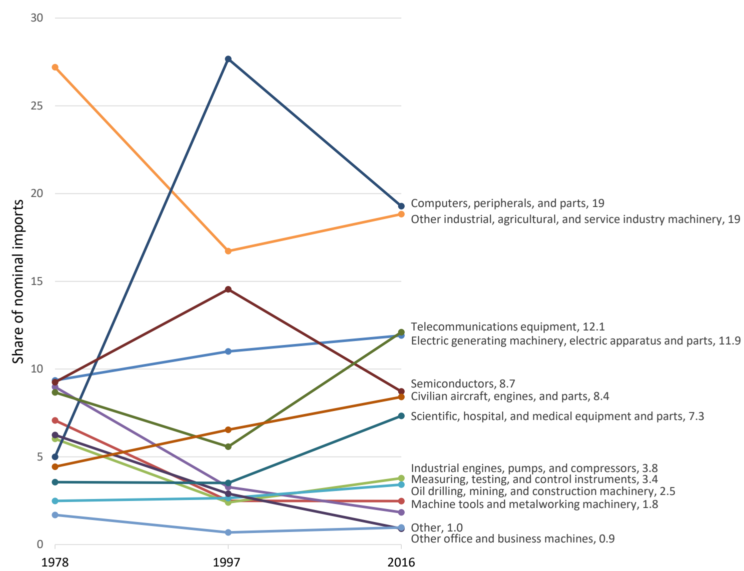
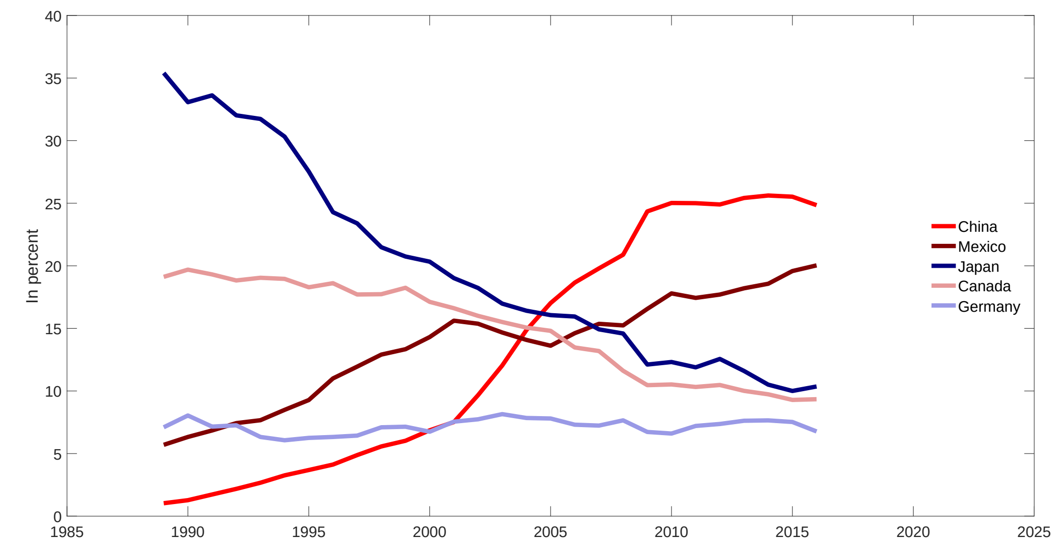


