Investment-Specific and Multi-Factor Productivity in Multi-Sector Open Economies: Data and Analysis

Luca Guerrieri, Dale W. Henderson, and Jinill Kim

In the second half of the 1990s, labor productivity growth rose in the United States and declined in most parts of Europe. This paper documents changes in capital deepening and multi-factor productivity (*MFP*) growth in information and communication technology (*ICT*) and non-*ICT* sectors. We consider *MFP* growth in the *ICT* sector as investment-specific productivity (*ISP*) growth. We perform simulations suggested by the data by adopting a two-country dynamic general equilibrium model with traded and nontraded goods. For *ISP*, we consider level increases and persistent growth rate increases that are symmetric across countries and allow for costs of adjusting capital-labor ratios that are considerably high in one country because of structural differences. Investment-specific productivity increases generated investment booms unless adjustment costs are excessively high. For *MFP*, we consider persistent growth rate shocks that are asymmetric. When these *MFP* shocks affect only traded goods (as commonly assumed), movements

Luca Guerrieri, Federal Reserve Board, (e-mail): luca.guerrieri@frb.gov; Dale Henderson, Center for Applied Macroeconomic Analysis, (e-mail): dale.henderson@rcn.com; Jinill Kim (corresponding author), Korea University, (e-mail): JINILLKIM@korea.ac.kr, respectively.

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in "international" variables are qualitatively similar to those in the data. However, when such shocks also affect nontraded goods (as suggested by the data), movements in some of the variables are not qualitatively similar to those in the data. For the acquisition of plausible results for the growth rate shocks, slow recognition needs to be taken into account.

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JEL Classification: D83, F43, O41

I. Introduction

Changes in labor productivity growth in the United States and Europe are among the major economic events in the 1990s and early 2000s. Scholars generally agree that in the second half of the 1990s, labor productivity growth rose in the United States and declined in most parts of Europe. In the first half of the 1990s, labor productivity growth in the U.S. was significantly below that in European countries. However, in the second half of the 1990s, the situation reversed in almost every case. Recently, several analysts have provided breakdowns of changes in labor productivity growth by country, by component, and by sector.[1]

The data provide some generalizations. In both the United States and Europe, multi-factor productivity (*MFP*) growth in the information and communication technology (*ICT*) sector increased. Surprisingly, these increases were the same or even considerably great in Europe. Consequently, the relative prices of *ICT* goods decreased substantially.[2] At least partly for this reason, capital deepening through investment in *ICT* goods increased in the United States and Europe. However, the increase was approximately twice as high in the United States.

[1] Most of our data come from three sources: the Groningen Growth and Development Center (GGDC), Dale Jorgenson and his associates, and the Organization for Economic Cooperation and Development (OECD).

[2] In particular, the relative price of investment goods declined more rapidly in the second half of the 1990s.

We consider *MFP* growth in the *ICT* sector as investment-specific productivity (*ISP*) growth, which is a convention adopted by several other scholars.[3]

Multi-factor productivity growth in the non-*ICT*-producing sector significantly increased in the United States and by comparable amounts in some European countries but declined by more than double these amounts in other European countries. Capital deepening through investment in non-*ICT* goods increased markedly in the United States but decreased in Europe. Increases in labor productivity and *MFP* growths have been substantially high in the United States in critical sectors that produce mostly nontraded goods.

The changes in relative productivity growth rates in the second half of the 1990s were accompanied by some dramatic changes in other variables. In the United States, an investment boom, a deterioration in the trade account, a temporary improvement in terms of trade (*TOT*), and a significant real appreciation of the dollar occurred.

In an attempt to provide perspective on the data, we perform simulations using a dynamic general equilibrium (*DGE*) model with two countries (Home and Foreign).[4] Each country produces a traded good and a nontraded good, and the two traded goods are imperfect substitutes for each other.[5] In each country, consumption and investment goods are aggregates assembled using the two traded goods and the local nontraded good. The baskets of traded goods used in consumption and investment are biased toward the locally produced

[3] See, for example, Greenwood *et al.* (1997). Generally, this shock should be regarded as a shock to the marginal efficiency of investment, as in Guerrieri *et al.* (2014).

[4] Pioneering contributions to the analysis of productivity shocks in open-economy dynamic general equilibrium (*DGE*) models include those of Backus *et al.* (1994a, 1994b), Stockman, and Tesar (1995), Baxter, and Crucini (1995), and Kollmann (1998). Recent contributions include those of Erceg *et al.* (2002), Laxton, and Pesenti (2003), and Hunt, and Rebucci (2003). Closed-economy contributions include those of Edge *et al.* (2003, 2004).

[5] Nontraded goods are a large fraction of output in the U.S. and Europe. The increasingly unsatisfactory convention of identifying goods as traded and services as nontraded leads to the conclusion that approximately 75% of output is nontraded. Taking account of the familiar argument that some services are traded, the authors of the current work assume that nontraded goods constitute 63% of consumption and 52% investment. These figures are in the middle of the wide range of assumptions in the literature.

goods, but the "local bias" in consumption is substantially great. The model nests most of the two-country *DGE* models employed over the past fifteen years to analyze productivity changes.

Our reading of the disparate productivity growth experiences of the United States and Europe has determined our choice of simulation experiments. The present paper focuses primarily on two persistent productivity growth shocks. The first one is a symmetric *ISP* growth shock. This shock has different effects on the two countries, because one of these countries has less structural rigidity, as reflected in the substantially low costs of adjusting capital–labor (*K*–*L*) ratios. The second one is an *MFP* growth shock that is (perfectly) asymmetric across countries. Deviating from most of the previous analysis, the present paper emphasizes the case in which the shock affects the traded-goods and nontraded-goods sectors. To take account of the slow adjustment of consumption and slow recognition of persistent growth shocks, we incorporate consumption habits and learning about shocks. To organize concepts, we consider symmetric *ISP* level shocks before discussing the two growth shocks.

We calibrate the symmetric *ISP* growth shock to ensure that this shock causes an increase in the decline rate of the relative price of investment that closely matches the one in U.S. data. In countries with low *K*–*L* adjustment costs, the investment incentive of the shock is relative to the wealth effect. Consequently, an investment boom, a reduction in consumption for several periods, and a modest trade deficit occurred. By contrast, in countries with high *K*–*L* adjustment costs, the wealth effect dominates: investment increases minimally, but consumption rises significantly. The movements in the *TOT* and the real exchange rate (*RER*) are qualitatively different from those in the data.

We calibrate the asymmetric *MFP* growth shock to ensure that for the country receiving the increase, the initial rise in labor productivity growth is the same as for the symmetric *ISP* shock. With *MFP* shocks, the wealth effect is relative to the investment incentive. For positive shocks, both consumption and investment rise, and a sizeable trade deficit occurs. The large wealth effect combined with locally produced good bias keeps the *TOT* from deteriorating for a while because the demand for the locally traded good increases by as much as the supply.

The succeeding sections will present data relevant for analyzing productivity shocks in the United States and Europe, as well as the model, simulations, and conclusions of this study.

II. Data

A. Accounting for Changes in Labor Productivity Growth

Considerable progress has been made in accounting for changes in labor productivity growth in the United States and Europe in the 1990s.[6] Separating the contributions of capital deepening and *MFP* growth for the economy as a whole and for individual sectors is a challenging task.[7] Data revisions and improvements in methodology continue to have significant effects on conclusions.[8]

The current study focuses primarily on data from three sources: (1) the Groningen Growth and Development Center (GGDC), (2) Dale Jorgenson and associates, and (3) the Organization for Economic Cooperation and Development (OECD) Standard Analysis database.[9] Data from all of the three sources have at least three desirable features: (1) they are reported on a standardized basis across several countries, (2) they include estimates of hours instead of only the number of employees for all countries, and (3) they include estimates of real investment that are quality adjusted using the same methodology.[10]

[6] The current study does not attempt to explain why labor productivity growth was higher in Europe for many years before 1995 or to compare the levels of labor productivity in the United States and Europe.

[7] Some analysts also separate out the contribution of changes in labor quality. By contrast, the current study abstracts from such changes.

[8] For example, the estimate of the contribution of multi-factor productivity (*MFP*) growth in the non-information and communication technology (*ICT*) sector to the change in labor productivity growth in the U.S. fell from 0.22 in Jorgenson (2003) to 0.03 in Jorgenson (2004) and then rose to 0.35 in Jorgenson (2005).

[9] Two GGDC sources are GGDC (2004) and Inklaar *et al.* (2003). The work of Jorgenson and his associates is summarized in Jorgenson (2005). For the OECD STandard ANalysis (STAN) data base source, see OECD (2004).

[10] Data from these three sources also have some important differences. The GGDC data take the STAN data as a starting point, include more recent data obtained from national sources, and fill in some of the gaps in the STAN data using industry data. In the GGDC and STAN data, the concepts of output and capital services are the same as those in countries' national accounts. By contrast, in the Jorgenson data, these concepts both include imputed services from durable goods (including *ICT* goods) purchased by consumers and the government. In addition, the Jorgenson data include land and inventories in the capital stock. The STAN data include country breakdowns for more countries than either of the others. To the best of the authors' knowledge, neither detailed

Table A2 presents a comparison of the data obtained from the GGDC and Jorgenson and associates in the United States, France, Germany, and the U.K.[11] In addition, for the GGDC, data for the Netherlands and an aggregate called the "EU-4" (France, Germany, the U.K., and the Netherlands) are avaliable.[12] For Jorgenson and colleagues, data for Italy are available, but no aggregate of European countries exists.[13] In our comparisons, we use average annual growth rates for the periods 1990–1995 and 1996–2001.[14] We focus our attention on changes in average growth rates between the two periods in the United States and European countries. Unless stated otherwise, growth rate differences are presented in percentage point (pp) form.

Changes in U.S. growth rates are essentially the same in the data from the GGDC as well as Jorgenson and colleagues, and these rates will be treated as if they were the same in the following discussion.[15]

explanations of differences among the data nor all of the data necessary for reconciliation are publicly available.

