Labor Productivity Growth, Relative Prices, and the Current Account: Experience and Analysis

Luca Guerrieri, Dale W. Henderson, and Jinill Kim*
Federal Reserve Board

September 10, 2004

Abstract

   We discuss alternative estimates of changes in labor productivity growth and its components in the U.S. and several European countries during the 1990s. Also we review some stylized facts about several other aspects of the U.S. experience during that period including relative prices and the current account. The important relative prices are the relative price of investment goods, the terms of trade, and the real exchange rate. In an attempt to shed light on these empirical findings, we build and simulate a two-country DGE model with traded and nontraded goods sectors in each country. There are two types of shocks: (1) investment quality (IQ) shocks designed to generate effects similar to those of increases in multifactor productivity in the information and communication technology sector and (2) investment usefulness (IU) shocks designed to represent improvements in methods of production and distribution that can be implemented only by accumulating capital and that are independent of any improvements in IQ There are also costs of adjusting capital stocks and factor proportions. Both shocks and adjustment costs may differ across countries. As suggested by the data, we assume that well over half of output is nontraded goods and that the local bias in the use of traded goods for consumption is much larger than that for investment. From our simulations it appears that a combination of shocks and more costly adjustment in Europe are helpful in analyzing the 1990s. At a minimum, the combination of shocks includes a persistent increase in IQ growth in both the U.S. and Europe and a temporary increase in IU growth in the U.S.

1 Introduction

Changes in labor productivity growth in the U.S. and Europe are among the major economic events of the last fifteen years. Much effort has been devoted to analyzing the origins and effects of these changes. In this paper, we summarize (as least some of) what happened and proffer some (partial) explanations for why.

There now seems to be general agreement that in the last half of the 1990s labor productivity growth rose in the U.S. and fell in "Europe" to rates that were roughly equal. Accounting for the changes has turned out to be a difficult task. However, researchers have recently provided breakdowns of changes in productivity growth by major components and sometimes by sector. We call attention to some generalizations suggested by these breakdowns. During the same period there were dramatic changes in the U.S. economy that we summarize briefly below.

In an attempt to provide perspective on these "stylized facts," we put forward an open-economy analytic framework. Insights can be gained by analyzing shocks to productivity growth using models of closed economies.[1] However, the effects of productivity shocks on open economies can be quite different from those on closed economies.[2] In open economies, there is a safety valve for adjustment. It is possible to import goods to be used for investment (to take advantage of new production opportunities) and goods to be used for consumption (to satisfy increased demand associated with increases in wealth). Adjustment paths are influenced by country size, openness, local-good bias in the use of home and foreign traded goods in investment and consumption, and the degree of substitutability between these goods. Furthermore, with standard utility functions for consumption and leisure, labor supply effects are often significantly larger in open economies.

We use a two-country dynamic general equilibrium (DGE) model in which a traded good and a nontraded. good are produced in each country, and the two traded goods are imperfect substitutes for one another.[3] [4] Taking the international perspective, we spell out the effects on the trade balance and four relative prices: the terms of trade (TOT), the (two) relative prices of nontraded goods, and the real exchange rate (RER), defined as the CPI adjusted nominal exchange rate. In both countries

---

[1]Examples of useful analysis of changes in productivity growth in closed economies are Edge, Laubach, and Williams (2003, 2004).

[2]Pioneering work on the analysis of productivity shocks using open-economy DGE models includes Backus, Kehoe, and Kydland (1994a, 1994b); Stockman and Tesar (1995); Baxter and Crucini (1995); and Kollmann (1998). Recent contributions include Erceg, Guerrieri, and Gust (2003), Laxton and Pesenti (2003), and Hunt and Rebucci (1988)

[3]The division of goods into traded and nontraded goods for purposes of analysis is standard in international economics. In the data for or the U.S. (and most other countries) little or no attempt is made to classify goods in this way. In attempting to draw a connection between our analysis and the available data we follow standard but increasing suspect practice of thinking of the output of the manufacturing sector as being mostly traded goods and the output of the distribution and financial services sectors as being mostly nontraded goods.

[4]Important contributions to the analysis of investment specific productivity shocks include Greenwood, Hercowitz, and Krusell (1997), Greenwood, Hercowitz, and Huffman (1988), Hercowitz (1998), and Hercowitz and Sampson (1991).

consumption and investment are aggregates of the two traded goods and the local non-traded good. The baskets of traded goods used in both consumption and investment are biased toward the locally-produced good, but the "local bias" in consumption is greater. This model nests most two-country DGE models used over the past fifteen years to analyze productivity changes.[5]

We consider two types of shocks that affect labor productivity growth. Both have their effects through investment which in our framework includes consumer durables. In the last half of the 1990s there was a significant increase in multifactor productivity (MFP) growth in the information and communication technology (ICT) sector in both the U.S. and Europe. In the U.S., this increase accounted for the lion's share of the overall increase in MFP while in Europe it was (more than) offset by a decrease in MFP growth in other sectors. In this paper we do not explicitly model the ICT sector. Rather, our first type of shock is an investment quality (IQ) shock designed to generate effects similar to those of a persistent MFP growth shock in the ICT sector. In particular, we assume that inputs used to produce investment goods are enhanced by an exogenous, persistent increase in the rate of quality improvement while those used to produce the consumption good are not. An example is a speed up in the rate of improvement of chips. Accordingly, the relative prices of constant-quality goods purchased by the investment sector decrease more rapidly.

Also in the last half of the 1990s there was a sustained pickup in investment in the U.S. as measured by an increase in investment growth relative to GDP growth. In forward-looking models like ours, a persistent increase in the rate of quality improvement, taken by itself, actually causes a slowdown in investment. The anticipation that quality will be even better in the future creates an incentive to postpone investment for a time. Our second type of shock is an investment usefulness (IU) shock designed to represent an improvement in methods of production and distribution that can be implemented only by accumulating capital. An example is an improvement in methods of inventory control that require the use of computers. In particular, we assume that there are exogenous (possibly different) temporary increases in the growth rates of investment usefulness (IU) in both the traded and nontraded goods sectors that induce pickups in purchases of investment goods. IU shocks are independent of IQ shocks and induce purchases of investment goods even if the quality of investment goods remains unchanged.

We calibrate the model and perform and discuss four simulations designed to help us interpret recent experience. No single type of shock seems to match enough of the stylized facts that it alone can be regarded as a completely satisfactory basis for analysis. Indeed, from the simulations it appears that, at a minimum, a combination of a persistent increase in IQ growth and an increase in IU with more costly adjustment in "Europe" is required to provide a credible qualitative analysis. Perhaps it is not a surprise that even this combination leaves some important facts unaccounted for.

---

[5]That is, most of the flexible wage and price models. Recently, many authors have used models with nominal inertia to analyze productivity shocks.