Figure A2: **Capital-Goods Imports Categories**



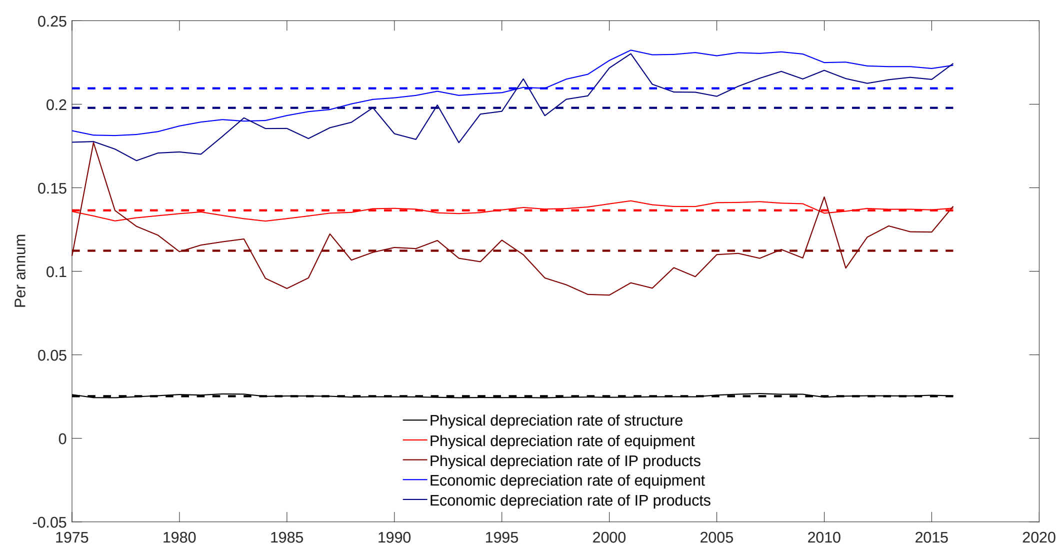
Note: Fraction of nominal imports (SAAR).

Figure A3: **Expenditure Shares of Capital-Goods Imports**, by Country of Origin



Note: Fraction of nominal imports (SAAR).

Figure A4: **Physical and Economic Depreciation Rates**



Note: Dashed lines are depreciation rates averages.

B The Competitive Equilibrium

In the equations below, we add the time subscript t to the depreciation rates to derive our first order conditions, as the physical depreciation rates in equipment and IP products are determined by the evolution in their relative prices. A competitive equilibrium is a set of prices $p_{e,t}, p_{ip,t}, w_t, r_{s,t}, r_{e,t}, r_{ip,t}$, and allocations $c_t, l_t, i_{s,t}, i_{e,t}$, $i_{ip,t}$ for the representative household, and $l_t, k_{s,t}, k_{e,t}, k_{ip,t}$ for the firm such that: (i) given prices, the allocation $c_t, l_t, i_{s,t}, i_{e,t}, i_{ip,t}$ maximizes the representative household's utility, (ii) given prices, the allocation $l_t, k_{s,t}, k_{e,t}, k_{ip,t}$ maximizes firm's profit, and (iii) the resource constraint is satisfied.

(i) The household makes consumption, labor, and investment in structures, equipment, and IP products decisions to maximize utility,

$$u(c_t, l_t) = \theta log c_t + (1-\theta) log(1-l_t), 0 < \theta < 1, \tag{B.1}$$

given the budget constraint, the law of motions for the stock of structures, equipment, and IP products, the initial capital stocks, and the non-negativity constraints,

$$c_t + i_{s,t} + i_{e,t} + i_{ip,t} \leq (1-\tau_l)w_t l_t + (1-\tau_k)(r_{s,t}k_{s,t} + r_{e,t}k_{e,t} + r_{ip,t}k_{ip,t}) + g_t, \tag{B.2}$$

$$k_{s,t+1} = i_{s,t} + (1-\delta_{s,t})k_{s,t}, \tag{B.3}$$

$$k_{e,t+1} = q_{e,t} i_{e,t} + (1-\delta_{e,t})k_{e,t}, \tag{B.4}$$

$$k_{ip,t+1} = q_{ip,t} i_{ip,t} + (1-\delta_{ip,t})k_{ip,t}, \tag{B.5}$$

$$c_t, l_t, k_{s,t}, k_{e,t}, k_{ip,t} \geq 0, l_t \leq 1, \tag{B.6}$$

$$k_{s,T_0}, k_{e,T_0}, k_{ip,T_0} \geq 0, \tag{B.7}$$

where $q_{e,t} = 1/p_{e,t}$, and $q_{ip,t} = 1/p_{ip,t}$. Note that these equations are normalized so that both output and investment are measured in units of consumption. Substituting (B.3), (B.4), (B.5) into (B.2), the maximization problem can be represented by the following Lagrangian:

$$L = \max_{c_t, l_t, k_{s,t+1}, k_{e,t+1}, k_{ip,t+1}} \sum_{t=0}^{\infty} \beta^i \left[\theta \log c_t + (1-\theta)\log(1-l_t)\right] + \tag{B.8}$$

$$\sum_{t=0}^{\infty} \beta^i \lambda_{t+i} \left[\begin{array}{l} (1-\tau_l)w_t l_t + (1-\tau_k)(r_{s,t}k_{s,t} + r_{e,t}k_{e,t} + r_{ip,t}k_{ip,t}) + \\ (1-\delta_{s,t})k_{s,t} + (1-\delta_{e,t})\frac{k_{e,t}}{q_{e,t}} + (1-\delta_{ip,t})\frac{k_{ip,t}}{q_{ip,t}} + \\ g_t - c_t - k_{s,t+1} - \frac{k_{e,t+1}}{q_{e,t}} - \frac{k_{ip,t+1}}{q_{ip,t}} \end{array} \right].$$

The first order conditions are

$$c_t : \frac{\theta}{c_t} - \lambda_t = 0 \tag{B.9}$$
$$: c_t = \frac{\theta}{\lambda_t},$$

$$l_t : \frac{(1-\theta)}{(1-l_t)} + \lambda_t(1-\tau_l)w_t = 0 \tag{B.10}$$
$$: \frac{(1-\theta)}{\theta}c_t = w_t(1-\tau_l)(1-l_t),$$

$$k_{s,t+1} : -\lambda_t + \beta\lambda_{t+1}\left((1-\tau_k)r_{s,t+1} + (1-\delta_{s,t+1})\right) = 0 \tag{B.11}$$
$$: \frac{\lambda_t}{\beta\lambda_{t+1}} = (1-\tau_k)r_{s,t+1} + (1-\delta_{s,t+1})$$
$$: \frac{c_{t+1}}{\beta c_t} = (1-\tau_k)r_{s,t+1} + (1-\delta_{s,t+1}),$$

$$k_{e,t+1} : -\lambda_t \cdot \frac{1}{q_{e,t}} + \beta\lambda_{t+1}\left((1-\tau_k)r_{e,t+1} + (1-\delta_{e,t+1})\frac{1}{q_{e,t+1}}\right) = 0 \tag{B.12}$$
$$: \frac{\lambda_t}{\beta\lambda_{t+1}} = q_{e,t}\left((1-\tau_k)r_{e,t+1} + (1-\delta_{e,t+1})\frac{1}{q_{e,t+1}}\right)$$
$$: \frac{c_{t+1}}{\beta c_t} = q_{e,t}(1-\tau_k)r_{e,t+1} + \frac{q_{e,t}}{q_{e,t+1}}(1-\delta_{e,t+1}),$$

$$k_{ip,t+1} : -\lambda_t \cdot \frac{1}{q_{ip,t}} + \beta\lambda_{t+1}\left((1-\tau_k)r_{ip,t+1} + (1-\delta_{ip,t+1})\frac{1}{q_{ip,t+1}}\right) = 0 \tag{B.13}$$
$$: \frac{\lambda_t}{\beta\lambda_{t+1}} = q_{ip,t}\left((1-\tau_k)r_{ip,t+1} + (1-\delta_{ip,t+1})\frac{1}{q_{ip,t+1}}\right)$$
$$: \frac{c_{t+1}}{\beta c_t} = q_{ip,t}(1-\tau_k)r_{ip,t+1} + \frac{q_{ip,t}}{q_{ip,t+1}}(1-\delta_{ip,t+1}).$$

(ii) The firm maximizes profit by optimally choosing the amount of labor and capital needed given its production technology,

$$\max_{l_t,k_{s,t},k_{e,t},k_{ip,t}} \pi_t = a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip}} l_t^{1-\alpha_s-\alpha_e-\alpha_{ip}} - w_t l_t - r_{s,t}k_{s,t} + r_{e,t}k_{e,t} + r_{ip,t}k_{ip,t}. \tag{B.14}$$