[11] The GGDC data were obtained from GGDC (2004), and the Jorgenson data were obtained from the work of Jorgenson (2005). As another example of cross-country study, Fukao *et al.* (2016) compared the productivities of Korea and Japan.

[12] The Netherlands is included for completeness of data, because the data necessary to construct an aggregate that includes only the other three EU-4 countries are unavailable.

[13] The authors cannot construct a meaningful aggregate for France, Germany, Italy, and the U.K., using the Jorgenson data, because the data necessary to determine the appropriate weights for the contributions to labor productivity growth are not reported in his papers.

[14] The current study employs period averages for simplicity. Given that the Jorgenson data is only presented in such form, period averages are chosen based on data from the same years as those of Jorgenson. The authors begin choosing period averages in data for 1990 to avoid the break in German data resulting from reunification. We have adopted the labeling convention under which, for example, level-hours data for 1989 to 1995 are used to construct the average growth of hours for the period labeled 1990–1995. Jorgenson (2005) used a different convention under which the period he labels 1989–1995 corresponds to the period the current work labels as 1990–1995. GGDC uses yet another convention under which the period it labels 1990–1995 employs level data for 1990 through 1995. Given that GGDC annually provides data, the present study can construct the desired period averages.

[15] The possible exceptions to this statement are the growth rates for labor quality, which are not considered in the current study.

Most of the major qualitative features that are emphasized in this work can be illustrated by comparisons between the U.S. and the EU-4 aggregate in the GGDC data.[16] In the second half of the 1990s, labor productivity growth rose in the United States and declined in Europe, resulting in a difference between changes in growth rates of 1.5 pp. In the first half of the 1990s, U.S. labor productivity growth was significantly below that in the EU-4. However, in the second half, the figure was slightly above that in the EU-4.

Employing the same data, we can break down the changes in labor productivity into changes in components. Overall capital deepening increased in the United States: increases were observed for *ICT* capital (0.4 pp) and non-*ICT* capital (0.2 pp). By contrast, overall capital deepening declined in the EU-4 because the increase in *ICT* capital deepening (0.2 pp) was only half as much as in the United States and was more than offset by the decrease in non-*ICT* capital deepening (−0.6 pp). The contribution of *MFP* growth increased in both the United States and the EU-4, but the U.S. increase was more than twice as high (0.7 pp versus 0.3 pp).

The Jorgenson data include a breakdown of the contributions of *MFP* growth into those from *ICT*-producing sectors and those from all other sectors.[17,18] These data confirm considerably early findings that the

[16] In the GGDC data, France is the only country where the qualitative pattern is different from that in the EU-4 aggregate. Labor productivity growth rose slightly in France as a combination of a relatively large increase in *MFP* growth (0.5) and a moderate increase in labor quality growth (0.2) that is a little more than offsetting a large decrease in capital deepening (−0.6).

[17] Inklaar *et al.* (2003) presented a similar breakdown of the contributions of *MFP* growth. This breakdown is not discussed in the present paper, because the data used to construct it do not have the same coverage as the data used to construct Table A2.

[18] The GGDC data and the Jorgenson data have significant differences, which are not relevant to the points of this paper. These differences include (1) a larger decline in labor productivity growth in France resulting from both a smaller increase in output growth and a larger increase in hours growth, (2) a larger increase in *MFP* growth in France associated with a reduction in labor quality growth for Jorgenson because of a significant increase in labor quality growth rather than a decrease that is half as large, (3) larger decreases in labor productivity growth and *MPF* growth in Germany both resulting from a larger decrease in output growth as well as a larger increase in hours growth, (4) a larger decrease in labor productivity growth in the U.K. largely because of a

contribution of *MFP* growth in the *ICT*-producing sector in the United States increased significantly (0.3 pp).[19] However, suprisingly, these data also imply that the contribution of this sector has been just as high in the European countries. In the non-*ICT* sectors, *MFP* growth increased by 0.4 pp in the United States and slightly more in France and the U.K. but decreased by 1.2 pp in Italy and declined even more in Germany.

The sectoral breakdown of the changes in labor productivity growth has received considerable attention. Employing OECD data on *value added by sectors* in the United States (a rearrangement of BEA data), we constructed a sectoral breakdown of labor productivity growth for the United States, as shown in the leftmost three columns of Table A3.[20] Evidently, most of the increases in aggregate growth were accounted for by three sectors: manufacturing (0.2 pp); wholesale and retail trade as well as restaurants and hotels (0.4 pp); and finance, insurance, real estate, and business sector services (0.2 pp).

Conceptually, sectoral contributions to changes in aggregate labor productivity growth can be broken down into changes in capital deepening and changes in *MFP* growth. Definitive conclusions about the relative importance of these contributions are difficult to reach. Evidence corroborates that sectoral changes in *ICT* capital deepening have been important.[21] For example, the data in Table A3 support the view that the sectors that have made the largest sectoral contributions are the ones with the largest increases in investment in *ICT* goods. Sectoral data for the ratio of nominal gross investment in *ICT* goods to nominal value added are shown in the rightmost three columns of Table A3. The increases in this ratio for wholesale and retail trade as well as finance, insurance, real estate and business sector services

considerably lower increase in output growth, and (5) a larger increase in *MFP* growth rather than a small decrease because of a considerably larger decrease in the contribution of non-*ICT* capital deepening.

[19] See, for example, Oliner, and Sichel (2000).

[20] The contributions in Table A3 are calculated using the standard methodology summarized in Equation A.43 on p. 145 of Pilat, and Schreyer (2001).

[21] Inklaar *et al.* (2003) presented explicit breakdowns of labor productivity growth at the sectoral level. However, the authors of the current work have been unable to reconcile them with breakdowns at the aggregate level, even for the United States.

are significantly larger than those for all of the other sectors (except for transportation, storage, and communication). These sectors are two of the three sectors that made the largest contributions. However, although manufacturing has the third largest contribution, the increase in its ratio is on the low end. Furthermore, the largest increase in the ratio thus far occurred in the transportation, storage, and communication sector, where a negative contribution was noted.

Evidence also confirms that sectoral changes in *MFP* growth have been important. Inklaar *et al.* (2003) verified that some of the sectors that have made the largest contributions to the increase in the difference between aggregate U.S. and EU-4 labor productivity growth are sectors in which increases in the difference between *MFP* growth rates have also been high.[22] According to their data, for some of these sectors, the increases in *MFP* growth were considerably more important than the increases in *ICT* capital deepening.[23] Three sectors that exhibit both of these phenomena are (1) electrical and electronic equipment; instruments, (2) repairs and wholesale trade, and (3) retail trade.[24]

The data clearly suggest at least three generalizations regarding the breakdown of the increase in the difference between U.S. and European labor productivity growth rates. First, although *MFP* growth in the *ICT* sector was roughly the same in the United States and Europe, susbtantial increases were observed in the differences between *ICT* capital deepening in the *ICT*-producing sectors and that in the non-*ICT*-producing sectors. Second, *MFP* growth in the non-*ICT*-producing sectors increased in the United States but declined on balance in Europe. Third, in contrast to the expectations of some scholars, differentials in *MFP* growth rates for nontraded goods as well as for traded goods significantly increased. In the current study, these generalizations have been taken into account in constructing the model

[22] See Figure III.3.c in Inklaar *et al.* (2003). The analysis in Fernald, and Ramnath (2004) also supports this conclusion. These authors pointed out that a correlation possibly exists between *ICT* capital deepening and *MFP* growth as conventionally measured, because *ICT* is a “general purpose technology” that can change ways of doing business.

[23] See Appendix Tables III.C.1 to III.C.6 in Inklaar *et al.* (2003).

[24] The GGDC sectoral breakdown is somewhat different from the OECD breakdown referred to above, but the difference is irrelevant to the points of this paper.

used to elucidate recent experiences.

B. Further Discussion on the U.S. Economy in the 1990s

Figure A1 presents additional data on the U.S. economy relevant for analyzing the effects of productivity shocks. In discussing figures, we use the convention that, for example, “panel 4 of Figure A1” is referred to simply as “FA1.4.”

In the second half of the 1990s, prices of investment goods significantly declined rapidly. In particular, the decline rate in the price of aggregate investment relative to *GDP* (FA1.1) increased by 0.69 pp. A significantly high increase for consumer durables and a substantially low increase for private investment (by businesses) considerably offset the small decline for government investment. For the subcategory of investment in equipment and software, the increase was 1.28 pp.

At least partly in response to this substantially rapid price decline, an investment boom transpired. The share of investment in *GDP* (FA1.4, broken line) increased throughout this period from about 0.19 to about 0.22. By contrast, the saving rate (solid line) increased by 2 pp between 1995 and 1998 but decreased back to slightly below its 1994 level by the end of 2000. Given that the fraction of *GDP* devoted to government spending was fairly constant in the late 1990s, the continued increase in investment accompanied by the reduction in savings implied a deterioration in the overall trade balance of the U.S. (FA1.5).

The increase in the nominal investment share does not fully capture the magnitude of the investment boom because of the decline in the prices of investment goods. To profoundly capture the relative magnitude of the changes in quality-adjusted real investment, we plot the difference between the growth rates of chain-weighted real investment and chain-weighted real *GDP* (FA1.2). The difference between these two growth rates in the second half of the 1990s reached at least as high as in earlier booms and remained high for a long period. Furthermore, the drop in the difference in the recession of the early 2000s was significantly less than in earlier recessions.

However, Figure A1 does not indicate that a considerable portion of growth in investment can be attributed to outlays for *ICT* investment (information-processing equipment and computer software); nominal outlays on these items were 9% of the total nominal investment in 1990 and 22% in 1999. Real outlays grew considerably fast because computer prices diminished. The increase in *ICT* investment growth accounts for 60% of the increase in all investments.[25]

The U.S. labor productivity growth (FA1.3) abruptly increased in the second half of the 1990s.[26]

The overall U.S. trade balance as a ratio of GDP (FA1.5, dotted line) deteriorated rapidly in the second half of the 1990s. We are especially interested in a comparison of the United States with Europe. The U.S. bilateral trade balance with the European Union (solid line) worsened slightly. After improving for a while, the overall trade balance of Europe (dashed line) diminished below its initial level.