2 Accounting for Labor Productivity Growth

Much effort has been devoted to accounting for labor productivity growth. It is no easy task to separate out the contributions of capital accumulation and technical progress of different kinds.[6] There is still considerable disagreement among experts concerning how best to go about it. However, we argue that the data from different sources do support a few general conclusions.

Our assessment is based on the implications accounting for labor productivity growth at a highly-aggregated level in the U.S. and some European countries during the periods 1989-1995 and 1996-2001. We present two versions of this type of accounting that have roughly similar implications. They are based on data sets from the OECD and Jorgenson (2004), respectively.[7] Both data sets have two desirable properties. (1) data from several countries are reported on a standardized basis and (2) data on real investment for each country are quality adjusted using the same methodology. The OECD data set includes more countries but extends back only to 1985 for most countries. The Jorgenson data set provides a more disaggregated accounting and extends back farther.[8]

In our comparisons we use average growth rates over the periods 1990-1995 and 1996-2001. The OECD data is available on an annual basis. However, we use period averages because the Jorgenson data is available in that form. We choose periods to match available Jorgenson averages. We begin in 1990 because of German reunification.

Table 1 contains OECD data for the U.S., an aggregate that we call "Europe", the individual countries that make up this aggregate (France, Germany, Italy, the Netherlands, Belgium, and Denmark) as well as the U.K. and Sweden for completeness.[9] The U.K. is excluded from our analysis because its regulatory environment is quite different from that in most of the rest of Europe, and we focus on regulatory differences between the U.S. and Europe as a possible explanation for different productivity growth experiences. Sweden is excluded because the pattern of its productivity growth is quite different from that in the other countries in Europe for reasons that we do not yet understand.[10]

---

[6] Jorgenson (2004) attributes some of the changes in productivity growth to changes in the growth of "labor quality", but the OECD does not.

[7] In some cases, the OECD data and the Jorgenson data are different for as yet undocumented reasons. Which data is to be preferred on grounds of "accuracy" is now, and may well remain, an open question.

[8] Jorgenson has worked with many others in constructing the data that we refer to the "Jorgenson data". In the revised version of this paper, we will try to do a better job of giving appropriate credit to Jorgenson's coworkers.

[9] The European countries in the OECD for which capital stock data are available are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. Austria is excluded because there is no data in the OECD data set on labor's share. Greece, Ireland, Portugal and Spain are excluded because they are "catch-up" countries. Finland is excluded because of the disruptions in its trading relations that followed the breakup of the Soviet Union.

[10] The pattern of France's productivity growth is also different from that in the other countries in Europe in the OECD data. However, it is similar in the Jorgenson data. In any case, it seems

As shown in Table 1, productivity growth increased in the U.S. by 0.7 percentage points between the two periods and decreased in Europe by 0.4 percentage points to essentially equal levels.[11] Although these changes are small in absolute terms, they are large in relative terms (for example, an increase of about 58 percent for the U.S.). Experience was by no means the same in all the European countries. Among the larger countries, Germany and Italy experienced bigger than average decreases while France experienced a significant increase (0.4) and remained above the U.S. level. Among the smaller countries, Denmark experienced a larger than average decrease, and Belgium and the Netherlands had small increases.

The OECD breaks labor productivity growth into two components: capital deepening (percentage increase in the ratio of quality adjusted capital to labor multiplied by capital's share) and growth in multi-factor factor productivity (MFP).[12] Neither component by itself provides a complete explanation for the observed patterns of in labor productivity growth. Capital deepening and MFP growth account for 0.4 and 0.3 percentage points of the increase in the U.S. and for equal amounts (0.2 percentage points) of the decrease in Europe, respectively.

Jorgenson (2004) provides a breakdown of labor productivity growth into components for the G-7 countries.[13] Table 2 contains a comparison of the OECD and Jorgenson figures for European countries for which data is available from both sources.[14] At the most general level, the two breakdowns tell essentially the same story, and this is the story we will use in our later analysis. There was a pickup in labor productivity growth in the U.S. and a slowdown in the large European countries of France, Germany, and Italy (FGI). Capital deepening increased in the U.S. and fell in FGI, and MFP growth increased in the U.S. and fell in Europe.

However, there are some significant differences between the two sets of estimates. In the Jorgenson data, productivity growth for FGI is significantly below that for the U.S. in the later period. The Jorgenson data show a slowdown rather than a pickup in France, a much larger decline for Germany, and a somewhat larger decline for Italy. As for capital deepening, Jorgenson shows a larger increase for the U.S. and a larger decline for FGI and for France and Germany individually. Regarding MFP growth, Jorgenson finds a pattern that is similar to that found by the OECD—little change in both the U.S. and FGI with a large increase in France more than offset by large declines in Germany and Italy—but finds that the declines in Germany and Italy are bigger and smaller, respectively. Jorgenson shows labor quality growth falling

---

unreasonable to exclude France from a "Europe" aggregate.

[11] Average growth for Europe is computed by adding up average growth for the individual countries weighted by their shares in nominal European GDP. It is not affected at all if Sweden is added and is changed only slightly if the U.K. is added.

[12] Since the OECD has adjusted investment for quality change, capital deepening includes both increases in the physical amount of capital and increases in the quality of a given physical amount.

[13] We have adopted the OECD labeling convention under which, for example, hours data for 1989 through 1995 are used to construct the average growth of hours for the period labeled 1990-1995. Jorgenson (2004) uses a different labeling convention under which the period we label as 1990-1995 is labeled as 1989-1995 instead. In presenting Jorgenson's data, we have used our labeling convention.

[14] Jorgenson also presents data for the U.K., but, as stated above we have chosen not to include the U.K. in our analysis.

everywhere but in Italy, and especially in France. In contrast, the OECD data are constructed under the assumption that labor quality is constant.

Jorgenson provides a further breakdown of capital deepening and MFP growth which is shown in Table 3. Information and communication technology (ICT) capital deepening (the percentage increase in the ratio of quality-adjusted ICT capital to total employment times the ICT capital's share) increased more than twice as much in the U.S. as in FGI, 0.42 versus 0.18. (These data are expressed in percentage points, as are all the data presented in the rest of this section unless indicated otherwise.) Non-ICT capital deepening increased in the U.S. and fell in FGI by 0.23 and 0.67, respectively. MFP in the ICT sector grew one-third faster in FGI, 0.16 versus 0.25.[15] MFP growth in the non-ICT sector remained essentially unchanged in the U.S. fell 0.75 in FGI where an increase in France was more than offset by decreases in Germany and Italy.

