Can IT be Japan's Savior?

Fumio Hayashi
University of Tokyo

Koji Nomura
Keio University

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Abstract

This paper constructs a multi-sector model to take explicit account of the very sharp change in the relative price between non-IT and IT goods. The model is calibrated to the Japanese economy, and its solution path from 1990 on is compared to Japan's macroeconomic performance in the 1990s. Compared to the one-sector analysis of Japan in the 1990s in Hayashi and Prescott (2002), our model does slightly better or just as well in accounting for Japan's output slump and does worse in accounting for the capital-output ratio. We also show that, to revive a 2% long-term growth in percapita GDP, Japan needs to direct 10% of private total hours to the IT sector.

Journal of Economic Literature Classification Numbers: E2, O4, O5,

Key words: IT, growth model, TFP, Japan

1. Introduction

We live in a world where IT goods, such as computers and communications equipments, are continuously getting cheaper than the rest of the goods, at a relentless rate. As shown in Figure 1 for Japan, the relative price of IT goods to non-IT goods in 2000 is one-eightieth of what it was in 1960.[1]

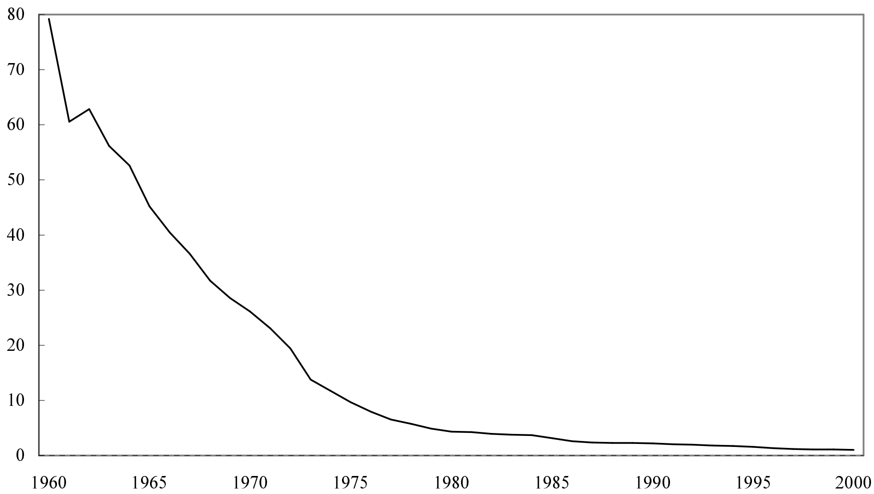

Figure 1: Relative Price of IT Goods in Terms of non-IT Goods (year 2000 = 1)

The rapid change in the relative price creates potentially serious problems for the one-good world of macroeconomics. The Hicks aggregation theorem, which allows a bundle of many goods to be treated as if it is a single good, is no longer valid. If the relative price of two goods is not constant, the utility function and the production function must have those two goods as separate arguments. One could invoke the theory of aggregation of heterogenous capital goods to have a single variable representing capital in the production function, but that single index, called the capital services index, is different from the simple sum of the capital stocks, as Jorgenson and Griliches (1967) first pointed out.

For both the (aggregated) capital stock and the capital services index, the growth rate is a

[1]See the text below for the definition of non-IT and IT goods and how the relative price is calculated.

weighted averages of the growth rates of individual capital stocks. The weights are the value shares for the capital stock and the user-cost shares for capital services. The difference can be substantial when non-IT capital and IT capital are to be aggregated. IT capital's user cost is much higher than non-IT capital's because IT capital depreciates fast physically and in value. If the stock of IT capital is growing fast, the growth rate of capital services is higher than that of the capital stock by a substantial margin, even if IT capital's value share is small. In the growth accounting typically practiced in macroeconomics, the contribution of capital is measured by the growth rate of the aggregated capital stock. The TFP (total factor productivity) growth calculated by the macro growth accounting, therefore, confuses genuine TFP growth with the contribution of IT capital to the growth of capital services.

Hayashi and Prescott (2002) showed that Japan's great stagnation in the 1990s is well-accounted for by the standard neoclassical growth model with a TFP slowdown in the 1990s. Their one-good model, however, does not explicitly take into account the relentless decline in the relative price of IT goods. It is possible that the decline in TFP growth, which is the cornerstone of their analysis, is contaminated by the confusion with capital services and the capital stock.