The U.S. *TOT* with the rest of the world (FA1.6, dotted line) improved by as much as 5% before regaining much of its gain by the end of the decade.[27] The dollar appreciated dramatically in real terms against the "rest of the world" (dashed line) and even more dramatically against the Euro (solid line).

Government and private analysts took some time to become convinced that the increase in productivity growth was going to persist. The Congressional Budget Office and the consensus of Blue Chip forecasters produce five-year-ahead forecasts of real *GDP* growth. As reported by Erceg *et al.* (2002), these forecasts were virtually unchanged until the late 1990s and then increased gradually.

III. Model

In our analysis of the effects of different productivity shocks, we adopt a *DGE* model with two countries, referred to as Home and Foreign, which are mirror images of each other. This section describes the behavior of the representative Home agent.

[25] See, for example, Bosworth, and Triplett (2000).

[26] The quarterly data shown were obtained from the productivity release of the Bureau of Labor Statistics. It differs from the data presented in Table A2 in that it excludes the government and farm sectors.

[27] The U.S./ROW terms of trade is the ratio of the U.S. import deflator to the U.S. export deflator. This work has not calculated a U.S./EURO terms of trade (*TOT*) because no bilateral data for some countries in Europe are available. The U.S./ROW real exchange rate (*RER*) is the ratio of the U.S. CPI to the trade-weighted sum of exchange-rate-adjusted CPIs for 25 major trading partners of the United States.

A. Tastes

In period t, the agent maximizes the intertemporal utility function[28]

$$\sum_{s=t}^{\infty} \beta^{s-t} \frac{V_s^{1-\gamma}-1}{1-\gamma}. \tag{1}$$

Period utility is a constant elasticity function of V_s, which, in turn, depends on the current consumption of the agent (C_s), lagged total consumption ($\mathcal{C}_{s-1}$), and leisure, which is given by one minus labor (L_s):

$$V_s = V(C_s, \mathcal{C}_{s-1}, L_s) = \left(\frac{C_s - \eta \mathcal{C}_{s-1}}{1-\eta}\right) \exp\left\{\chi_0 \left[\frac{(1-L_s)^{1-\chi}-1}{1-\chi}\right]\right\}. \tag{2}$$

Therefore, external consumption habit exists. The agent also chooses holdings of a single bond (B) denominated in the Home traded good (the numeraire good for the model) and traded internationally.

B. Technology

Home technology comprises six sectors. First, two sectors produce traded (T) goods and nontraded (N) goods using identical Cobb–Douglas production functions scaled by adjustment costs:[29]

$$Y_{is} = K_{is}^{\alpha} L_{is}^{1-\alpha} X_{is}^{1-\alpha} \left[1 - \frac{\psi_{KL}}{2}\left(\frac{K_{is}}{L_{is}} / \frac{K_{is-1}}{L_{is-1}}\right)^2\right] = F(\underline{K}_{is}, \underline{L}_{is}) X_{is}^{1-\alpha}, \tag{3}$$

where $\underline{K}_{is}$ and $\underline{L}_{is}$ are vectors containing current and lagged values for $i = T, N$, respectively, and *MFP* shocks (X_{is}) may differ between the two sectors.

For sector i, output (Y_{is}) is produced using sector-specific capital (K_{is}) and labor (L_{is}). The T and N sectors use all of the labor supplied:

$$L_s = L_{Ts} + L_{Ns}. \tag{4}$$

[28] The Lagrangian expression for the Home maximization problem is presented in the Appendix.

[29] The steady state of the model is considerably easier to characterize if production functions are identical.

Each sector has quadratic adjustment costs (governed by ψ_{KL}) associated with changing capital–labor ratios.[30] Examples of such adjustment costs are training costs and satisfying regulation costs.

Subsequently, two sectors accumulate capital stocks. In each of these sectors, yesterday's sector-specific capital stock (K_{is-1}) and some of yesterday's investment goods (J_{is-1}) are used to generate today's sector-specific capital stock:

$$K_{is} = \left[\delta \left(\frac{J_{is-1}}{\delta} \right)^{1-\phi} + (1-\delta)\,(K_{is-1})^{1-\phi} \right]^{\frac{1}{1-\phi}}, \qquad i = T, N,$$

where ϕ governs the costs of adjusting capital stocks.[31]

In the last two sectors, goods are assembled into a consumption good (C_s) and an investment good (J_s). C_s is a constant elasticity of substitution (CES) function of consumption inputs of traded goods (C_{Ts}) and of the local nontraded goods (C_{Ns}):

$$C_s = \left[(1-\nu_C) \left(\frac{C_{Ts}}{1-\nu} \right)^{1-\theta_{CN}} + \nu_C \left(\frac{C_{Ns}}{\nu} \right)^{1-\theta_{CN}} \right]^{\frac{1}{1-\theta_{CN}}}, \tag{5}$$

and J_s is a CES function of "quality-adjusted" investment inputs of traded goods ($\Im_{Ts}$) and of the local nontraded goods (I_{Ns}):[32]

$$J_s = \left[(1-\nu_I) \left(\frac{\Im_{Ts}}{1-\nu} \right)^{1-\theta_{IN}} + \nu_I \left(\frac{I_{Ns}}{\nu} \right)^{1-\theta_{IN}} \right]^{\frac{1}{1-\theta_{IN}}}, \tag{6}$$

[30] In future work, the authors plan to investigate the case in which changing labor inputs has costs.

[31] Trend growth is easier to accommodate in the current formulation of adjustment costs than in the conventional quadratic formulation.

[32] For example, in Edge *et al.* (2003, 2004), an investment sector similar to that of the current work is called an IT-producing sector. The IT good produced by this sector is the only capital good. For some purposes, constructing a model with both IT capital and other capital might be useful. However, constructing such model is not part of the current work's scope.

where $\Im_{Ts}$ is the "quality-adjusted" input of traded goods defined below. In assembly sector i, where $i = I$, C the parameters v_i and $1/\theta_{iN}$ are, respectively, the weight given to nontraded goods in production and the elasticity of substitution between traded and nontraded goods.

In turn, the consumption input of traded goods is a CES function of consumption inputs of Home traded goods (C_{Hs}) and of Foreign traded goods (C_{Fs}):

$$C_{Ts} = \left[l_C \left(\frac{C_{Hs}}{l_C} \right)^{1-\theta_{CT}} + (1 - l_C) \left(\frac{C_{Fs}}{1 - l_C} \right)^{1-\theta_{CT}} \right]^{\frac{1}{1-\theta_{CT}}}, \qquad l_C = n + \kappa_C. \tag{7}$$

By analogy, the investment input of quality-adjusted traded goods is a CES function of quality-adjusted inputs of Home traded goods ($\Im_{Hs}$) and of Foreign traded goods ($\Im_{Fs}$):

$$\Im_{Ts} = \left[l_I \left(\frac{\Im_{Hs}}{l_I} \right)^{1-\theta_{IT}} + (1 - l_I) \left(\frac{\Im_{Fs}}{1 - l_I} \right)^{1-\theta_{IT}} \right]^{\frac{1}{1-\theta_{IT}}}, \qquad l_I = n + \kappa_I. \tag{8}$$

$0 < l_C$, $l_I < 1$ are, respectively, the weights on the Home traded good in traded-good inputs into consumption and investment. n is the proportion of the world's population living in the Home country. In this paper, we make the simplifying assumption that the two countries are of equal size ($n = 1/2$). The parameters κ_C and κ_I ($0 < \kappa_C$, $\kappa_I < 1 - n$) determine the amount of local good bias in the composition of traded good inputs into consumption and investment, respectively. (For example, no local-good bias exists when $\kappa_C = \kappa_I = 0$). We incorporate the empirically based assumption that the local good bias is greater in consumption than in investment.

Traded investment inputs are referred to as "quality adjusted," because some *ISP* increases occur, which are defined as follows:

$$\Im_{Hs} = Q_{Hs}^{\frac{1-\alpha}{\alpha}} I_{Hs}, \qquad \Im_{Fs} = Q_{Fs}^{\frac{1-\alpha}{\alpha}} I_{Fs},$$
$$\wp_{Hs} = \frac{1}{Q_{Hs}^{\frac{1-\alpha}{\alpha}}}, \qquad \wp_{Fs} = \frac{P_{Fs}}{Q_{Fs}^{\frac{1-\alpha}{\alpha}}}, \tag{9}$$

where the Q_{js}, $j = H$, F represents *ISP* shocks that can be different between the two goods.[33] If a Q_{js} increases, a given physical unit of the output of good j can contribute more to investment good output (J_s) than the same unit did before. I_{Hs} and I_{Fs} are measured in units of Home and Foreign traded goods, respectively, whereas $\mathfrak{I}_{Hs}$ and $\mathfrak{I}_{Fs}$ are measured in performance units. For example, I_{Hs} and I_{Fs} might be measured in the numbers of computers in which case $\mathfrak{I}_{Hs}$ and $\mathfrak{I}_{Fs}$ might be measured in terms of computing power. Given that the traded good is the numeraire, the price of a unit of I_{Hs} is unity. P_{Fs} is the price of the Foreign traded good in terms of the Home traded good, and $\mathcal{P}_{Hs}$ and $\mathcal{P}_{Fs}$ are prices of Home and Foreign performance units in terms of the Home traded good.

Our *ISP* shocks are designed to generate effects similar to those of an increase in *MFP* in a separate *ICT* sector. The traded-good sector can be thought of as being divided into two sub-sectors—one producing investment inputs that are subject to quality improvements and the other producing consumption inputs that are not—with perfect mobility of capital and labor between the two subsectors. Note that all of the *ISP* shocks affect the output of the investment good, which can be used to increase the capital stock in the traded and nontraded good sectors.

Q shocks are reflected in the relative prices of investment goods. Using the model results for sectoral prices and quantities, we can construct aggregate prices and quantities. To generate model results comparable with the data, we construct chain-weighted aggregates. For example, for the relative price of investment, we employ the ratio of Fisher indices for the investment (J_s) deflator and the GDP deflator, where the deflator for J_s is calculated using the prices of $\mathfrak{I}_{Hs}$, $\mathfrak{I}_{Fs}$, and I_{Ns}, and the GDP deflator is calculated using the prices of C_{Hs}, C^*_{Hs}, C_{Ns}, $\mathfrak{I}_{Hs}$, $\mathfrak{I}^*_{Hs}$, and I_{Ns}.