The first order conditions are

$$l_t : w_t = (1-\alpha_s-\alpha_e-\alpha_{ip,t}) \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip}} l_t^{-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{B.15}$$

$$k_{s,t} : r_{s,t} = \alpha_s \cdot a_t k_{s,t}^{\alpha_s - 1} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip}} l_t^{1-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{B.16}$$

$$k_{e,t} : r_{e,t} = \alpha_e \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e - 1} k_{ip,t}^{\alpha_{ip}} l_t^{1-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{B.17}$$

$$k_{ip,t} : r_{ip,t} = \alpha_{ip} \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip} - 1} l_t^{1-\alpha_s-\alpha_e-\alpha_{ip}}. \tag{B.18}$$

(iii) The resource constraint,

$$y_t = c_t + i_{s,t} + i_{e,t} + i_{ip,t}, \tag{B.19}$$

is satisfied.

Combining the household's optimality conditions, 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 equation that determines the amount of hours worked,

$$\frac{(1-\theta)}{\theta} c_t = (1-\tau_l)(1-l_t)(1-\alpha_s-\alpha_e-\alpha_{ip,t}) \cdot a_t k_{s,t}^{\alpha_s} k_{e,t}^{\alpha_e} k_{ip,t}^{\alpha_{ip}} l_t^{-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{B.20}$$

and three intertemporal equations that determine the evolution of the stock of structures, equipment, and IP products,

$$\frac{c_{t+1}}{c_t} = \beta \left((1-\tau_k)\alpha_s \cdot a_{t+1} k_{s,t+1}^{\alpha_s - 1} k_{e,t+1}^{\alpha_e} k_{ip,t+1}^{\alpha_{ip}} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + (1-\delta_{s,t+1}) \right), \tag{B.21}$$

$$\begin{aligned} \frac{c_{t+1}}{c_t} &= \beta \left(q_{e,t}(1-\tau_k)\alpha_e \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e - 1} k_{ip,t+1}^{\alpha_{ip}} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + \frac{q_{e,t}}{q_{e,t+1}}(1-\delta_{e,t+1}) \right) \\ &= \beta \left(q_{e,t}(1-\tau_k)\alpha_e \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e - 1} k_{ip,t+1}^{\alpha_{ip}} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + \frac{q_{e,t}}{q_{e,t+1}} \frac{q_{e,t+1}}{q_{e,t}}(1-d_{e,t+1}) \right) \\ &= \beta \left(q_{e,t}(1-\tau_k)\alpha_e \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e - 1} k_{ip,t+1}^{\alpha_{ip}} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + (1-d_{e,t+1}) \right), \end{aligned} \tag{B.22}$$

$$\begin{aligned} \frac{c_{t+1}}{c_t} &= \beta \left(q_{ip,t}(1-\tau_k)\alpha_{ip} \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e} k_{ip,t+1}^{\alpha_{ip} - 1} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + \frac{q_{ip,t}}{q_{ip,t+1}}(1-\delta_{ip,t+1}) \right) \\ &= \beta \left(q_{ip,t}(1-\tau_k)\alpha_{ip} \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e} k_{ip,t+1}^{\alpha_{ip} - 1} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + \frac{q_{ip,t}}{q_{ip,t+1}} \frac{q_{ip,t+1}}{q_{ip,t}}(1-d_{ip,t+1}) \right) \\ &= \beta \left(q_{ip,t}(1-\tau_k)\alpha_{ip} \cdot a_{t+1} k_{s,t+1}^{\alpha_s} k_{e,t+1}^{\alpha_e} k_{ip,t+1}^{\alpha_{ip} - 1} l_{t+1}^{1-\alpha_s-\alpha_e-\alpha_{ip}} + (1-d_{ip,t+1}) \right). \end{aligned} \tag{B.23}$$