The OECD produces data on growth in ICT and non-ICT capital services which is shown in Table 4. We have not as yet been able to use these data to construct a breakdown of capital deepening data that is directly comparable to Jorgenson's.[16] However, the bottom two rows of Table 4 seem to be roughly consistent with Jorgenson's data. Growth in ICT capital services increased by 1.7 in the U.S. and less than a third that much (0.5) in Europe with Germany (0.3) being the outlier on the low side. Non-ICT capital services increased by 0.7 in the U.S. and fell by 0.5 in Europe with increases in only the Netherlands and Denmark and with France having an exceptionally large decrease (0.9).

There has been much interest in the sectoral breakdown of the changes in labor productivity growth in the United States. There are considerable differences among the results obtained by various investigators. To some extent, results seem to depend on whether the investigators use sectoral data on value added or on gross output. We briefly discuss some of the main contributions to the debate about which data are more appropriate but make no attempt to resolve it. Rather our objective is to provide some support for the choices we make in our analysis below.

Using OECD data on *value added by sector* in the U.S. (a rearrangement of BEA data) we constructed a sectoral breakdown of labor productivity growth for the U.S. which is shown in Table 5.[17] In this table labor productivity growth is weighted by the importance of the sector in the economy. It appears that the pickup in productivity growth was restricted to three sectors: (i) Manufacturing (.2), (ii)Wholesale and Retail Trade; Restaurants and Hotels (.4), and (iii) Finance, Insurance, Real Estate, and Business Services (.2).[18]

---

[15] Cite Oliner and Sichel on increase in MFP in the ICT sector.

[16] Among other problems, we have not yet been able to find factor share data by sector.

[17] The contributions in Table 5 were constructed by netting the sectoral contribution to the growth of hours from the sectoral contribution to the growth of output. The former was obtained by using the following formula: $c_{i,t} = (h_{i,t} - h_{i,t-1})/H_{t-1}$, where $c_{i,t}$ is sector i's contribution at time t, $h_{i,t}$ is hours worked in sector i at time t, and H_{t-1} is total hours worked at time $t-1$. The latter was computed using Equation 3 in Whelan (2000).

[18] These conclusions are broadly consistent with those of the study by McKinsey and Company. We will provide support for this assertion in the next draft.

There is considerable disagreement among the experts about the relative merits of sectoral breakdowns based on value added data and gross output data. Using BEA data on *gross output by sector*, Stiroh (2002) constructed the sectoral breakdown for similar periods in Table 7.[19] His breakdown shows labor productivity growth not weighted by the importance of the sector in the economy. For the most part, the breakdown based on gross output reveals roughly the same as pattern as that based on value added. However, there are some differences. In particularly, in the Stiroh breakdown the increase in labor productivity growth in manufacturing seems larger.[20]

It is obvious that much remains to be learned about the causes of and sectoral breakdowns of the increase in labor productivity growth in the U.S. both absolutely and relative to 'Europe'. However, three things seem clear. First, roughly two-thirds of the growth in labor productivity is due to capital deepening, and the rest in due to increases in MFP in the ICT sector. Second, it seems implausible to attribute all of the increase in capital deepening to decreases in the 'quality-adjusted' relative price of investment goods, so there must have other contributing factors. Third, significant increases in labor productivity growth have been experienced in sectors in which output is arguably largely nontraded, such as wholesale and retail trade. Thus, in analyzing the 1990s it does not seem appropriate to follow the common practice in the studies of productivity increases in open economies to focus attention only on sectors in which output is traded, such as manufacturing.

3   The U.S. Economy in the 1990s

Some additional data for the U. S. economy relevant for analyzing the effects of productivity shocks is shown in Figure 1. The top left panel shows that the increase in labor productivity growth was abrupt.[21]

As shown in the top right panel, there was an investment boom in the last half of the 1990s. Investment (as a share of GDP), the broken line, rose throughout this period from about 19% to about 22%. In contrast, the saving rate, the solid line, climbed by 2 percentage points between 1995 and 1998 but fell back to slightly below its 1994 level by the end of 2000. Since 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 trade balance, as shown in the bottom right panel.

Finally, the bottom left panel shows that the TOT, the darker line, improved by as much as 5 percent before giving back much of their gain by the end of the decade.

---

[19] Tlhe choice of periods can sometimes matter quite a bit when summarizing productivity growth experience and plan to try to get gross output data for the periods used in the rest of our tables.

[20] Outsourcing may distort productivity data. Outsourcing from one sector to another leaves gross output in the outsourcing sector unchanged but reduces value added and hours worked in that sector. Gross output data would show a productivity increase in the outsourcing sector. Value added would show a change in productivity to the extent that value added and hours decreased by different proportions.

[21] The quarterly data shown comes from the productivity release of the Bureau of Labor Statistics. It differs from the OECD data presented earlier in that it excludes the government and farm sectors.

As indicated by the lighter line, the dollar appreciated dramatically in real terms.

What is not shown in the figure is that the an overwhelming portion of growth in investment can be attributed to outlays for IT investment (information-processing equipment and computer software); nominal outlays on these item were 9 percent of total nominal investment in 1990 and 22 percent in 1999. Real outlays grew faster because computer prices have fallen. Increase in IT investment growth accounts for 60 percent of increase in all investment.[22]

There is another important feature of the U.S. experience that we do not address here.[23] It apparently took private agents some time to become convinced that productivity growth had picked up. Real GDP growth was significantly above forecasts for some time at the beginning of the period, and price inflation, as measured by the GDP deflator was below forecasts throughout most of the period.

4 Model

In our analysis of the effects of different productivity shocks, we use a dynamic stochastic general equilibrium model with two countries designated home and foreign. In each country there is a representative agent. We describe the behavior of the home agent. The behavior of the foreign agent is analogous.

4.1 Tastes

In period t, the home agent maximizes the intertemporal utility function[24]

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

Period utility is a constant elasticity function of V_s which, in turn, is a Cobb-Douglas function of consumption and leisure which is given by one minus labor (L_s):

$$V_s = V\left(C_s, L_s\right) = C_s^a \left(1 - L_s\right)^{1-a} \tag{2}$$

The representative agent also chooses holdings of a single bond (B) denominated in the home traded good (the numeraire for the model) and traded internationally.

4.2 Technology

The agent must take into account the structure of technology. This technology is represented in the flow chart labeled Figure 2 which shows details for the home country. In each country there are six sectors. First there are two sectors in which traded

---

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

[23]This feature is addressed in Erceg, Guerrieri, and Gust (2003), Edge, Laubach, and Williams (2004), and Hunt and Rebucci (1988).

[24]The Lagrangian expression for the home agents maximization problem is in the Appendix.