C. Budget Constraint

The agent must also consider a budget constraint. Income from the production of traded and nontraded goods plus interest from claims

[33] The quality shocks are entered with the exponent $(1 - \alpha)/\alpha$ to ensure that if the Q_{js} are equal, doubling all of them doubles steady-state outputs. More precisely, if $Q_{js} = Q_s$, $j = H, F, N$, then Y_{is}/Q_s, $i = T, N$ is constant in the nonstochastic steady state. This study assumes that Q_n remains constant at unity.

on Foreign during the last period need to be at least enough to cover purchases of traded goods and the Home nontraded good for use in assembling consumption and investment plus claims on Foreign during this period and "portfolio management costs" associated with claims on or liabilities to Foreign:[34]

$$F(\underline{K}_{Ts}, \underline{L}_{Ts})X_{Ts}^{1-\alpha} + F(\underline{K}_{Ns}, \underline{L}_{Ns})X_{Ns}^{1-\alpha} + R_{s-1}B_{s-1} \geq \tag{10}$$

$$\left[C_{Hs} + P_{Fs}C_{Fs} + P_{Ns}C_{Ns} + \frac{\Im_{Hs}}{Q_{Hs}^{\frac{\alpha}{1-\alpha}}} + \frac{P_{Fs}\Im_{Fs}}{Q_{Fs}^{\frac{\alpha}{1-\alpha}}} + P_{Ns}I_{Ns} + B_s + \frac{\zeta}{2}\frac{B_s^2}{Z_{Ts}} \right].$$

P_{Ns} is the price of Home nontraded goods in terms of Home traded goods. R_s is the gross return on the bonds that denominated in the Home traded good. A positive value of B_s indicates claims of Home on Foreign.

D. Relative Prices

This paper focuses on four relative prices. Two of them are the relative prices of the two countries' nontraded goods in terms of their traded goods represented by P_{Ns} and P_{Ns}^*, respectively. An asterisk on a variable indicates that it relates to Foreign. The *TOT* and *RER* are given by the following:

$$TOT_s = \frac{1}{P_{Fs}}, \qquad RER_s = \frac{P_{Cs}}{P_{Fs}P_{Cs}^*}, \tag{11}$$

where P_{Cs}^* is the price of the Foreign consumption bundle in terms of the Foreign traded good. The *TOT* is defined as the number of Foreign traded goods required to buy a unit of Home traded goods; thus, an increase implies improvement. The *RER* is the CPI-adjusted exchange rate defined as the number of Foreign consumption bundles required to buy a Home consumption bundle; thus, an increase indicates an appreciation of the Home currency in real terms. Improvements in

[34] Portfolio management costs are included to insure that the model has a well-defined steady state. Including these costs is the easiest among several roughly equivalent ways of guaranteeing stationarity as explained by Schmitt-Grohe, and Uribe (2003).

the *TOT* and increases in P_{Ns} result in the appreciation of the Home currency in real terms but increases in P^*_{Ns} result in its depreciation. In the neighborhood of the steady state,

$$\widehat{RER}_s = \nu(\hat{P}_{Ns} - \hat{P}^*_{Ns}) + (1-\nu)(\kappa_C + \kappa^*_C)\widehat{TOT}_s, \tag{12}$$

where a hat over a variable indicates a percentage deviation from its steady-state value. $0 < \kappa^*_C < n$ is the degree of local good bias in consumption in Foreign, and we assume that $\kappa^*_C = \kappa_C$.

IV. Simulations

This section presents the results of the simulations. To organize concepts, we first discuss symmetric increases in the levels of *ISP* in Home and Foreign. Subsequently, we analyze two types of persistent productivity growth shocks suggested by the data: symmetric increases in *ISP* growth and (perfectly) asymmetric changes in *MFP* growth. The values of the parameters used in the simulations are in Table A1 in the Appendix. Unless stated otherwise, we assume that Home and Foreign parameters are identical.

In explaining our simulations, we use the terms "wealth effect" and "investment incentive." In this study, a shock is considered to have a positive wealth effect if this event gives rise to an increase in the excess of income over the spending needed to support the initial steady-state path (both measured in Home traded goods). In calculating this excess, we hold constant relative prices of *physical* units, consumption allocations, effective investment input allocations ($\Im_{Hs}$ and $\Im_{Fs}$), and bond holdings.[35] With *MFP* shocks, income increases. Agents receive the value of the production of traded and nontraded goods through either wages or capital income, and *MFP* shocks increase the amounts produced. With *ISP* shocks, spending decreases. The relative price of *effective* traded-goods investment inputs depreciates. When positive wealth effects exist, agents can considerably consume, increase the

[35] Given that the initial excess is zero, the wealth effect is given by the first line of Equation (10) minus the second where X_{Ts}, X_{Ns}, $Q_{Hs}^{(1-\alpha)/\alpha}$, and $Q_{Fs}^{(1-\alpha)/\alpha}$, are at their post-shock values, and all other variables are at their initial steady-state values. Our definition of the term "wealth effect" is quite different from the one in Baxter (1995).

capital stock, or work less. What they choose to do depends on the incentives they face.

A positive investment incentive can arise either because of a depreciation in the consumption price of quality-adjusted investment or because of a rise in the marginal product of capital.[36] Changes in the consumption price of investment are associated with changes in the *GDP* price of investment in the same direction. We employ and consider the latter variable the "relative price of investment." U.S. data for this relative price are presented in FA1.1.

A. Symmetric ISP *Level Increases*

In the first experiment, symmetric permanent increases occur in the levels of *ISP*. We compare the results for two cases: (1) the identical (adjustment) cost case, in which adjusting *K–L* ratios is costless in both countries (ψ_{KL} = 0), and (2) the substantially high Foreign (adjustment) cost case, in which adjusting *K–L* ratios is costly in Foreign (ψ^{*}_{KL} = 5000). In both cases, adjusting capital stocks has positive costs that are the same in both countries.

FA2 and FA3 illustrate the effects of 1% increases in the productivities of Home and Foreign traded goods that are used as inputs in the assembly of investment goods (Q_{Hs} and Q_{Fs}, respectively). Considering that these increases in the *ISP* of tradable investment inputs are symmetric, they have the same positive wealth effects in both countries in both cases. In each country, significantly few resources are needed to support the initial steady-state path.

The case with identical costs (dashed lines) is treated as a benchmark. In this case, the two countries are completely symmetric; thus, all of the effects are the same in the two countries. These results are similar to those for a closed economy in many respects.

The shocks inevitably create positive investment incentives. Before the adjustment of consumption and investment, the relative prices of investment decrease. With optimal adjustment, the relative prices of investment (FA2.1) decrease by roughly 0.45%. The magnitudes of these declines reflect the fact that tradables account for roughly half of investment inputs. After their initial drop, the relative prices of investment remain roughly constant.

[36] For further discussion of the investment incentive, see the Appendix.

In our calibration, the costs of adjusting capital stocks are low enough that (gross) investment shares (FA2.3) increase because quantity increases outweigh price declines. The increases in investment shares by 0.09 pp must be matched by equal decreases in consumption shares (FA2.4). The investment incentive is large enough relative to the wealth effect that decreases occur not only in the consumption shares but also in the chain-weighted levels (FA3.1). Although the consumption shares remain below baseline for 25 years, the levels rise above baseline after 4 years. The hump-shaped responses of consumption shares result from the effects of consumption habits. In each country, the same spikes are observed in the excess of (quality-adjusted) investment growth over GDP growth (FA2.2), labor productivity growth (FA2.5), and GDP growth (FA2.7), as well as persistent increases in capital deepening (FA2.6) and hours worked (FA2.8).

Currently, we turn to the case with significantly high Foreign costs (solid and dotted lines). Recurrently, both countries have positive investment incentives. Before the adjustment of consumption and investment, the declines in the relative prices of investment are similar. However, the positive investment incentive is considerably high in Home. The marginal product of capital is substantially high in such country because no *K*–*L* adjustment costs are incurred. The initial increase in the Home investment share is approximately twice as great as in the identical cost case. About one-third of this change is financed by an additional reduction in the Home consumption share and the remaining two-thirds by borrowing from Foreign. As in the identical cost case, the investment incentive effect is large enough relative to the wealth effects that reductions occur not only in the share of Home consumption but also in its level. Further increase in investment can be deterred by additional borrowing. Nontraded goods constitute a large share of Home investment-assembly inputs and are complements to the other inputs; thus, either the decline in consumption or the rise in work effort would have to be relatively large.[37]

[37] We assume that nontraded goods are complements in the assembly of investment (and consumption) goods. In our simulations, the elasticity of substitution between nontraded and traded goods is one half. Raising it to one has small quantitative effects. Raising it to four (the value of the elasticity of substitution between the two traded goods) has large effects at the sectoral level and significant but considerably smaller effects at the aggregate level.

By contrast, in Foreign, the investment incentive is low enough relative to the wealth effect that the investment share is reduced rather than increased. Given that investment inputs are currently substantially low-cost, Foreign residents can maintain their capital stocks and even slightly increase them, even though they drastically reduce their investment share. These residents choose to allocate the largest portion of the freed resources to increasing their consumption share because the incentive will have a relatively small increase to lend to Home.

In Home, the effects on the excess of investment growth over GDP growth, labor productivity growth, GDP growth, capital deepening, and hours worked will be magnified.[38] However, in Foreign, only three variables are significantly influenced: GDP growth, labor productivity growth, and hours. The initial spike in labor productivity growth is larger in Foreign (0.14 pp) than in Home (0.1 pp). Output growth increases less in Foreign, but hours remain virtually unchanged in such country, whereas they increase significantly in Home. At first, hours in Foreign remain virtually unchanged because of the high cost of changing the capital–labor ratio. Over time, total hours increase as a gradual increase in nontraded hours (not shown) offsets a significantly gradual decrease in traded hours (not shown). Two observations help in understanding this phenomenon: (1) steady-state capital stocks increase in Foreign as much as they do in Home, and (2) nontraded investment inputs are complements to traded inputs but do not benefit from an improvement in *ISP*.