The purpose of this paper is to do a multi-sector version of the Hayashi-Prescott one-sector exercise. Besides government, there are two market sectors — non-IT and IT sectors — and the household sector producing service flows from owner-occupied housing and consumer durables. By definition, the TFP growth for household and government is zero. In Section 2, we present our multi-sector accounting system matching this multi-sector model. Our data shows, not surprisingly, that the TFP growth in the IT sector is much higher than that in the non-IT sector. We confirm in Section 3 that the TFP growth rate by the macro growth accounting is indeed higher than the genuine TFP growth, which a weighted average of the sectoral TFP growth rates. However, the two TFP growths show similar movements, with a marked decline in the 1990s. Section 4 presents the multi-sector growth model. It distinguishes between non-IT capital and IT capital in the production function. In Section 5, following Hayashi and Prescott (2002), we calibrate the model to the Japanese economy in the 1984-89 period and report results from the simulation of the model from year 1990 on. The multi-sector model does well in accounting for the output slump of the 90s but less well than the one-sector model for the rise in the capital-output ratio in the 1990s. The model's prediction about the long-run output growth depends on how much resources are directed to the IT sector. If the allocation of hours between non-IT and IT sectors remains at the (97.2%, 2.8%) breakdown of year 2000, the long-run percapita GDP growth rate is 1.1%. To raise it to 2.0%, the private labor allocation must move in favor of IT, from (97.2%, 2.8%) to (90%, 10%). Section 6 is a brief conclusion.

2. The Multi-Sector Accounting Framework

The theoretical model to be presented later in the paper is a multi-sector model with two market sectors (non-IT and IT goods-producing sectors) and two non-market sectors (the household and government sectors). This section describes how the model's empirical counterpart, a multi-sector accounting system, is constructed. Its production account is derived from the 47-sector system developed in Jorgenson and Nomura (2005) (hereafter, JN).[2] Its final demand components, too, are from the KEO Database.

Output and Value Added

Table 1: Value Added at Factor Costs

	market production		non-market production	
	non-IT sector (j = 1)	IT sector (j = 2)	household sector (j = H)	gov't sector (j = G)
value added	$P_{1t}Y_{1t}$	$P_{2t}Y_{2t}$	$P_{Ht}Y_{Ht}$	$P_{Gt}Y_{Gt}$
non-IT capital cost	$P_{1t}r_{11t}K_{11t}$	$P_{2t}r_{12t}K_{12t}$	$P_{Ht}r_{1dt}K_{1Ht}$	$P_{Gt}r_{1Gt}K_{1Gt}$
IT capital cost	$P_{1t}r_{21t}K_{21t}$	$P_{2t}r_{22t}K_{22t}$	$P_{Ht}r_{2dt}K_{2Ht}$	$P_{Gt}r_{2Gt}K_{2Gt}$
labor cost	$W_{1t}L_{1t}$	$W_{2t}L_{2t}$		$W_{Gt}L_{Gt}$

[2]It builds on the 43-sector KEO Database, which is a comprehensive productivity database for the Japanese economy maintained at the Keio Economic Observatory (KEO), Keio University, Japan. It consists of a time-series of input-output tables and detailed inputs of capital and labor. See Kuroda, Shimpo, Nomura, and Kobayashi (1997) for a detailed documentation. From the 43 industries in the KEO database, JN separates out three IT producing industries — computers, communications equipment, and electronic components — to form 47 industries.

By way of establishing the notation, Table 1 shows value added (also called net output in the productivity literature) at producer prices and their breakdown into factor costs for the four sectors. We define the IT sector (j=2) as consisting not only of the three IT industries in JN's 47 industries (which are computers and peripherals, communications equipment, and electronic components), but also of computer software. The software sector is defined narrowly as computer programming and other software services: custom software, pre-packaged software, own-account software, games, and other software, excluding data processing and other related information services.[3]

Real value added of the IT sector, Y_{2t}, is the translog index of value added of these four industries.[4] Similarly, we define real value added of non-IT sector Y_{1t} as the translog index of value added of all the industries except the IT sector, household, and government sectors. The price indexes of value added at producer prices, P_{jt} ($j = 1, 2$), are derived by dividing the aggregated nominal value added by real value added in each sector.