(T) goods and nontraded (N) goods are produced using a Cobb-Douglas production functions modified by costs of changing capital-labor ratios:

$$Y_{is} = F\left(K_{is}, L_{is}, K_{is-1}, L_{is-1}\right)$$

$$= \left[K_{is}^{\alpha} L_{is}^{1-\alpha}\right] \left[1 - \frac{\psi_{iKL}}{2}\left(\frac{K_{is}/L_{is}}{K_{is-1}/L_{is-1}} - \mu_K\right)^2\right], \qquad i = T, N \tag{3}$$

That is, for sector i, output (Y_{is}) is produced using sector-specific capital (K_{is}) and labor (L_{is}). The production functions are assumed to have identical coefficients.[25] As stated above, there are costs associated with changing factor proportions. We think of these costs as including hiring and firing costs as well as the training costs associated with bringing new workers into a sector. In particular, for sector i, there are quadratic costs of changing the capital-labor ratio at a rate different from a common steady-state growth rate (μ_K).[26] These costs are governed by ψ_{iKL}.[27] The T and N sectors use all the labor that is supplied:

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

Next, there are two sectors for the accumulation of sector-specific capital. Each of these sectors uses yesterday's sector-specific capital stock $(K_{i,s-1})$ and some of yesterday's investment good $(J_{i,s-1})$ to generate today's sector-specific capital stock and experiences its own investment usefulness (IU) shock (U_{is}):[28]

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

where ϕ governs the costs of adjusting the capital stock.[29] An increase in investment usefulness in a sector makes it possible for investment goods $(J_{i,s-1})$ of a *given quality* to generate bigger additions to the effective capital stock. It can be thought of as

---

[25] It is much easier to characterize the steady state of the model if the coefficients are identical.

[26] Since steady-state labor is constant, μ_K is equal to the common steady-state growth rate of capital.

[27] Under our assumptions and with $\psi_{iL} = 0$, a Cobb-Douglas production function with costs of adjusting the capital-labor ratio approximates a constant elasticity production function of the form

$$\mathcal{F}(K_{is}, L_{is}, X_{is}) = \left[\alpha\left(K_{is}\right)^{\frac{-\psi_{iKL}}{\alpha(1-\alpha)}} + (1-\alpha)\left(X_{is}L_{is}\right)^{\frac{-\psi_{iKL}}{\alpha(1-\alpha)}}\right]^{\frac{\alpha(1-\alpha)}{-\psi_{iKL}}}$$

which has the elasticity of substitution

$$\frac{\alpha(1-\alpha)}{\psi_{iKL}+\alpha(1-\alpha)} \quad .$$

[28] The usefulness shocks are entered with the exponent $\frac{1-\alpha}{\alpha}$ so that $\frac{Y_{is}}{U_{iis}}, i = T, N$ is constant in the nonstochastic steady state. That is, a one percent increase in U_{is} raises the steady-state path of Y_{is} by one percent.

[29] Relative to the conventional quadratic adjustment costs, it is easier to accommodate trend growth in our formulation.

an improvement in methods of production and distribution that can be implemented only by capital accumulation involving the purchase of investment goods. An example is the development of new software that makes it desirable to buy more computers even though the quality of computers has not increased. In Figure 2 the stages of the production process at which IU shocks have their effects are indicated by rectangles. Since IU shocks do not affect the quality of investment goods, they do not directly affect their relative price (the price of investment goods relative to the GDP deflator). Of course, they do create incentives to increase capital accumulation and to produce more at given factor prices.

Finally, there are sectors in which 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 good (C_{Ns}):

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

and J_s is a CES function of 'quality-enhanced' investment inputs of traded goods ($\tilde{I}_{Ts}$) and of the local nontraded good ($\tilde{I}_{Ns}$):[30]

$$J_s = \left[(1 - \nu_I) \left(\frac{\tilde{I}_{Ts}}{1 - \nu_I} \right)^{1 - \theta_{IN}} + \nu_I \left(\frac{\tilde{I}_{Ns}}{\nu_I} \right)^{1 - \theta_{IN}} \right]^{\frac{1}{1 - \theta_{IN}}} \tag{6}$$

where ν_i and $1/\theta_{iN}$, $i = C, I$ are, respectively, the weight given to the nontraded input in the production of good i, and the elasticity of substitution between the traded and nontraded inputs in the production of good i. The meaning of the term 'quality-enhanced' is explained below. J_s, $\tilde{I}_{Ts}$, and $\tilde{I}_{Ns}$ are measured in effective units, such as number of megahertz, not in physical units, such as the number of computers.

In turn, consumption of traded goods is a CES function of consumption of home traded goods (C_{Hs}) and of foreign traded goods (C_{Fs}):

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

By analogy, the investment input of quality-enhanced traded goods is a CES function of quality-enhanced inputs of home traded goods ($\tilde{I}_{Hs}$) and of foreign traded goods ($\tilde{I}_{Fs}$):

$$\tilde{I}_{Ts} = \left[\ell_I \left(\frac{\tilde{I}_{Hs}}{\ell_I} \right)^{1 - \theta_{IT}} + (1 - \ell_I) \left(\frac{\tilde{I}_{Fs}}{1 - \ell_I} \right)^{1 - \theta_{IT}} \right]^{\frac{1}{1 - \theta_{IT}}}, \qquad \ell_I = n + \kappa_I \tag{8}$$

---

[30] In, for example, Edge, Laubach, and Williams (2003, 2004) an investment sector like ours is called an IT producing sector. The IT good produced by this sector is the only capital good. For some purposes, it might be useful to construct models with both IT capital and other capital, but we do not attempt to do so in this paper.

where ℓ_C and ℓ_I, respectively, are the weights on the home traded good in consumption and investment inputs of traded goods. 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 ($n = \frac{1}{2}$). The parameters κ_C and κ_I ($0 < \kappa_C$, $\kappa_I < \frac{1}{2}$), respectively, determine the amount of local-good bias in the in consumption and investment inputs of traded goods; there is no home bias when $\kappa_C = \kappa_I = 0$. We incorporate the empirically based assumption that the local-good bias in consumption ($\kappa_C = .32$ so that $\ell_C = .82$) is greater than the local-good bias in investment ($\kappa_I = .08$ so that $\ell_I = .58$).

'Quality enhancement' occurs when a unit of physical input yields more units of effective input. We assume that all investment inputs (but no consumption inputs) are subject to quality enhancement:

$$\tilde{I}_{Hs} = Q_{Hs}I_{Hs}, \qquad \tilde{I}_{Fs} = Q_{Fs}I_{Fs}, \qquad \tilde{I}_{Ns} = Q_{Ns}I_{Ns}$$

$$\tilde{P}_{Hs} = \frac{P_{Hs}}{Q_{Hs}}, \qquad \tilde{P}_{Fs} = \frac{P_{Fs}}{Q_{Fs}}, \qquad \tilde{P}_{Ns} = \frac{P_{Ns}}{Q_{Ns}}$$

(9)

where the $\tilde{I}_{js}$ are effective inputs, the I_{js} are physical inputs, and the Q_{js} are investment quality (IQ) shocks that can be different. In Figure 2, the stages in the production process at which IQ shocks have their effects are indicated by octagons. Our IQ shocks are designed to generate effects similar to those of an increase in multifactor productivity in an unmodeled investment and communication technology sector. Note that while all of the IQ shocks affect output of the investment good which is used to increase the capital stocks in both the traded and nontraded goods sectors, each of the IU shocks discussed above affects the desirability of capital accumulation in only one of the two sectors.