Home runs a trade balance deficit (FA3.3) for approximately five years and a trade surplus for many years thereafter. The significantly high level of Home investment increases demand for both tradable investment inputs. The increase in the trade deficit as a share of GDP is at its maximum (–.05 pp) initially when this increase is about a fourth of the total increase in the Home investment share.

The Home *TOT* (FA3.4) remains roughly unchanged initially and then deteriorates slowly over time. At first, the supply of and demand

Using traded goods in both investment and consumption is more viable; thus, investment can be higher without having consumption to be any lower. At its peak, the trade deficit is 0.10 pp instead of 0.07 pp.

[38] The initial decrease in capital deepening occurs because hours can increase in the period of the shock, but the capital stock cannot.

for traded goods (not shown) are reduced by roughly equal amounts in Home and in Foreign. In Home, a significant amount of labor (not shown) is shifted from the traded to the nontraded good sector. However, almost immediately, the supply of traded goods begins to considerably rapidly increase in Home because the Home traded good capital stock substantially rapidly increases and because Home traded good hours rebound rapidly. In each country, the relative price of the nontraded goods (FA3.6), P_N or P_N^*, rises by roughly the same amount initially. This price continues to rise in Foreign but begins to decline in Home because of the divergent movements in consumption assembly, which is relatively intensive in nontraded goods. Initially, the Home currency appreciates in real terms (FA3.5). Equation (12) helps in understanding the reason behind such phenomenon. The *RER* slightly increases initially because the *TOT* improves, and the movements in the relative prices of nontraded goods offset one another. However, the RER begins to decrease almost immediately because the effects of the divergent movements in the relative prices of nontraded goods reinforce those of the deterioration in the *TOT*.

B. Symmetric ISP *Growth Rate Increases*

The data indicate that *MFP* growth in the *ICT* sector persistently increased in the second half of the 1990s in the United States and Europe. For this reason, persistent symmetric increases in the growth rates of *ISP* are interesting to analyze. For simplicity, we focus on the profoundly relevant case of asymmetric adjustment costs. Similar to other analysts of persistent growth rate shocks, we assume that agents need to learn the process governing the growth rate shocks to obtain results that resemble the data.[39] We focus on the learning case and show results for the full-information case primarily for exposition purposes.

We assume that the Home *ISP* growth rate follows an *AR*(1) process:

$$\tilde{Q}_{Hs} = 0.95\tilde{Q}_{Hs-1} + \varepsilon_{Hs}, \tag{13}$$

where a tilde over a variable indicates a growth rate. We set the

[39] Learning has been employed by Erceg *et al.* (2002) and Edge *et al.* (2004), in the analysis of productivity shocks.

coefficient on the lagged growth rate equal to 0.95 to ensure that the relative price of investment (FA4.1) decreases by 1% per year during the first six years of the simulation (1996–2001). This rate of decrease closely matches the one in the U.S. data. The process for the Foreign *ISP* growth rate is analogous.

In the case with learning, agents hypothesize that $\tilde{Q}_{Hs}$ is the sum of a persistent shock (S_{Ps}) and a temporary shock (S_{Ts}), and that this variable evolves according to

$$\tilde{Q}_{Hs} = S_{Ps} + S_{Ts}, \quad S_{Ps} = 0.95 S_{Ps-1} + e_{Ps}, \quad S_{Ts} = e_{Ts}, \tag{14}$$

where e_{Ps} and e_{Ts} are the normally distributed innovations. Having observed $\tilde{Q}_{Hs}$, the agent infers S_{Ps} and S_{Ts} using a Kalman filter. We assume that agents set the autoregressive coefficient for their hypothesized persistent process equal to the true coefficient.[40] The ratio of the variances of e_{Ps} and e_{Ts} perceived by agents determines the length of the learning period. We choose this ratio to ensure that the part of the observed shock attributed to the persistent component is 75% after five years and virtually 100% after ten years. The learning process for the Foreign *ISP* growth rate is analogous.

We choose the *ISP* growth rate innovations (ε_{Hs} for Home) to ensure that they raise the level of *ISP* by 1% in the first period. Therefore, the first-period effects of the *ISP* growth rate shocks on the levels of *ISP* are the same as those of the *ISP* level shock considered in Subsection *A*. Scaling the shocks in this manner facilitates easy comparison of the initial effects in the learning and full information cases. However, this condition implies that the effects of persistent growth rate shocks are an order of considerably large magnitude because the *ISP* shocks asymptotically approach level 13% higher than their pre-shock levels.

Similar to the case of increases in the *ISP* levels, the wealth effects are the same in both countries because the shocks are symmetric. However, the wealth effects are smaller in the benchmark case with learning than with full information because agents are unsure whether the shock is truly a persistent growth rate shock.

Positive investment incentives exist in both countries, but the

[40] If agents must also learn the coefficient of the autoregressive process, they figure out the true shock process more slowly.

incentive in Home is considerably great. The initial decreases in the relative prices of investment are the same in both countries. However, the marginal product of capital is substantially high in Home because no *K–L* adjustment costs are incurred. With optimal adjustment, the paths for the relative prices of investment (FA4.1) in Home and Foreign are slightly different because the investment demand significantly increases in Home, thereby limiting the price decline to some extent. The increase in Home investment demand is reflected in the increase in the investment share (FA4.3) over time and in the rise in the excess of investment growth over output growth (FA4.2) by approximately 0.5 pp for the first 5 years. As in the level shock case, investment is attractive enough that the share (FA4.4) and the consumption level (FA5.1) decrease. In addition, Home is induced to borrow from Foreign. By contrast, Foreign residents reduce the investment share but increase the investment level gradually because of the high costs of adjusting the *K–L* ratios. They increase the consumption share by less than they decrease the investment share and lend to Home.

To substantially understand the adjustment process in the learning case, we should consider the full information case. We present only the results for Home. With full information, the wealth effect is significantly great. Agents know well that the relative price of investment will be substantially low in the future. For Home residents, investment is unattractive enough initially that they cut the investment share (FA4.3) by roughly 2 pp and the investment level (FA5.2) by roughly 8%. The growth rate of investment is temporarily below that of output (FA4.2). Slightly more than half of the decrease in the investment share is used to raise the consumption share, and the rest is lent to Foreign. We do not discuss the full information case any further, except to note that in the early periods, the paths for all the variables deviate from those in the learning case in the manner implied by a considerably large perceived wealth effect.

With learning, the response of the Home investment share in the first period is a weighted average of what the response would be for a persistent growth rate shock with full information (–1.77 pp from FA4.2) and what this response would be with a level shock (0.17 pp from FA2.2). Agents initially attribute only 6% of the observed movement in *ISP* to the persistent component and the other 94% to a level shock. When these percentages are used to weigh the effects of the two possible kinds of shocks, the average effect is 0.05 pp (FA4.3).

Given that the U.S. investment share did not decrease in the data when the the relative price of investment substantially rapidly declined, the results with learning seem more plausible to us than those with full information.

Home labor productivity growth (FA4.5) increases on impact by 0.14 pp, which is roughly the amount of the initial increase in *ISP* multiplied by the share in GDP of traded investment inputs (Home and Foreign). As the large increase in investment raises the contribution of capital deepening (FA6.6), labor productivity growth rises above its initial level. By contrast, in Foreign, no significant contribution of capital deepening occurs; thus, the evolution of labor productivity growth closely matches that of the *ISP* shock.

In Home, hours (FA6.8) rise relatively rapidly and then decrease back toward their initial level. In Foreign, hours increase considerably slow and reach a significantly high level.

The Home trade balance (FA5.3) is in deficit for a time but then moves into surplus. The Home *TOT* (FA5.4) deteriorates over time, making Home traded goods relatively highly attractive. The relative price of the nontraded good rises in Foreign because consumption is intensive in nontraded goods. This rise reinforces the deterioration in the Home *TOT* both of which cause the Home currency to depreciate in real terms (FA5.4).

C. Asymmetric MFP *Growth Rate Shocks*

According to the data presented above, in the late 1990s, *MFP* growth in the non-*ICT* sector in the United States increased rapidly, and European countries generally experienced a reduction. In both regions, changes were observed in several sectors, some of which clearly produce nontraded goods. We perform simulations designed to isolate the effects of persistent changes in *MFP* growth rates.

For clarity, we make two simplifying assumptions. First, the shocks are (perfectly) asymmetric, meaning that the increase in Home and the decrease in Foreign are equal in absolute value. Second, adjusting the *K–L* ratios in either Home or Foreign has costs.[41] We report responses

[41] Allowing for costs of adjusting –ratios in Foreign would make less difference in the case of growth-rate shocks, because capital deepening contributes less to labor productivity growth in this case.

only for Home because, with symmetric economic structures and asymmetric shocks, Foreign responses are the exact opposites of Home responses.

As a benchmark, we take the case in which *MFP* shocks of equal magnitude occur in the traded good and nontraded good sectors, as suggested by the data. For comparison, we also consider the profoundly familiar case, in which *MFP* shocks only occur in the traded good sector. This case is employed in discussions of the well-known Harrod–Balassa–Samuelson effect. In both cases, we assume that agents face a learning problem with the same structure as the one described in Subsection *B.* We also discuss some of the differences between the results for *MFP* shocks and those for *ISP* shocks.

In the benchmark case, the *MFP* growth rate increases initially by 0.33 pp in the traded and nontraded good sectors in Home (and declines by 0.33 pp in Foreign).[42] We have chosen the size of the shocks to ensure that the initial rise in Home labor productivity growth matches the one in the simulation for a 1% *ISP* growth rate shock.[43]

A positive wealth effect exists because the outputs of traded and nontraded goods increase. Before quantities adjust, the relative price of investment goods does not change because *MFP* rises by the same proportion in the traded and nontraded good sectors. Nonetheless, Home still has a positive investment incentive because the marginal products of capital rise in both sectors.