As in JN (Jorgenson and Nomura (2005)), the household sector produces rental service of owner-occupied housing and consumer durables with no labor input. Those rental services are consumed by the household sector itself, by definition. Nominal production, $P_{Ht}Y_{Ht}$, equals factor costs, which consist entirely of the user costs of owner-occupied housing and consumer durables. The government sector produces government service that is consumed by the government itself, by definition. The imputed nominal value of government services, $P_{Gt}Y_{Gt}$, is defined

[3]We estimate the output and inputs of computer software sector as follows. In the Japanese 2000 benchmark input-output table produced by Statistics Bureau, Ministry of Internal Affairs and Communications, production activity of software sector is not divided from information services (851201), although the commodity of software (8512011) is separated. We estimate production of the software sector using the activity in 851201. The own-account software is not included in the production of software (8512011) of the Japanese 2000 benchmark IO table and still is not capitalized in the Japanese National Accounts by Economic and Social Research Institute (ESRI), Cabinet Office. For output and inputs of own-account software, we use the estimates in Nomura (2004b).

[4]In general, let Y_{jt} and P_{jt} be real value added and the associated price index of sector j in period t. The translog quantity index Y_t is defined as

$$\Delta \ln Y_t = \sum_j \bar{v}_{jt} \, \Delta \ln Y_{jt},$$

where $\Delta \ln Y_t \equiv \ln Y_t - \ln Y_{t-1}$ and $\bar{v}_{jt}$ is the two-period average share of sector j's nominal value added in total nominal value added.

as capital costs and the value of labor input, where capital costs include not only consumption of public capital but also total capital service cost of publicly owned capital. Table 2 report sectoral shares of nominal value added. The imputed prices of value added P_{jt} for those two nom-market sectors (j=H,G) are defined by dividing nominal value added by the quantities Y_{jt} (j=H,G), which are defined in Equation (2.5) below.[5]

Table 2: Value Added Shares

	private	sectoral breakdown of private				G	Total
		non-IT (v^Y_{1t})	IT (v^Y_{2t})		H (v^Y_{Ht})		
1960	95.0	89.3	0.8	(0.8)	10.0	5.0	100.0
1973	94.9	87.5	1.1	(1.0)	11.4	5.1	100.0
1984	93.8	85.7	2.1	(1.6)	12.2	6.2	100.0
1990	94.1	84.7	2.7	(1.9)	12.5	5.9	100.0
1995	93.5	83.7	2.6	(1.8)	13.7	6.5	100.0
2000	93.2	82.0	3.3	(2.0)	14.7	6.8	100.0

Note: Shares in percents. Values in parentheses represent shares of IT producing sector excluding software.

Various capital assets can be divided into two groups, depending on their sectoral origin. The non-IT capital or asset 1 is those assets produced in the non-IT sector, while the IT capital or asset 2 are produced in the IT sector.[6] Since value added is at factor costs, it can be divided into payments to asset 1 (non-IT capital), asset 2 (IT capital), and labor. We use v^K_{ijt} for the factor share

[5]In JN, the government and household sectors have intermediate inputs to produce their non-market services. In this paper, to simplify the production functions, we treat these intermediate inputs as government consumption and household consumption of non-IT good (i=1) at the final demand, respectively, so that there is no intermediate inputs for these sectors.

[6]In JN, the most detailed asset classification has 102 assets. Of those 102 assets, to reflect the definition of the IT sector mentioned above, the IT capital in this paper is composed of electronic computer and peripherals, wired communication equipment, wireless communication equipment, other communication equipment, custom software, pre-packaged software, and own-account software.

of asset i ($i = 1, 2$) and v^L_{jt} for the labor share in sector j ($j = 1, 2, \mathrm{H}, \mathrm{G}$). So $v^K_{1jt} + v^K_{2jt} + v^L_{jt} = 100\%$. Data on factor cost shares are in Table 3.

Table 3: Factor Cost Shares

	non-IT			IT			H		G		
	v^K_{11t}	v^K_{21t}	v^L_{1t}	v^K_{12t}	v^K_{22t}	v^L_{2t}	v^K_{1Ht}	v^K_{2Ht}	v^K_{1Gt}	v^K_{2Gt}	v^L_{Gt}
1960	43.7	0.4	55.9	34.9	3.0	62.1	99.9	0.1	33.0	0.3	66.8
1973	41.2	1.4	57.4	40.4	8.3	51.4	99.9	0.1	36.8	0.7	62.5
1984	34.8	1.8	63.4	40.5	7.5	52.0	99.5	0.5	39.7	1.9	58.5
1990	36.6	3.2	60.2	35.2	11.8	53.0	99.3	0.7	40.9	2.5	56.6
1995	31.6	3.2	65.3	26.7	11.3	62.0	98.6	1.4	39.9	3.5	56.6
2000	29.9	4.3	65.8	29.6	12.7	57.7	97.0	3.0	45.2	3.9	50.9

Note: Shares in percents. v^K_{ijt} and v^L_{jt} are the cost shares of capital and labor, respectively.