Note that we have substituted (15) and (16) into (B.26) and (B.27). When we simplify, and take averages of the depreciation rates over time, the system of equations becomes

$$\frac{(1-\theta)}{\theta}c_t = (1-\tau_l)(1-l_t)(1-\alpha_s-\alpha_e-\alpha_{ip,t})\cdot\frac{y_t}{l_t}, \tag{B.24}$$

$$\frac{c_{t+1}}{c_t} = \beta\left((1-\tau_k)\alpha_s\cdot\frac{y_{t+1}}{k_{s,t+1}} + (1-\delta_s)\right), \tag{B.25}$$

$$\frac{c_{t+1}}{c_t} = \beta\left(q_{e,t}(1-\tau_k)\alpha_e\cdot\frac{y_{t+1}}{k_{e,t+1}} + (1-d_e)\right), \tag{B.26}$$

$$\frac{c_{t+1}}{c_t} = \beta\left(q_{ip,t}(1-\tau_k)\alpha_{ip}\cdot\frac{y_{t+1}}{k_{ip,t+1}} + (1-d_{ip})\right). \tag{B.27}$$

These are the four equations that we use to solve the model, and the paper's equations (17) to (20).

C Back-of-the-Envelope Calculations

In this appendix, we follow the balanced-growth path approach of Greenwood et al. (1997) as a back-of-the-envelope calculation to gauge the contribution of equipment, capital-goods imports, and IP products to the growth in U.S. output per hour presented in Section 3.1.

First, on the balanced-growth path, the growth rate in output per hour is determined from the production function 3 such that

$$g = \gamma_a^{1/(1-\alpha_s-\alpha_e-\alpha_{ip}} \gamma_e^{\alpha_e/(1-\alpha_s-\alpha_e-\alpha_{ip}} \gamma_{ip}^{\alpha_{ip}/(1-\alpha_s-\alpha_e-\alpha_{ip}}, \tag{C.1}$$

where γ_a is the annual average growth rate of TFP, γ_e is the annual average growth rate of investment-specific productivity in equipment, and $\gamma_i p$ is the annual average growth rate of investment-specific productivity in IP products. With $\gamma_a = 1.0012$, $\gamma_e = 1.0289$, and $\gamma_{ip} = 1.0148$, the model predicts that the average growth rate in U.S. output per hour was 0.78 percent between 1975 and 2016. This growth rate compares fairly well with the NIPA data that indicate that between 1975 and 2016, the average growth rate in U.S. output per hour was 0.80.

Then, we simply shut off some of the growth channel to determine the contribution of investment-specific productivity in equipment, capital-goods imports, and IP products. With only investment-specific productivity in equipment (i.e., $\gamma_a = 1$ and $\gamma_i p = 1$), the average growth rate in U.S. output per hour would have been 0.47 percent. This implies that investment-specific productivity in equipment has contributed about 60 percent (0.47/0.78) to growth in U.S. output per hour between 1975 and 2016. Without investment-specific productivity in capital-goods imports, investment-specific productivity in equipment would have followed the average annual growth in investment-specific productivity in all other equipment investment (i.e., $\gamma_e = 1.0187$), and the average growth rate in U.S. output per hour would have been 0.62 percent. This implies that investment-specific productivity embodied in capital-goods imports has contributed about 21 percent ((1-0.62)/0.78) to growth in U.S. output per hour between 1975 and 2016. These contributions in investment-specific productivity in equipment and capital-goods imports to growth in U.S. output per hour are somewhat larger than what we found in Section 3. This is primarily because the balanced-growth path methodology does not take appropriate account of the time-series changes in investment-specific productivity in equipment (i.e., the balanced-growth path uses sample average growth rate) or time-series changes in the expenditure share of capital-goods imports in equipment investment.

Finally, with only investment-specific productivity in IP products (i.e., $\gamma_a = 1$ and $\gamma_e = 1$), the average growth rate in U.S. output per hour would have been 0.14 percent. This implies that investment-specific productivity in IP products has contributed about 18 percent (0.14/0.78) to growth in U.S. output per hour between 1975 and 2016.