The positive investment incentive leads to increases in the Home investment share (FA6.3) and in the excess of investment growth over GDP growth (FA6.2). At the point at which the increase is the largest (0.8 pp), about half of the increase in the investment share is financed by a reduction in the consumption share (FA6.4), and the remainder is financed by borrowing from Foreign. Although the consumption share declines, the wealth effect is strong enough relative to the investment incentive that the consumption level rises steadily.

In the benchmark *MFP* case, the initial rise in Home labor productivity growth (FA7.1, solid line) of roughly 0.2 pp reflects the 0.33 pp increase in *MFP* growth across the economy and labor's share

[42] As before, the (1) process governing the evolution of growth has a coefficient of 0.95.

[43] With shocks of the type we consider, we cannot match the entire path of labor productivity growth.

of income (0.7 pp). As *MFP* growth subsides, labor productivity growth declines, and the contribution of capital deepening (FA6.6)—as opposed to the shock itself—accounts for an increasingly large share of labor productivity growth.

For the first several years, Home continues to borrow and run a trade balance deficit (FA7.3). Considering that Home and Foreign traded goods are good substitutes, the deterioration is substantial, reaching as much as 0.5% of GDP in our baseline case. Given that local good bias exists in both consumption and investment, the large initial increase in home absorption results in a slight improvement in the *TOT*. However, as Home production continues to expand, the Home *TOT* (FA7.4) deteriorate.

Currently, we turn to the profoundly familiar case, in which the *MFP* shock is concentrated in the traded good sector. We refer to this case as the "traded-sector-only" case and double the magnitude of the shock for affecting only one sector. The traded-sector-only case is similar to the benchmark case in several ways. Home has a positive wealth effect and a positive investment incentive because the output of traded goods and the marginal product of capital in the traded good sector both rise.

However, some differences between the two cases are noted. In the traded-sector-only case, the path for the relative price of investment (FA6.1) is significantly low in all countries. The reason is that investment assembly is more intensive in traded goods compared with consumption assembly.[44] Consequently, the investment share of GDP considerably increases. Given that the reduction in the consumption share (FA6.4) is roughly the same in both cases, the substantially high investment share is reflected in additional borrowing from Foreign accompanied by considerable deterioration in the trade balance (FA7.3).

The most significant differences from the benchmark case lie on the results for some relative prices. The deterioration of the Home *TOT* (FA7.4) in the first few years is not very different from that in the benchmark case. By contrast, the relative price of the nontraded good (FA7.6) increases rapidly in Home (and decreases rapidly in Foreign) instead of remaining constant and becomes approximately 7% high in the long run. The large and divergent movements in the relative prices

[44] In our calibration, the traded shares for investment and consumption are 0.48 and 0.37, respectively.

of nontraded goods dominate movements in the *TOT*; thus, the *RER* (FA7.5) rises in accordance with Equation (12). Therefore, in contrast to the benchmark case, the Home currency appreciates dramatically in real terms, exemplifying the Harrod–Balassa–Samuelson effect.

A comparison of the effects of *MFP* growth rate shocks with those of *ISP* reveals some important differences. The *MFP* and *ISP* shocks we have chosen are the ones suggested by our reading of the data, not those best suited for a head-to-head comparison of the two kinds of shocks. Nonetheless, our simulations reveal salient differences between these shocks.

The relative importances of the wealth effect and the investment incentive are opposite in the two cases. With *MFP* shocks, the relative strength of the wealth effect is great enough that the consumption level rises from the outset. By contrast, with *ISP* shocks, the wealth effect is relatively weak; thus, the consumption level declines for some time.

The increase in labor productivity can be divided into the contribution of capital deepening and the contribution of the shocks themselves.[45] Capital deepening is relatively less important with *MFP* shocks, that is, this situation accounts for a substantially small fraction of labor productivity growth. For example, in 2000 (four years after the start of the simulation), capital deepening accounted for one-fourth of labor productivity growth with *MFP* shocks (FA6.5 and FA6.6) as opposed to one half with *ISP* shocks (FA4.5 and FA4.6).

We calibrate the shocks to ensure that the initial change in labor productivity growth is the same for *MFP* and *ISP* shocks. Given this normalization and our calibration of the parameters, for example, the trade balance considerably deteriorates with *MFP* shocks.

V. Conclusions

Our analysis highlights the major difference between positive *ISP* and *MFP* shocks. Both shocks lead to marked increases in labor productivity growth. However, with *ISP* shocks, raising labor productivity growth requires considerable investment. Increases in labor productivity are accounted for more by increases in capital deepening than by the shock itself. This finding supports the view that *ISP* shocks played a relatively

[45] See the Appendix.

more important role than *MFP* shocks in generating the persistent excess of investment growth over GDP growth in the United States in the late 1990s.

Lags in recognition are key in explaining our results for persistent growth rate shocks. Under full information, with positive *ISP* shocks, investment declines initially and remains below its initial level for a few years. Agents postpone investment because they realize that the price of investment goods will be even substantially low in the future. With learning, our simulation results are significantly close to the observed outcomes: investment remains constant initially but rises immediately thereafter.

We confirm that the treatment of nontraded goods can make a big difference.[46] In the case of *ISP* shocks, changing the degree of substitutability between traded and nontraded goods has large effects at the sectoral level. In the case of *MFP* shocks, we can reproduce the conventional Harrod–Balassa–Samuelson result: when a country experiences a positive shock that affects only traded goods, its currency appreciates in real terms, and its trade balance deteriorates, such as changes similar to those that occurred in the United States in the late 1990s. However, the data suggest that real-life *MFP* shocks also affected nontraded goods. Our model implies that such shocks should have virtually no effect on the *RER* and that they should generate a significantly small trade-balance deterioration.

Our simulations provide insights into the effects of observed productivity shocks. However, our simulations fail to consider some features of the data. We use a two-country model. Nonetheless, a model with several regions, including a separate East Asia bloc, is certainly required to analyze some of the developments in the 1990s, such as the large increase in the U.S. trade account deficit—accompanied by a minimal increase in the bilateral trade surplus of Europe with the United States—and the large real appreciation of the dollar. We consider only productivity shocks. However, other critical shocks, such as the

[46] Like many other scholars, we assume that the dividing line between traded and nontraded goods is exogenous. Research on endogenous tradability is necessary. An early contribution is the work of Dornbusch *et al.* (1977), and recent contributions include those of Bergin, and Glick (2003) and Ghironi, and Melitz (2005). The outsourcing abroad of record keeping and customer service functions is a familiar concrete example.

Asian crisis, influenced economic outcomes in the 1990s.

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Appendix

Lagrangian Expression for Home Agent

The Lagrangian expression for the home agent is as follows:

$$\sum_{s=t}^{\infty} \beta^{s-t} \left\{ \frac{[V(C_s, \mathcal{C}_{s-1}, L_s)]^{1-\gamma} - 1}{1-\gamma} + \Lambda_{Ts}[K(J_{Ts-1}, K_{Ts-1}) - K_{Ts} \right\}$$

$$+\Lambda_{Ns}[K(J_{Ns-1}, K_{Ns-1}) - K_{Ns}] + \Lambda_{Js}\left[J\left(Q_{Hs}^{\frac{1-\alpha}{\alpha}} \mathfrak{I}_{Hs}, Q_{Fs}^{\frac{1-\alpha}{\alpha}} \mathfrak{I}_{Fs}, I_{Ns} \right) - J_{Ts} - J_{Ns} \right]$$

$$+\Lambda_{Cs}\left[R_{s-1}B_{s-1} + F(\underline{K}_{Ts}, \underline{L}_{Ts})X_{Ts}^{1-\alpha} + P_{Ns}F(\underline{K}_{Ns}, \underline{L}_{Ns})X_{Ns}^{1-\alpha} - \frac{\zeta}{2}\frac{B_s^2}{Z_{Ts}} \right.$$

$$\left. -C_{Hs} - P_{Fs}C_{Fs} - P_{Ns}C_{Ns} - \frac{\mathfrak{I}_{Hs}}{Q_{Hs}^{\frac{1-\alpha}{\alpha}}} - \frac{P_{Fs}\mathfrak{I}_{Fs}}{Q_{Fs}^{\frac{1-\alpha}{\alpha}}} - P_{Ns}I_{Ns} - B_s \right]$$

where Λ_{Ts}, Λ_{Ns}, Λ_{Js}, and Λ_{Cs}, are the shadow prices of K_{Ts}, K_{Ns}, $J = J_{Ts} + J_{Ns}$, and income, respectively.

Parameter Values

The parameter values used in the simulations are given in Table A1. In the initial steady state, P_F, P_N, P_N^*, Q_T, Q_T^*, X_T, X_N, X_T^*, and X_N^* are unity.

Decomposing Labor Productivity Growth

This section shows that the usual decomposition of labor productivity growth into a contribution from capital deepening and a contribution from a productivity shock is as relevant for *ISP* shocks as this decomposition is for *MFP* shocks. For simplicity, we focus on a special case, in which all goods are traded but the argument generalizes.