Capital and Labor

Each sector utilizes many different capital assets. At the most detailed level of asset classification, the real capital stock and capital services are identical. However, when assets are aggregated into broader classes, the two are not the same, as first pointed out by Jorgenson and Griliches (1967). The real capital stock is the simple sum (valued at some base year prices) of those assets that belong to the broader asset class in question, while capital services aggregated over those assets is an index (e.g., the translog index) constructed from the user costs and the real capital stocks of those assets. The user costs of capital fully reflect the heterogeneity in productivity *within* the broader asset class.

For the 47 sectors, JN calculated the real capital stock and the translog index of capital services for non-IT and IT assets.[7] Those quantities are aggregated into our four broader sectors ($j = 1, 2, \mathrm{H}, \mathrm{G}$) to obtain the real capital stock and the translog capital services index for the

[7] The user costs in JN incorporate the Japanese tax structure. The detailed formula is given in Nomura (2004a, ch.3), where he considers capital consumption allowance, income allowance and reserves, special depreciation, corporate income tax, business tax, property tax, acquisition taxes, debt/equity financing, and personal taxes on capital gain and dividend. Nomura (2004a, ch.3) measures effective tax rates and tax wedges, based on estimated before-tax and after-tax rates of return. This estimate gives the effective tax rate for capital income τ_{kt} in our model.

non-IT and IT assets. For asset i (i=1 for non-IT or 2 for IT) in sector j in period t, we use K_{ijt} for the real capital *stock* and K^*_{ijt} for the capital *services* index.[8] The ratio $Q^K_{ij} \equiv K^*_{ijt}/K_{ijt}$, which converts real capital stock into capital services, is called the *capital quality* in the productivity literature. It captures the heterogeneity *within* the asset class mentioned above. Going back to Table 1, the rental rate r_{ijt} is defined to satisfy the relationship

$$P_{jt} r_{ijt} K_{ijt} = \text{nominal value of capital services for asset } i \text{ in sector } j. \tag{2.1}$$

By definition, for any sector j ($j = 1, 2, \mathrm{H}, \mathrm{G}$), the IT capital stock K_{2jt} and IT capital services K^*_{2jt} do not include land. Land would be in non-IT capital, but we do not include land in K_{1jt} and K^*_{1jt}; see below for how we account for land as non-IT capital. Despite the exclusion of land from K_{1jt}, the rental rate r_{1jt} of non-IT capital *includes* land rent.

The labor equivalent of real capital stock is total hours worked. Labor input differs from hours worked because it is an index of labor inputs of various kinds, distinguished by worker characteristics such as education. JN calculated total hours worked and the translog index of labor input for the 47 industries.[9] We can aggregate those quantities into our four broader sectors ($j = 1, 2, \mathrm{H}, \mathrm{G}$). We use L_{jt} for total hours worked in sector j and L^*_{jt} for the translog index of labor services. The *labor quality* Q^L_{jt} (j=1,2,G) is L^*_{jt}/L_{jt}. Nominal hourly wage rate in sector j, W_{jt}, is defined to satisfy

$$W_{jt} L_{jt} = \text{nominal labor costs in sector } j. \tag{2.2}$$

[8]JN use symbol K for capital services and Z for the real capital stock.

[9]JN utilizes the KEO Database, which classifies workers by sex, age (eleven classes), educational attainment (four classes for males, three classes for females), employment class (three types: employees, self-employed, and unpaid family workers), and industry (forty-three). See Kuroda, Shimpo, Nomura, Kobayashi (1997, ch.4) for more detail.

Table 4: Allocation of Capital and Labor

	hours worked: L_{jt}				non-IT capital stock: K_{1jt}					IT capital stock: K_{2jt}				
	private			G	private				G	private				G
		breakdown				breakdown					breakdown			
		non-IT	IT			non-IT	IT	H			non-IT	IT	H	
1960	97.1	99.1	0.9	2.9	85.4	50.3	0.2	49.5	14.6	96.0	93.6	4.6	1.8	4.0
1973	96.0	99.2	0.8	4.0	83.0	64.7	0.6	34.7	17.0	97.1	92.1	7.0	0.9	2.9
1984	95.5	98.2	1.8	4.5	80.7	63.1	0.9	36.0	19.3	94.1	90.1	7.2	2.7	5.9
1990	95.7	97.5	2.5	4.3	80.4	62.9	1.6	35.6	19.6	94.2	88.1	9.1	2.8	5.8
1995	95.9	97.5	2.5	4.1	79.8	62.5	1.9	35.6	20.2	92.6	83.9	9.5	6.6	7.4
2000	96.3	97.2	2.8	3.7	78.3	62.0	2.2	35.8	21.7	93.5	79.4	7.8	12.8	6.5

Note: Shares in percents. K_{1jt} excludes land.