In contrast to IU shocks, IQ shocks are reflected in the relative price of investment goods. Strict application of our model implies a particular measure of the price of investment goods.[31] However, for reasons of comparability with the data, we report a similar measure that is analogous to the deflator for a component of GDP. In particular, we use a weighted average of the prices of $\tilde{I}_{Hs}, \tilde{I}_{Fs}$, and $\tilde{I}_{Ns}$ where the weights are current expenditure shares.

4.3 The Budget Constraint

The agent must also take into account a budget constraint which we express using the home traded good as the numeraire. Income from production of traded and nontraded goods plus interest from claims on foreigners last period must be at least enough to cover purchases of both traded goods and the home nontraded good for use in assembling consumption and the investment input plus claims on foreigners

---

[31] This measure is constructed by minimizing the cost of investment inputs required to produce a unit of J_s.

this period and "portfolio management costs" associated with claims on or liabilities to foreigners:[32]

$$F\left(K_{Ts}, L_{Ts}, X_{Ts}\right) + P_{Ns}F\left(K_{Ns}, L_{Ns}, X_{Ns}\right) + R_{s-1}B_{s-1} \geq$$

$$C_{Hs} + P_{Fs}C_{Fs} + P_{Ns}C_{Ns} + I_{Hs} + P_{Fs}I_{Fs} + P_{Ns}I_{Ns} + B_s + \frac{\zeta}{2}\frac{B_s^2}{Z_{Ts}}$$

P_{Fs} and P_{Ns}, respectively, are the prices of foreign traded goods and home nontraded goods in term of home traded goods. R_s is the gross return on bonds denominated in the home traded good. A positive value of B_s indicates claims of home residents on foreign residents.

4.4 Relative Prices

In this paper we focus on four relative prices. For each country there is the relative price of that country's nontraded good in terms of its traded good represented by P_{Ns} and P_{Ns}^*. An an asterisk on a variable indicates that it relates to the foreign country.

We use the label "TOT" to refer to the price of the home traded good in terms of the foreign traded good denoted by $1/P_{Fs}$. An improvement in the TOT, the number of foreign goods it takes to buy a unit of home goods, is associated with a fall in P_{Fs}.

We use the label "RER" to refer to the CPI adjusted exchange rate, that is price of the home consumption bundle in terms of the foreign consumption bundle:

$$RER = \frac{P_{Cs}}{P_{Fs}P_{Cs}^*} \tag{10}$$

where

$$\frac{P_{Cs}}{P_{Fs}} = \left\{(1-\nu)\left[\ell_C\left(\frac{1}{P_{Fs}}\right)^{\frac{\theta_{CT}-1}{\theta_{CT}}} + (1-\ell_C)\right]^{\frac{(\theta_{CN}-1)\theta_{CT}}{(\theta_{CT}-1)\theta_{CN}}} + \nu\left(\frac{P_{Ns}}{P_{Fs}}\right)^{\frac{\theta_{CN}-1}{\theta_{CN}}}\right\}^{\frac{\theta_{CN}}{\theta_{CN}-1}}$$

$$\tag{11}$$

$$P_{Cs}^* = \left\{(1-\nu)\left[\ell_C^*\left(\frac{1}{P_{Fs}}\right)^{\frac{\theta_{CT}-1}{\theta_{CT}}} + (1-\ell_C^*)\right]^{\frac{(\theta_{CN}-1)\theta_{CT}}{(\theta_{CT}-1)\theta_{CN}}} + \nu\left(P_{Ns}^*\right)^{\frac{\theta_{CN}-1}{\theta_{CN}}}\right\}^{\frac{\theta_{CN}}{\theta_{CN}-1}}$$

where P_{Cs}^* is the price of the foreign consumption bundle in terms of the foreign traded good, and P_{Ns}^* is the price of the foreign nontraded good in terms of the foreign traded good. An increase in the RER is an appreciation of the home currency in real terms.

---

[32]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 relative prices of nontraded goods and the TOT play key roles in our analysis but the RER does not. We report it because it is a familiar if not very useful variable. Increases in P_{Ns} and improvements in the TOT (decreases in P_{Fs}) cause the home currency to appreciate in real terms but increases in P_{Ns}^* cause it to depreciate.

5   Simulations

Our simulations have not yet been completed but will be soon. At a minimum, we plan to report and discuss the following simulations

- A comparison of effects of symmetric (as regards country, sector, and adjustment costs) temporary increases in IQ and IU growth to show the similarity in effects of these two shocks in a 'closed economy' and to make possible comparisons with the results of well-known closed-economy studies.

- A comparison of a temporary increase in IQ growth in the U.S. alone with such a temporary increase in both countries with higher adjustment costs in Europe to show that the effects in the two cases are very similar and to contrast both theses open-economy results with the 'closed economy' results of the simulations described in the first bullet point.

- A comparison of persistent and temporary increases in the growth of IQ in the U.S. and Europe with high adjustment costs in Europe to show that this shock can generate significant increases in labor productivity but may well lead to a delayed pickup in investment (possibly preceded by an actual decline) in the U.S. and a much longer delayed pickup in Europe.

- Persistent increase in growth of IQ in U.S. and Europe as well as temporary increase in IU in U.S. and possibly in Europe with high adjustment costs in Europe to demonstrate that this combination of shocks and adjustment costs is very helpful in analyzing U.S. and European experience in the late 1990s.

6   Conclusions

From simulations we have already run and analyzed, we have drawn some tentative conclusions about the kinds of shocks that seem consistent with U.S. and European experience of the 1990s.

- An appealing way to generate something like the observed abrupt increases in the growth of labor productivity in the U.S. and the more rapid decrease in the relative price of investment goods in the U.S. and Europe is to include persistent shocks to the growth rate of investment quality in both the U.S. and Europe.

- A plausible explanation for the relatively quick and sizeable pickup in investment in the U.S. in both the traded and, especially, the nontraded sectors is

a temporary increase in the growth of investment usefulness (with quality held constant). With such a shock there is an immediate increase in investment while with a persistent increase in the growth rate of investment quality the increase in investment is likely to delayed and investment may actually fall in the short run because of the anticipation that investment goods will be even cheaper in the future.