The Törnqvist index for quality-adjusted, chain-weighted output

TABLE A1
PARAMETER VALUES

β	discount factor	0.98
γ	elasticity of marginal ntility w.r.t. V	1.0
α	share of capital in production	0.35
δ	depreciation rate	0.025
ϕ	governs capital adjustment costs	0.2
ν_C & ν_I	share of nontraded goods in C & I	0.63 & 0.52
$1/\theta_{CN}$	elasticity of substitution - T & N goods in C	0.5
$1/\theta_{IN}$	elasticity of substitution - T & N goods in J	0.5
n	relative size of home country	0.5
κ_C	local-good bias in C_T	0.32
κ_I	local-good bias in I_T	0.08
$1/\theta_{CT}$	elasticity of substitution - H & F goods in C_T	4.0
$1/\theta_{IT}$	elasticity of substitution - H & F goods in I_T	4.0
ψ_{KL} & ψ^*_{KL}	governs capital-labor ratio adjustment costs	0 & 5000
ζ	governs portfolio management costs	0.0001
$2/\chi$	Frisch elasticity of labor supply	0.4
χ_0	set so steady-state share of time worked is 0.33	0.719

growth, which approximates the Fisher index, is given by the following:

$$\begin{aligned}\tilde{Y}_t^{CW} = {} & S_{CHt}\tilde{C}_{Ht} + S^*_{CHt}\tilde{C}^*_{Ht} + S_{IHt}\left(\tilde{I}_{Ht} + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht}\right) \\ & + S^*_{IHt}\left(\tilde{I}^*_{Ht} + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht}\right),\end{aligned} \tag{15}$$

where Y_t^{CW}, C^*_{Ht}, and I^*_{Ht}, are chain-weighted output, consumption exports, and investment exports, respectively. For example, S_{CHt} is the average of the consumption shares of the Home good in total output in periods t and $t-1$.[47]

Quality-adjusted output at constant prices (Y_t^{CP}) and its growth rate ($\tilde{Y}_t^{CP}$) are as follows:

$$Y_t^{CP} = C_H + C^*_{Ht} + Q_{Ht}(I_{Ht} + I^*_{Ht}), \tag{16}$$

[47] Dumagan (2002) presented the relationship between the Törnqvist index and the Fisher ideal index used in computing chain-weighted GDP by the U.S. Bureau of Economic Analysis.

$$\tilde{Y}_t^{CP} = S_{CH}\tilde{C}_{Ht} + S_{CH}^*\tilde{C}_{Ht}^* + S_{IH}\left(\tilde{I}_{Ht} + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht}\right) + S_{IH}^*\left(\tilde{I}_{Ht}^* + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht}\right), \tag{17}$$

where in the initial steady state, $Q_t = 1$. For example, $S_{CHt} = S_{CH}$. Equations (15) and (17) clearly show that GDP growth at constant prices can be considered as the first-order approximation of the Törnqvist index with no trend growth because

$$\tilde{C}_{Ht} = \tilde{C}_{Ht}^* = \tilde{I}_{Ht} + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht} = \tilde{I}_{Ht}^* + \frac{1-\alpha}{\alpha}\tilde{Q}_{Ht} = 0$$

in the steady state.

Log-linearizing and combining Equation (16) and the technology constraint, we obtain the following:

$$C_H + C_{Ht}^* + I_{Ht} + I_{Ht}^* = K_t^{\alpha} L_t^{1-\alpha} X_t^{1-\alpha}, \tag{18}$$

and yield the usual decomposition in terms of percent deviations from the steady state:

$$\hat{Y}_t^{CP} - \hat{L}_t = \alpha(\hat{K}_t - \hat{L}_t) + (1-\alpha)\hat{X}_{Ht} + (Sh_{IH} + Sh_{IH^*})\ \frac{1-\alpha}{\alpha}\hat{Q}_{Ht}. \tag{19}$$

Equation (19) indicates that the *ISP* shock ($\hat{Q}_t$) can be interpreted as an *MFP* shock that affects only the investment-producing sector of the economy.

Defining the Investment Incentive

In this study, a positive investment incentive arises for one of the following two reasons. The first reason is a decrease in the relative price of investment. Under perfect competition, prices equal marginal costs. Therefore, this relative price equals the ratio of marginal costs, $(MC_{It})/(MC_{Ct})$, where MC_{It} and MC_{Ct} are obtained from the cost minimization problems

$$\min_{I_{Ht},\, I_{Nt},\, I_{Ft}} I_{Ht} + P_{Nt} I_{Nt} + P_{Ft} I_{Ft} + MC_{It}\,[J(Q_{Ht} I_{Ht},\, Q_{Ft} I_{Ft},\, I_{Nt}) - J_0)], \tag{20}$$

Table A2
Output Growth for the U.S. and Some European Countries

	U.S.			EU-4*	France			Germany			Italy		Netherlands	U.K.		
	OECD	Groningen	Jorgenson	Groningen	OECD	Groningen	Jorgenson	OECD	Groningen	Jorgenson	OECD	Jorgenson	Groningen	OECD	Groningen	Jorgenson
Output																
1990-1995	2.4	2.1	2.5	1.8	1.3	1.0	1.3	2.7	2.5	2.3	1.4	1.5	2.1	1.5	1.6	1.6
1996-2001	3.5	3.8	4.2	2.8	2.6	2.6	2.3	1.6	2.0	1.2	1.9	1.9	3.2	3.0	3.7	2.7
Hours																
1990-1995	1.1	1.1	1.0	-0.5	-0.5	-0.4	-0.4	-0.2	-0.1	-0.7	-1.2	-0.6	0.8	-1.0	-1.3	-1.2
1996-2001	1.4	1.6	1.5	0.8	0.5	1.0	0.9	-0.1	0.0	-0.1	0.9	1.0	2.1	0.9	1.1	1.0
Labor Productivity																
1990-1995	1.3	1.0	1.5	2.3	1.8	1.4	1.7	2.9	2.6	3.1	2.7	2.1	1.4	2.5	3.3	2.8
1996-2001	2.1	2.2	2.7	2.0	2.1	1.5	1.4	1.8	2.0	1.3	1.0	0.9	1.1	2.1	2.6	1.7
Capital Deepening																
Contribution from ICT Capital																
1990-1995		0.4	0.4	0.3		0.1	0.2		0.4	0.3		0.3	0.3		0.4	0.3
1996-2001		0.8	0.9	0.5		0.3	0.4		0.5	0.5		0.5	0.6		0.7	0.7
Contribution from non-ICT Capital																
1990-1995		0.2	0.4	0.8		0.5	1.2		1.0	1.3		1.1	0.4		0.8	2.1
1996-2001		0.4	0.6	0.2		-0.2	0.3		0.5	0.7		0.6	0.1		0.2	-0.2
1990-1995	0.5	0.6	0.8	1.2	0.9	0.6	1.4	1.0	1.4	1.6	1.1	1.3	0.7	1.3		2.4
1996-2001	0.9	1.2	1.5	0.7	0.5	0.0	0.6	0.9	1.1	1.2	0.6	1.1	0.7	0.9		0.5
Multifactor Productivity																
Contribution from ICT																
1990-1995			0.2				0.3			0.4		0.4				0.3
1996-2001			0.5				0.6			0.7		0.7				0.8
Contribution from non-ICT																
1990-1995			0.1				-0.6			0.7		0.0				-0.4
1996-2001			0.5				0.0			-0.8		-1.2				0.1
1990-1995	0.8	0.1	0.4	0.8	1.0	0.5	-0.3	1.9	1.1	1.1	1.6	0.4	0.5	1.2	1.5	-0.1
1996-2001	1.2	0.8	1.0	1.1	1.5	1.0	0.6	0.8	0.9	-0.1	0.4	-0.5	0.4	1.1	1.3	0.9
Labor Quality																
1990-1995	0	0.2	0.4	0.4	0	0.3	0.6	0	0.1	0.3	0	0.4	0.2	0	0.6	0.5
1996-2001	0	0.2	0.2	0.2	0	0.5	0.2	0	0.0	0.2	0	0.4	0.1	0	0.3	0.3

* Aggregate for France, Germany, U.K. and the Netherlands.

$$\min_{C_{Ht},\, C_{Nt},\, C_{Ft}} C_{Ht} + P_{Nt}\, C_{Nt} + P_{Ft}\, C_{Ft} + MC_{Ct}\, [C(C_{Ht}, C_{Nt}, C_{Ft}) - C_0)]. \qquad (21)$$

$J(\cdot)$ and $C(\cdot)$ are the CES aggregators (6) and (5), and J_0 and C_0 are the pre-shock levels of quality-adjusted investment and consumption, respectively. Positive *ISP* shocks lower the relative price of investment. The second reason is an increase in the marginal product of capital. Positive *MFP* shocks raise the marginal product of capital.

Table A3

Labor Productivity Growth and Investment in ICT by Sector (averages)

	Contribution to Labor Productivity Growth (%)			U.S. Nominal Gross Investment in ICT (percent of value added)*		
	1990-1995	1996-2001	Increase	1990-1995	1996-2001	Increase
Agriculture, hunting, forestry & fishing	0.0	0.0	0.0	0.7	1.0	0.3
Mining and quarrying	0.0	0.0	0.0	3.0	3.1	0.1
Manufacturing	0.4	0.6	0.2	3.2	3.5	0.3
Electricity, gas and water	0.1	0.0	-0.1	5.2	4.8	-0.4
Construction	-0.1	-0.1	0.0	0.6	0.7	0.2
Wholesale & retail	0.3	0.7	0.4	3.3	4.3	1.0
Tansportation, storage & communication	0.3	0.2	-0.1	10.0	13.6	3.6
Finance, insurance, real estate & business-sector services	0.3	0.5	0.2	3.8	5.0	1.2
Community, social & personal services**	-0.2	-0.3	-0.1	1.6	2.2	0.6
Total	1.1	1.7	0.6			

Source: OECD Stan Database.

* Includes other automation equipment. Source: Bureau of Economic Analysis.