Allocation of the capital stock (excluding land) and total hours among sectors are reported in Table 4.

Productivity

To account for the role of land in the measurement of TFP (total factor productivity), we introduce a variable, φ_{jt}, which converts the translog capital services index without land, K^*_{1jt}, into one with land for sector j. For each sector, we can define two measures of TFP growth, one (the "pseudo" TFP growth) that takes neither the capital and labor quality nor land into account (v^T_{jt}) and the one (the "genuine" TFP growth) that does (v^{T*}_{jt}). They are defined as

$$v^T_{jt} = \Delta \ln Y_{jt} - \sum_{i=1,2} \bar{v}^K_{ijt} \Delta \ln K_{ijt} - \bar{v}^L_{jt} \Delta \ln L_{jt}, \tag{2.3a}$$

$$v^{T*}_{jt} = \Delta \ln Y_{jt} - \sum_{i=1,2} \bar{v}^K_{ijt} \Delta \ln \left(Q^K_{ijt} K_{ijt} \right) - \bar{v}^K_{1jt} \Delta \ln \varphi_{jt} - \bar{v}^L_{jt} \Delta \ln \left(Q^L_{jt} L_{jt} \right), \tag{2.3b}$$

where $\bar{v}^K_{ijt}$ and $\bar{v}^L_{jt}$ are the two-period average cost shares of capital and labor in value added. So the genuine TFP growth v^{T*}_{jt} is related to its pseudo cousin v^T_{jt} as

$$v^{T*}_{jt} = v^T_{jt} - \sum_{i=1,2} \bar{v}^K_{ijt} \Delta \ln Q^K_{ijt} - \bar{v}^L_{jt} \Delta \ln Q^L_{jt} - \bar{v}^K_{1jt} \Delta \ln \varphi_{jt}. \tag{2.4}$$

Both versions of TFP growth recognize the heterogeneity in productivity *between* the non-IT and IT capital. The genuine TFP growth further takes into account the heterogeneity *within* each broad asset class. It also incorporates the labor heterogeneity and the contribution of land.

Quantities of services produced by the household and government sectors are defined as the translog index of factor inputs in sector j (j=H, G):

$$\Delta \ln Y_{jt} = \sum_{i=1,2} \bar{v}^K_{ijt} \Delta \ln \left(Q^K_{ij} K_{ijt} \right) + \bar{v}^L_{jt} \Delta \ln \ln \left(Q^L_{jt} L_{jt} \right) + \bar{v}^K_{1jt} \Delta \varphi_{jt}, \tag{2.5}$$

where labor input in the household sector is zero: $L_{Ht} = 0$.

Table 5 reports two measures of TFP growth, v^T_{jt} and v^{T*}_{jt}, and aggregate TFP growth for the privete sector. By construction, the genuine TFP growths for the household and government sectors are zero. The pseudo TFP growths, v^T_{jt} (j=H,G) differ from 0, thanks to the exclusion of quality change and land. For the two market sectors (non-IT and IT sectors), Figure 2 displays the genuine TFP growth v^{jT*}_t ($j = 1, 2$). The rapid IT productivity growth is in stark contrast to the stagnation of the non-IT sector. As noted in Jorgenson and Nomura (2005), the IT growth has accelerated in the second half of the 1990s. The dotted line in the Figure is the TFP growth of the IT sector when software is not included. The inclusion of software, while raising the value-added share of the IT sector in the 1980s and after as shown in Table 2, pulls down the TFP growth.