D Empirical Analysis

This appendix provides additional checks and figures, confirming that the estimated model does a good job of matching the salient features of the data. It also depicts our productivity measures across the sample period, and shows the dynamic response on macroeconomic aggregates in level following the implementation of a tariff on capital-goods imports.

Figure D1 shows that the Armington quantities and the resulting Fisher chain-weighted price of aggregate equipment investment match well the data published by the BEA. This suggests the optimal allocations between domestic-equipment investment and capital-goods imports resulting from the Armington aggregate are a good approximation of actual investment decisions.

Figures D2 to D4 show the dynamics of our macroeconomic variables of interest over the sample period in the model and in the data. Figure D2 shows estimation targets: the path output, structures, equipment, and IP product per hour. This figure confirms that the model fits the targets reasonably well. Figure D3 shows the price and quantity dynamics in equipment investment. The figure shows that the model's relative price of aggregate investment in equipment matches the data very well. It also shows that the model's evolution in the stock of equipment matches fairly well that observed in the data. Finally, Figure D4 shows that the model's expenditure shares in equipment investment closely follow those observed in the data. Overall, the estimated model, with investment decisions coming from change in relative prices, matches the salient features of the data fairly well.

Figure D5 shows our measures of total-factor productivity and investment-specific productivity. The upper panel shows that total-factor productivity displays steady growth throughout the sample periods, with large drops during the recessions of 1982, 1991, 2001, and 2008. The middle panel compares measures of investment-specific productivity in equipment. It shows stellar growth in investment-specific productivity in equipment investment compared with that of total-factor productivity (and of investment-specific productivity in IP products displayed in the lower panel). It also shows the enormous gains in investment-specific productivity in capital-goods imports compared with that in domestic-equipment investment. Finally, the lower panel compares measures of investment-specific productivity in IP products. It shows that the gains in investment-specific productivity in IP products have mainly come from the domestic economy and not from abroad.

Finally, Figure D6 shows the dynamic response on macroeconomic aggregates in level following the implementation of an additional tariff on capital-goods imports.