** Excludes government services for nominal gross investment shares

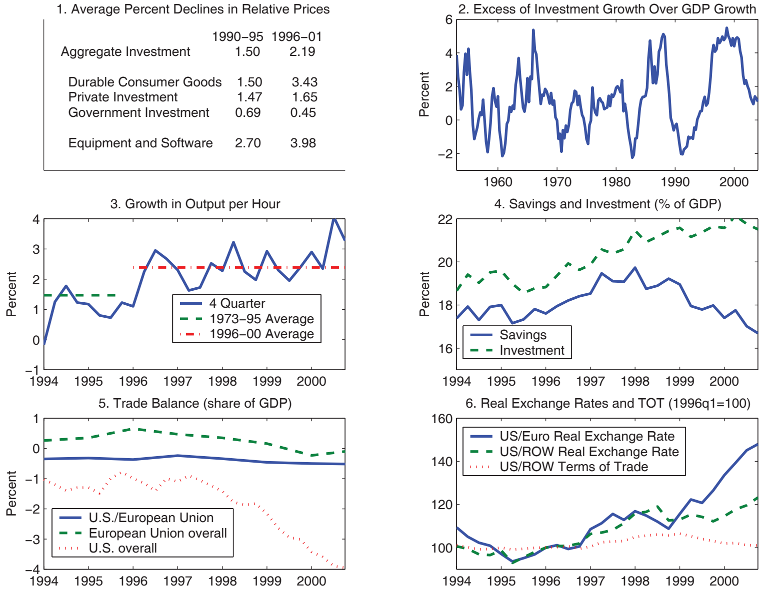

FIGURE A1
U.S. STYLIZED FACTS

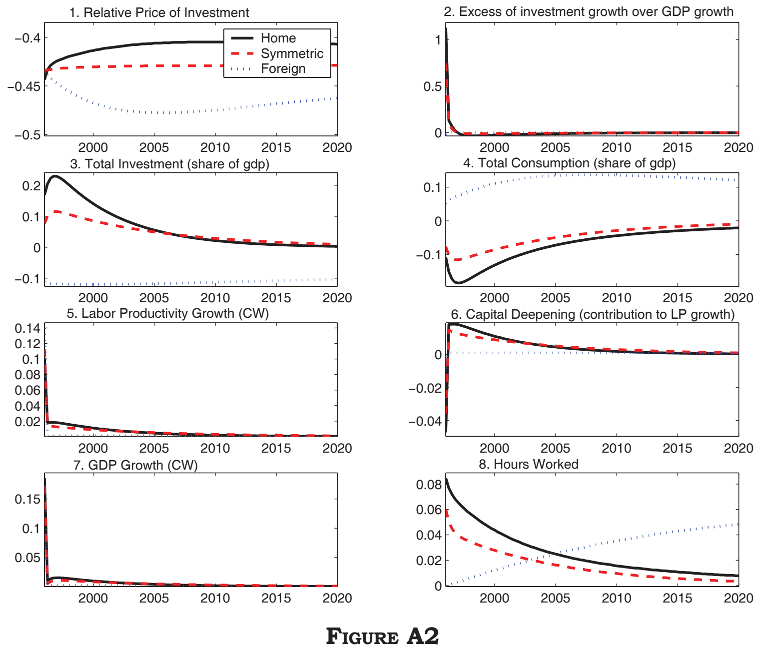

FIGURE A2
ISP LEVEL SHOCKS

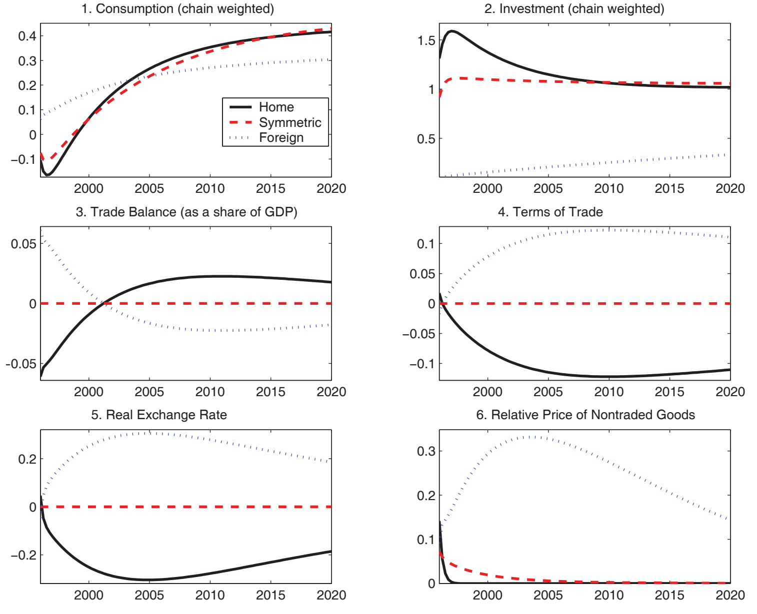

FIGURE A3
ISP LEVEL SHOCKS

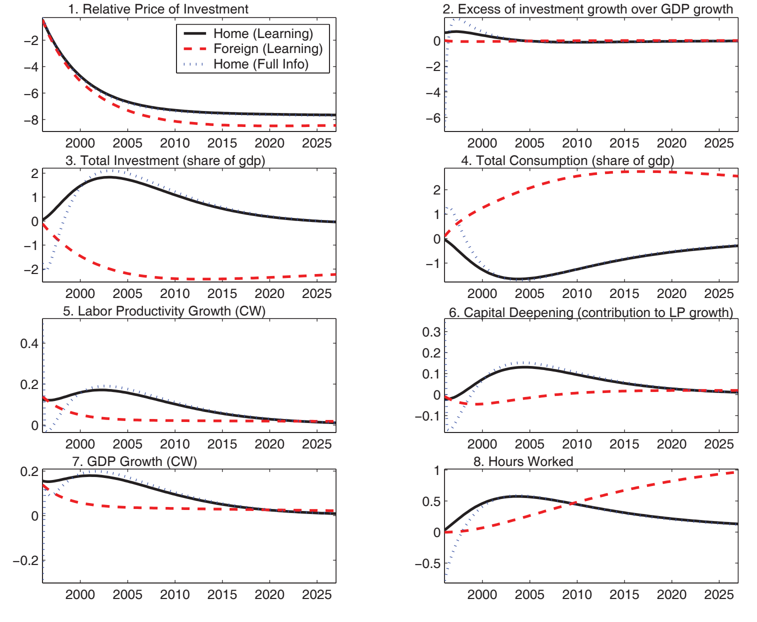

FIGURE A4
ISP GROWTH SHOCKS

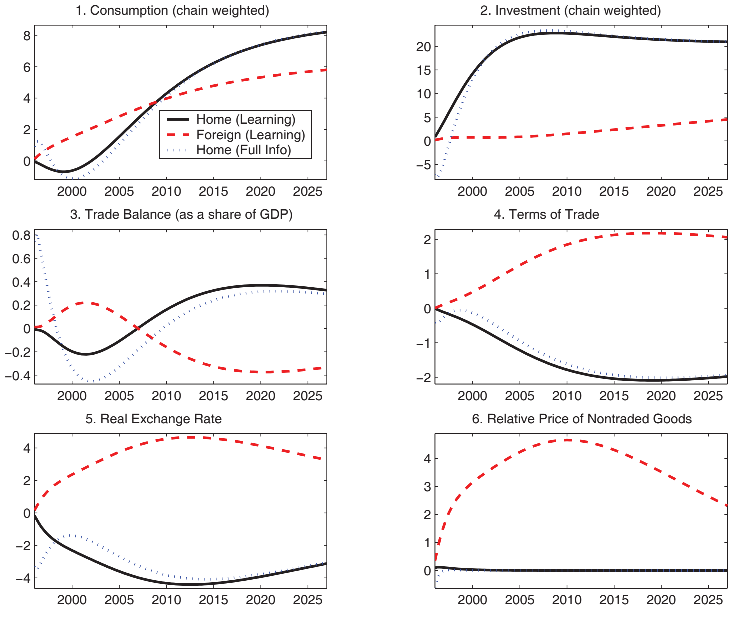

Figure A5
ISP Growth Shocks

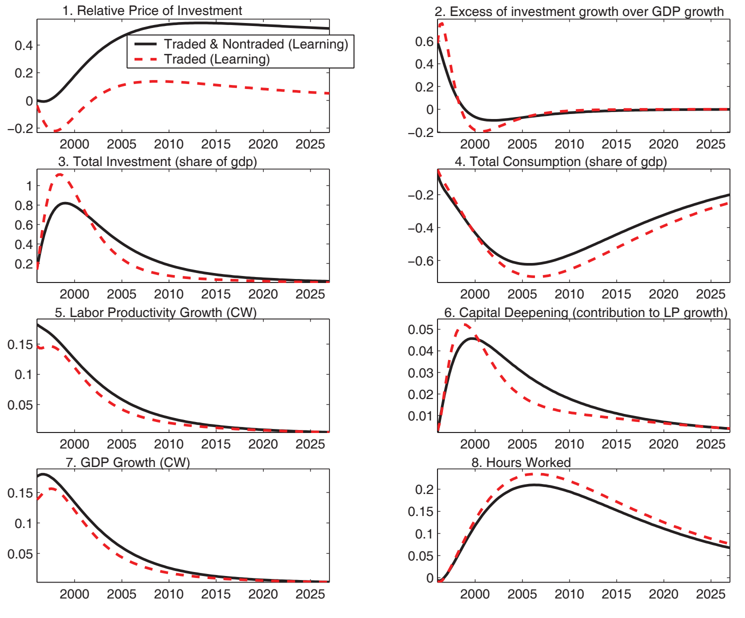

Figure A6
Home Response to MFP Growth Shocks

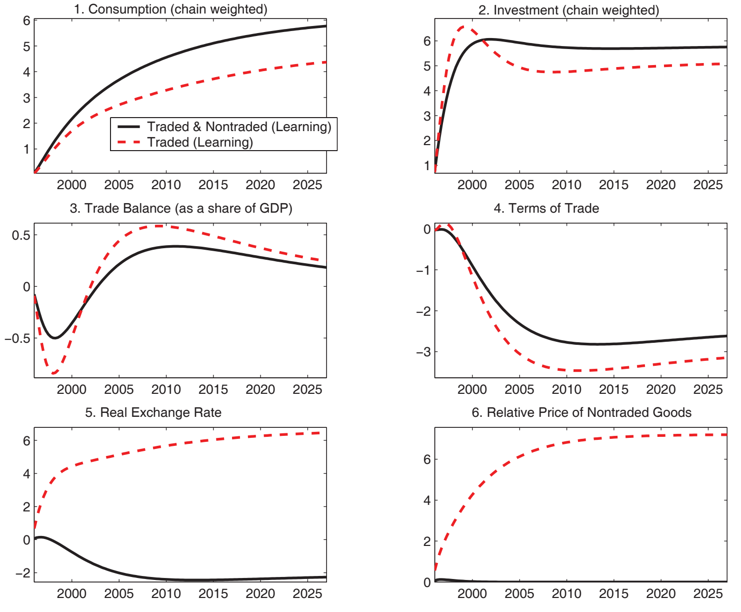

FIGURE A7
HOME RESPONSE TO MFP GROWTH SHOCKS

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