Table 5: TFP Growth: Two Measures

		pseudo TFP						genuine TFP			
		private					G	private			
			by sector (v_{jt}^{T})						by sector (v_{jt}^{T*})		
	private GDP		non-IT	IT		H			non-IT	IT	
1960-73	8.7	2.5	2.5	15.6	(16.3)	1.2	0.5	1.8	1.9	15.7	(16.4)
1973-84	3.4	0.6	0.6	12.7	(16.2)	-0.3	0.4	0.0	-0.1	12.3	(15.9)
1984-90	4.2	1.3	1.4	6.9	(12.1)	0.1	0.1	0.7	0.7	5.8	(11.1)
1990-2000	1.1	-0.1	-0.3	7.6	(11.2)	-0.2	0.5	-0.2	-0.5	7.0	(10.5)
1990-95	1.1	-0.4	-0.5	3.4	(4.3)	-0.2	0.5	-0.7	-0.9	2.8	(3.8)
95-2000	1.2	0.2	-0.1	11.8	(18.1)	-0.1	0.6	0.2	-0.2	11.2	(17.5)

Note: Average annual growth rate in percents. Values in parentheses is TFP growth rates for IT producing sector excluding software. Land is excluded from non-IT capital in the definition of v_{jt}^{T} and included in v_{jt}^{T*}. Private TFP growth is the weighted average, over $j = 1, 2, \mathrm{H}$, of the sectoral TFP growths, with the weights given by the value-added shares in Table 2. Private GDP growth is the weighted average, over $j = 1, 2, \mathrm{H}$, of the sectoral real value-added growths, with the weights given by the value-added shares in Table 2. Growth rates in all calculations are log differences.

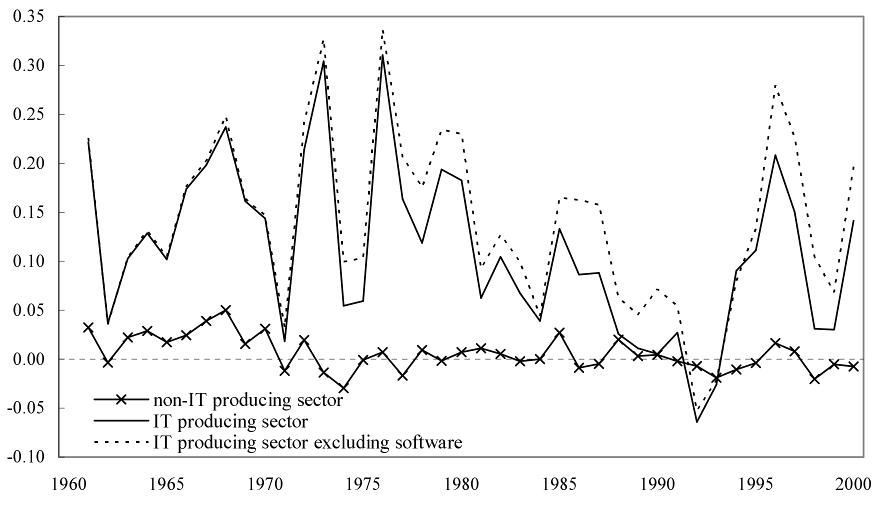

Figure 2: TFP Growth Rate: Non-IT and IT Producing Sectors

Consumption and Investment

The components of domestic final demand are in Table 6. Household consumes non-IT goods (C_{1Ht}) and own-produced rental services of consumer durables and owner-occupied housing (Y_{Ht}). C_{1Ht} includes intermediate inputs to household production Y_{Ht}. Similarly, C_{1Gt} includes intermediate inputs to government production of services Y_{Gt}. The output of the IT sector is not consumed.

Table 6: Domestic Final Demand

	Consumption		Investment			
	H	G	non-IT ind.	IT ind.	H	G
non-IT goods	$P_{1t}C_{1Ht}$	$P_{1t}C_{1Gt}$	$P_{1t}I_{11t}$	$P_{1t}I_{12t}$	$P_{1t}I_{1Ht}$	$P_{1t}I_{1Gt}$
IT goods			$P_{2t}I_{21t}$	$P_{2t}I_{22t}$	$P_{2t}I_{2Ht}$	$P_{2t}I_{2Gt}$
Hou. service	$P_{Ht}Y_{Ht}$					
Gov. service		$P_{Gt}Y_{Gt}$				

Our estimate of consumption is based on the time-series of input-output tables in the KEO Database. To define the value at before-tax prices, we deducted net indirect tax from C_{1Ht}. The consumption tax rate τ_{ct} is calculated as the ratio of the total value of net indirect tax to $P_{1t}C_{1Ht}$. Investments are calculated from the fixed capital formation matrix in Nomura (2004a).