Figure D1: **Equipment Investment Quantities and Prices**: Data versus Armington

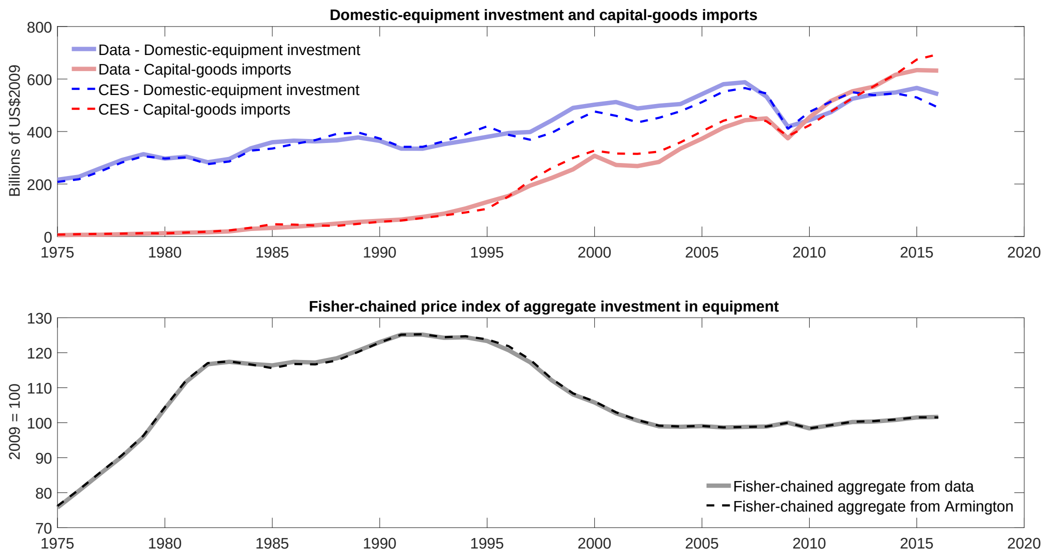


Figure D2: **Estimation Targets**: Data versus Model

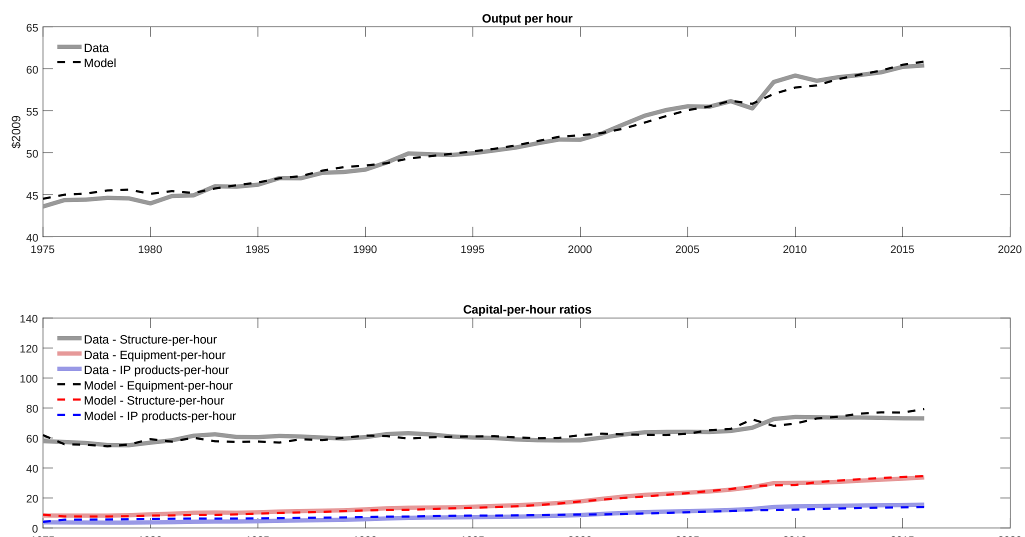


Figure D3: **Price and Quantity Dynamics in Equipment Investment**: Data versus Model