- The pickup in MFP growth in the ICT sector in Europe as well as casual empiricism suggest that the U.S. and Europe have available roughly the same improvements in technologies. There is evidence that the costs of adjusting to changes in technology are significantly higher in Europe and this cost differential is probably an important cause of the change in the labor productivity growth differential.

Appendix

The Langrangian expression for the home agent is

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

$$+ \Lambda_{Ns} \left[K \left(S_{N,s-1}^{\frac{1-\alpha}{\alpha}} J_{N,s-1}, K_{N,s-1} \right) - K_{Ns} \right] + \Lambda_{Js} \left[J \left(I_{Ts}, I_{Ns} \right) - J_{Ts} - J_{Ns} \right]$$

$$+ \Lambda_{Cs} \left(R_{s-1} B_{s-1} + F \left(K_{Ts}, L_{Ts}, X_{Ts} \right) + P_{Ns} F \left(K_{Ns}, L_{Ns}, X_{Ns} \right) - \frac{\zeta}{2} \frac{B_s^2}{Z_{Ts}} \right.$$

$$\left. \left. - C_{Hs} - P_{Fs} C_{Fs} - P_{Ns} C_{Ns} - I_{Hs} - P_{Fs} I_{Fs} - P_{Ns} I_{Ns} - B_s \right) \right\}$$

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.

Table A1: Steady-State Ratios	
share of time endowment worked	0.33
relative prices of nontraded goods	1
terms of trade	1

Table A2: Parameter Values		
β	discount factor	.99
γ	elasticity of marginal utility w.r.t. V	1.5
a	share of consumption in V (approximate)	0.37
α	share of capital in production	0.3
δ	depreciation rate	0.025
ϕ	governs capital adjustment costs	0.2
ν_C	share of nontraded goods in C	0.63
ν_I	share of nontraded goods in I	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	governs local-good bias in C_T	0.32
κ_I	governs 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}	governs capital-labor ratio adjustment costs	0.0
ζ	governs portfolio management costs	.001

References

Backus, D., P. Kehoe, and F. Kydland (1994a) "Dynamics of the Trade Balance and the Terms of Trade: The J Curve?", *American Economic Review*, 84, 84–103.

Backus, D., P. Kehoe, and F. Kydland (1994b) "Relative Price Movements in Dynamic General Equilibrium Models of International Trade", in F. van der Ploeg (ed.) *The Handbook of International Macroeconomics*, Blackwell, Oxford.

Baxter, M., and M. J. Crucini (1995) "Business Cycles and the Asset Structure of Foreign Trade", *International Economic Review*, 36, 821–854.

Bosworth, B. P., and J. E. Triplett (2000) "What's New About the New Economy? IT, Economic Growth, and Productivity", processed, Brookings Institution.

Edge, R. M., T. Laubach, and J. C. Williams (2003) "The Responses of Wages and Prices to Technology Shocks", Finance and Economics Discussion Papers 2003-65, Federal Reserve Board.

Edge, R. M., T. Laubach, and J. C. Williams (2004) "Learning and Shifts in Long-Run Productivity Growth", Finance and Economics Discussion Papers 2004-21, Federal Reserve Board.

Erceg, C. J., L. Guerrieri, and C. Gust (2003) "Productivity Growth and the Trade Balance in the 1990s: the Role of Evolving Perceptions", processed, Federal Reserve Board.

Greenwood, J., Z. Hercowitz, and G. W. Huffman (1988) "Investment, Capacity Utilization, and the Real Business Cycle", *American Economic Review*, 78, 402–417.

Greenwood, J., Z. Hercowitz, and P. Krusell (1997) "Long-Run Implications of Investment-Specific Technological Change", *American Economic Review*, 87, 342–362.

Hercowitz, Z. (1998) "The 'Embodiment' Controversy: A Review Essay", *Journal of Monetary Economics*, 41, 217–224.

Hercowitz, Z., and M. Sampson (1991) "Output Growth, the Real Wage, and the Employment Fluctuations", *American Economic Review*, 81, 1215–1237.

Hunt, B., and A. Rebucci (1988) "The U.S. Dollar and the Trade Deficit: What Accounts for the Late 1990s?", processed, International Monetary Fund.

Jorgenson, D. W. (2004) "Information Technology and the G7 Economies", processed, Harvard.

Kollmann, R. (1998) "U.S. Trade Balance Dynamics: the Role of Fiscal Policy and Productivity Shocks and of Financial Market Linkages", *Journal of International Money and Finance*, 17, 637–669.

Laxton, D., and P. Pesenti (2003) "Monetary Rules for Small, Open, Emerging Economies", *Journal of Monetary Economics*, 50, 1109–1146.

Schmitt-Grohe, S., and M. Uribe (2003) "Closing Small Open Economy Models", *Journal of International Economics*, 61, 163–185.

Stiroh, K. J. (2002) "Information Technology and the U.S. Productivity Revival:What Do the Industry Data Say?", *American Economic Review*, 92, 1559–1576.

Stockman, A., and L. Tesar (1995) "Tastes and Technology in a Two-Country Model of the Business Cycle: Explaining International Comovements", *American Economic Review*, 85, 168–185.

Table 1: Labor Productivity Growth: Breakdown by Region
(percentage points)

	U.S.	Europe*	France	Germany	Italy	Belgium	Denmark	Netherlands	Sweden	U.K.
Output										
1990-1995	2.3	1.8	1.3	2.1	1.5	1.8	1.8	2.4	0.7	1.7
1996-2001	3.4	2.2	2.6	1.6	2.1	2.4	2.5	3.3	2.8	2.8
Hours										
1990-1995	1.1	-0.6	-0.5	-0.7	-1.3	0.1	-0.2	1.0	-1.0	-1.0
1996-2001	1.5	0.5	0.4	-0.1	1.0	0.6	1.2	1.7	0.8	0.8
Labor Productivity										
1990-1995	1.2	2.2	1.8	2.4	2.7	1.7	2.0	1.4	1.7	2.6
1996-2001	1.9	1.8	2.2	1.9	1.1	1.9	1.3	1.6	2.0	2.0
Capital Deepening										
1990-1995	0.5	1.0	1.0	1.1	1.0	1.1	1.0	0.5	1.3	1.1
1996-2001	0.9	0.8	0.7	0.9	0.7	1.1	1.2	0.7	1.2	1.0
Multifactor Productivity										
1990-1995	0.7	1.2	0.8	1.4	1.7	0.6	1.0	0.8	0.4	1.6
1996-2001	1.0	1.0	1.5	1.0	0.4	0.7	0.1	0.9	0.8	1.0