Physical depreciation rates δ_{ijt} for asset i in sector j are aggregated from the depreciation rates for 95 produced assets and 16 consumer durables used in JN. For each asset i ($i = 1, 2$), the depreciation rate can differ across sectors and over time because the asset composition within each sector varies. Nevertheless, the aggregated depreciation rates reported in Table 7 are fairly uniform across sectors, except for the non-IT asset of government, which includes infrastructure.

Table 7: Depreciation Rates

	non-IT capital: δ_{1jt}				IT capital: δ_{2jt}			
	non-IT	IT	H	G	non-IT	IT	H	G
1960	5.5	6.8	5.2	2.5	23.9	24.6	24.1	25.7
1973	6.8	6.5	6.4	2.8	25.8	28.3	24.1	30.1
1984	6.4	6.5	6.5	2.7	28.1	30.7	28.9	31.5
1990	6.8	8.7	6.8	2.6	30.5	31.3	30.2	29.3
1995	6.5	8.6	7.0	2.6	30.4	30.7	29.1	30.4
2000	6.4	8.9	7.0	2.6	30.6	30.2	30.4	31.0

Note: in annual percentages.

3. Aggregation over Sectors and Assets

We have calculated, in Table 5, the TFP growth for each sector and the private sector as a whole that takes into account the heterogeneity *between* the two assets (non-IT and IT capital). In contrast, the growth accounting in the macro literature (see, e.g., Klenow and Rodriguez-Clare (2001) and Hayashi and Prescott (2002) (hereafter HP)) is so wedded to the one-sector paradigm that the aggregate capital input is defined simply as the value of nominal capital stock deflated by the output deflator. In this section, we apply this ”macro” growth accounting to the multi-sector dataset described in the previous section.

For real private GDP (real aggregate value added) at factor costs, we use the translog index. That is, let (P_{jt}, Y_{jt}) be the value-added deflator and real value added in sector j ($j = 1, 2, \mathrm{H}$) from our multi-sector dataset. We calculate aggregate real value added Y_t as the translog index over industry value added.[10] The growth rate of private real GDP has already been reported in Table 5. The implicit GDP deflator is defined as the ratio of nominal aggregate value-added to Y_t.

The solid line in Figure 3 is real GDP per working-age population (the number of persons aged 20-69) thus calculated from our multi-sector system, detrended at 2% (which has been the

[10]We also calculated the Fisher chain index and found it to be virtually identical to the translog index.

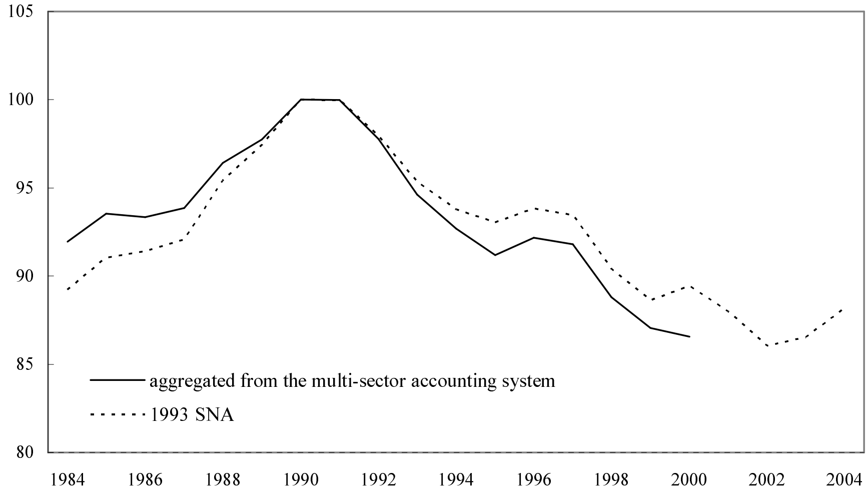

Figure 3: Real Private GDP Relative to 2% Trend

long-run growth rate for the leader country (the U.S.) over the past century) and normalized to 100 for 1990. It shows that real private GDP Y_t grew much faster than 2% until 1991 but slower than 2% thereafter. Just to show that the basic picture remains the same, the Figure also shows, in the dotted line, the similarly detrended official real GDP per worker from the Japanese national accounts (on the SNA93 basis).[11] There are a number of definitional differences between our GDP and the official Japanese SNA93 GDP: the official SNA93 GDP includes the government sector while our GDP doesn't; our GDP is a (translog) chain index while the official GDP is a fixed-weight Paasche index;[12] service flows from consumer durables are included in our GDP, and so forth. Compared to the official GDP, our measure shows slightly less growth in the 1980s and a slightly severer slump in the 1990s.