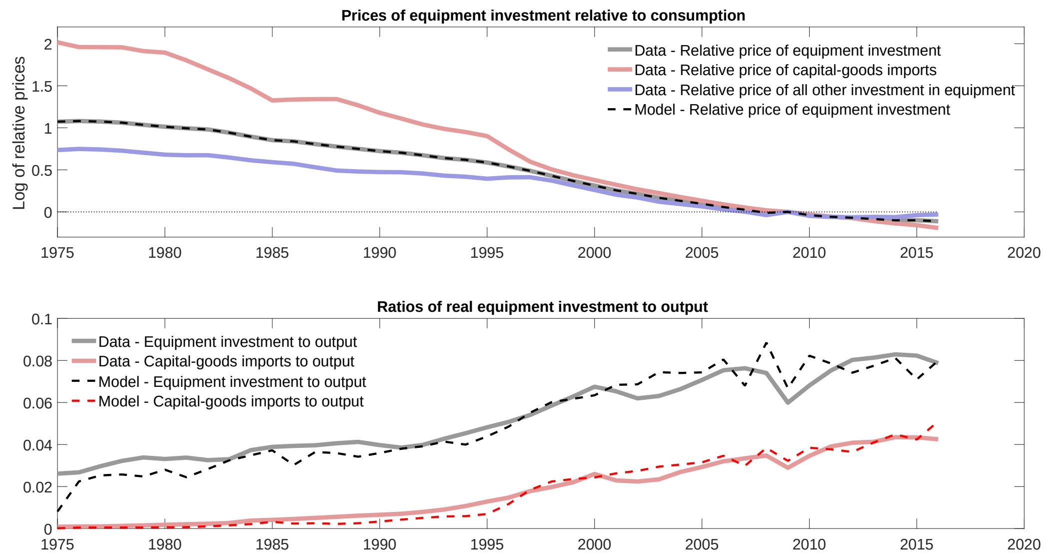


Figure D4: **Expenditure Shares in Equipment Investment**: Data versus Model

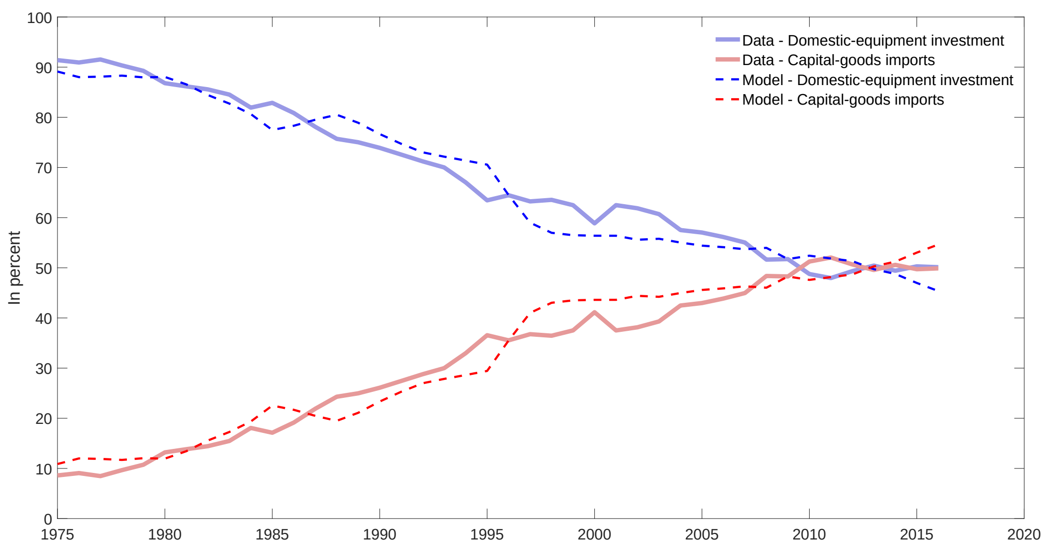


Figure D5: **Productivity Measures**

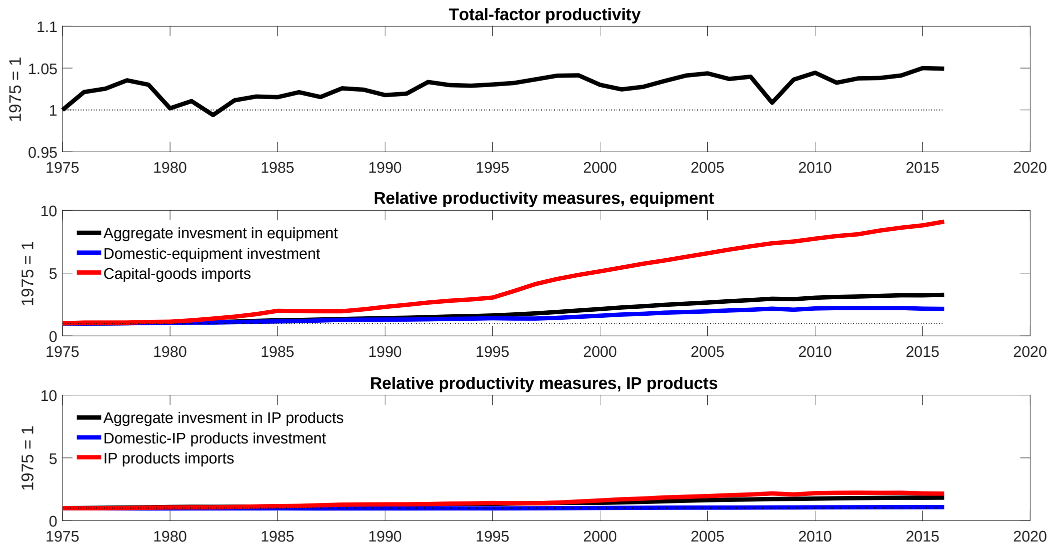


Figure D6: **Dynamics of Macroeconomics Aggregates**, in Level (2017=1)