* Aggregate for Belgium, Denmark, France, Germany, Italy, and Netherlands

Table 2: Labor Productivity Growth: Comparison of Two Breakdowns

	US		FGI*		France		Germany		Italy	
	OECD	Jorgenson	OECD	Jorgenson	OECD	Jorgenson	OECD	Jorgenson	OECD	Jorgenson
Output										
1990-1995	2.3	2.4	1.7	1.8	1.3	1.3	2.1	2.3	1.5	1.5
1996-2001	3.4	3.6	2.1	1.7	2.6	2.3	1.6	1.2	2.1	1.9
Hours										
1989-1995	1.1	1.0	-0.8	-0.6	-0.5	-0.4	-0.7	-0.7	-1.3	-0.6
1996-2001	1.5	1.5	0.3	0.5	0.4	0.9	-0.1	-0.1	1.0	1.0
Labor Productivity										
1990-1995	1.2	1.3	2.3	2.3	1.8	1.7	2.4	3.1	2.7	2.1
1996-2001	1.9	2.0	1.8	1.2	2.2	1.4	1.9	1.3	1.1	0.9
Capital Deepening										
1990-1995	0.5	0.8	1.0	1.5	1.0	1.4	1.1	1.6	1.0	1.3
1996-2001	0.9	1.4	0.8	1.0	0.7	0.6	0.9	1.2	0.7	1.1
Multifactor Productivity										
1990-1995	0.7	0.2	1.3	0.4	0.8	-0.3	1.4	1.1	1.7	0.4
1996-2001	1.0	0.4	1.0	0.0	1.5	0.6	1.0	-0.1	0.4	-0.5
Labor Quality										
1990-1995	0	0.4	0	0.4	0	0.6	0	0.3	0	0.4
1996-2001	0	0.2	0	0.3	0	0.2	0	0.2	0	0.4

* Aggregate for France, Germany, and Italy.

Table 3: Capital Deepening's Contribution to Labor Productivity Growth
Jorgenson Estimates

	US	FGI*	France	Germany	Italy
ICT Capital Deepening					
1990-1995	0.43	0.26	0.20	0.28	0.28
1996-2001	0.85	0.44	0.39	0.46	0.45
Non-ICT Capital Deepening					
1990-1995	0.32	1.21	1.15	1.33	1.06
1996-2001	0.55	0.54	0.25	0.70	0.61
ICT Multifactor Productivity					
1990-1995	0.25	0.38	0.29	0.43	0.38
1996-2001	0.41	0.63	0.56	0.65	0.68
Non-ICT Multifactor Productivity					
1990-1995	-0.02	0.14	-0.55	0.69	-0.01
1996-2001	0.01	-0.61	0.04	-0.75	-1.17

Table 4: Capital Services Growth: Breakdown by Region
OECD estimates

	US	FGI*	France	Germany	Italy
ICT					
1990-1995	1.97	0.76	0.48	0.88	0.62
1996-2001	3.70	1.34	1.05	1.18	1.46
Non ICT					
1990-1995	0.93	2.20	2.44	2.10	2.22
1996-2001	1.58	1.70	1.54	1.43	2.17

* Aggregate for France, Germany, and Italy.

Table 5: Average Contribution to Labor Productivity Growth by Sector*

	1990-1995	1996-2001	Increase
Agriculture, hunting, forestry & fishing	0.0%	0.0%	0.0%
Mining and quarrying	0.0%	0.0%	0.0%
Manufacturing	0.4%	0.6%	0.2%
Electricity, gas and water	0.1%	0.0%	-0.1%
Construction	-0.1%	-0.1%	0.0%
Wholesale & retail; Hotel & Resaurant	0.3%	0.7%	0.4%
Tansportation, storage & communication	0.3%	0.2%	-0.1%
Finance, insurance, real estate & business-sector services	0.3%	0.5%	0.2%
Community, social & personal services	-0.2%	-0.3%	-0.1%
Total	1.1%	1.7%	0.6%

* Source OECD Stan Database

Table 6: Average U.S. Nominal Gross Investment in ICT and Other Automation Equipment by Sector (percent of value added)*

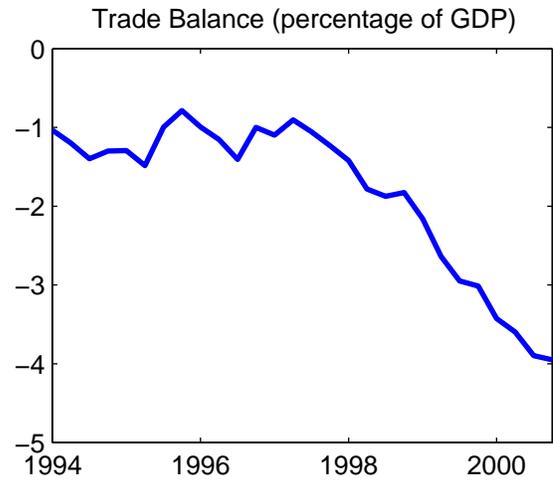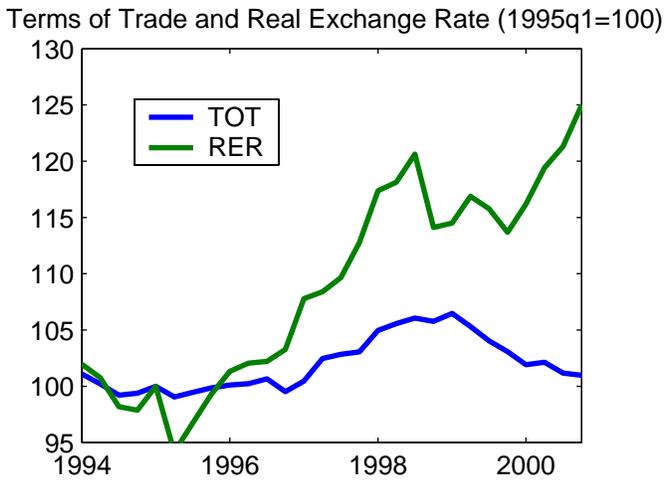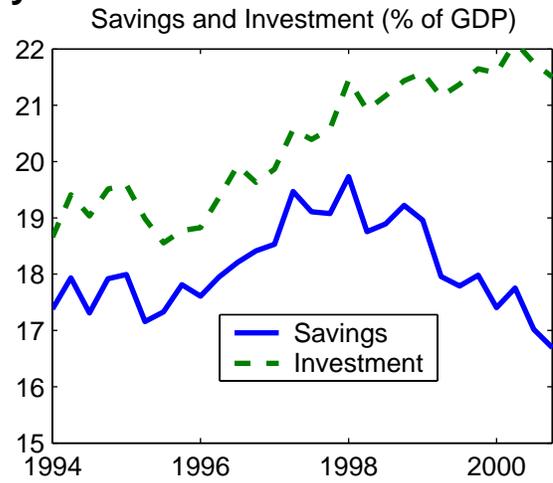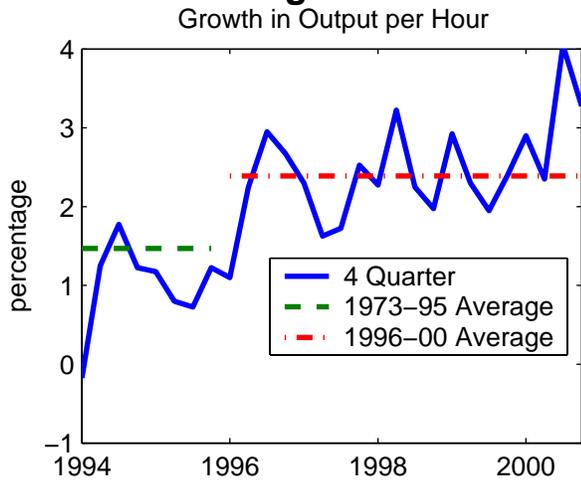|	1990-1995	1996-2001	Increase
Agriculture, hunting, forestry & fishing	0.7	1.0	0.3
Mining and quarrying	3.0	3.1	0.1
Manufacturing	3.2	3.5	0.3
Electricity, gas and water	5.2	4.8	-0.4
Construction	0.6	0.7	0.2
Wholesale & retail	3.3	4.3	1.0
Tansportation, storage & communication	10.0	13.6	3.6
Finance, insurance, real estate & business-sector services	3.8	5.0	1.2
Personal Services**	1.6	2.2	0.6

* source: Bureau of Economic Analysis
** excludes Government

Table 7: Average Labor Productivity Growth Rates: Gross Output by Sector*

Gross Output - Broad Sectors	Annual Growth Rate %		Acceleration 1995-2000 less
	1987-1995	1995-2000	1987-1995
Agriculture, Forestry & Fishing	0.58	-0.28	-0.86
Mining	3.14	2.16	-0.98
Construction	-0.87	-1.65	-0.78
Durable Goods Manufacturing	3.97	6.2	2.24
Nondurable Goods Manufacturing	1.48	2.72	1.24
Transportation and Public Utilities	2.27	2.23	-0.05
Wholesale Trade	3.23	3.99	0.75
Retail Trade	0.97	3.14	2.17
Finance, Insurance and Real Estate	2.33	3.4	1.07
Services	0.4	1.05	0.66

* Source: Stiroh (2002).

Figure 1: The U.S. Economy in the Late 1990s

Growth in Output per Hour

Legend:
- 4 Quarter
- 1973–95 Average
- 1996–00 Average

Savings and Investment (% of GDP)

Legend:
- Savings
- Investment

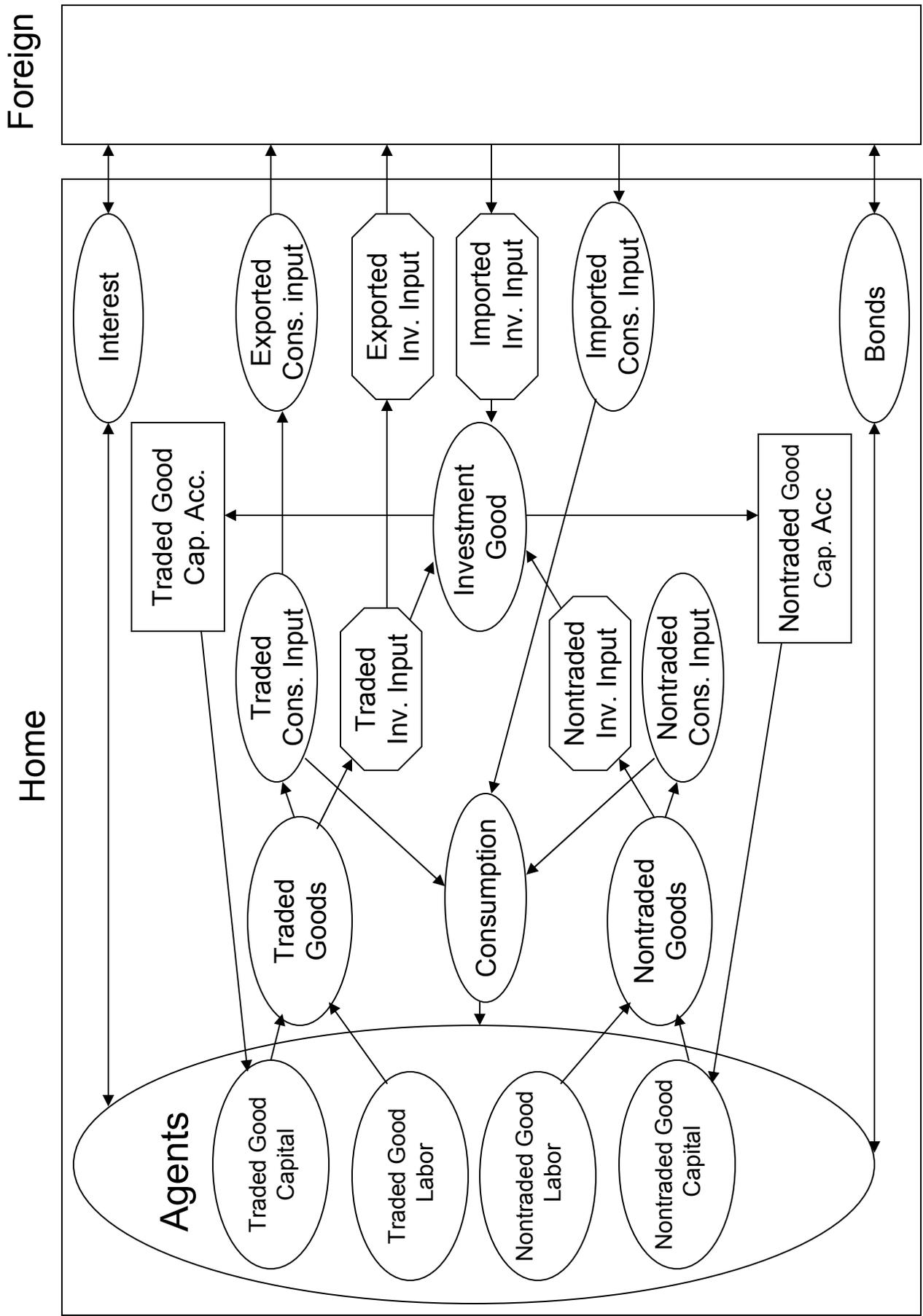## Terms of Trade and Real Exchange Rate (1995q1=100)

Legend:
- TOT
- RER

Trade Balance (percentage of GDP)

Figure 1: Flow Chart of Model