Another macro variable of interest is the capital-output ratio. The macro growth accounting typically uses the GDP deflator to convert nominal into real. That is, the aggregate capital stock K_t is defined as the ratio of the total nominal value of the capital stocks in sectors 1, 2, and H to the GDP deflator defined above. So the capital-output ratio K_t/Y_t equals the ratio of private

[11]The SNA refers to the System of National Accounts. The SNA93 is a set of rules and standard for national accounting recommended by the United Nations in 1993.

[12]Currently, the official SNA93 chain index is available only since 1994.

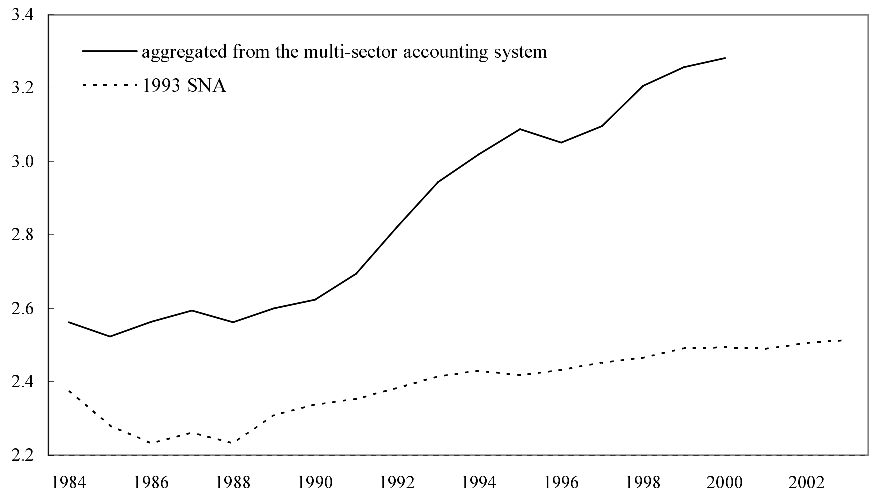

Figure 4: Capital-Output Ratio

nominal capital stock to nominal output:

$$\frac{K_t}{Y_t} \equiv \frac{P_{1t}\sum_{j=1,2,\mathrm{H}} K_{1jt} + P_{2t}\sum_{j=1,2,\mathrm{H}} K_{2jt}}{\sum_{j=1,2,\mathrm{H}} P_{jt}Y_{jt}}, \tag{3.1}$$

where K_{ijt} is the capital stock of asset i in sector j and P_{it} is the deflator for value added in sector i (see Table 1). Figure 4 shows, in the solid line, the capital-output ratio thus calculated from our multi-sector dataset. It shows a 25% rise from 2.62 in 1990 to 3.28 in 2000. The official capital-output ratio, with the capital stock as well as nominal GDP from the Japanese SNA93, is the dotted line. It is much lower and shows a much slower rise in the 1990s. The most important reason for the difference is that the depreciation rates in our multi-sector accounting system are lower.[13]

The macro growth accounting as practiced in HP (Hayashi and Prescott (2002)) is based on the following identity:

$$\frac{Y_t}{N_t} = A_t^{1/(1-\theta)} \left(\frac{K_t}{Y_t}\right)^{\theta/(1-\theta)} \left(\frac{L_t}{N_t}\right), \tag{3.2}$$

where N_t is the working-age population (persons aged 20-69) and A_t is the "macro" TFP defined

[13]Nomura (2004a, Chapter 2) argues that the depreciation rates in the Japanese SNA are too high. Other reasons include the following. Our measure of nominal capital stock does not equal the nominal capital stock valued at investment goods prices. Own-account software and pre-packaged software are included in our measure of the capital stock.

to satisfy the aggregate Cobb-Douglas production function:

$$Y_t = A_t\, K_t^{\theta}\, L_t^{1-\theta}. \tag{3.3}$$

Our measure of aggregate labor L_t is aggregate hours worked in the three private sectors. Table 8 shows the HP growth accounting applied to our multi-sector dataset with $\theta = 0.362$ (the capital share parameter used in HP). Despite the substantial differences in the definition, the overall picture is the same as in HP: both per capita output growth and the TFP growth slowed down to less than 1%, the capital-output ratio increased, and labor input declined in the 1990s. Comparing the "macro" TFP growth (the growth rate of A_t) in this table to the aggregate TFP growth reported in Table 5 (see the column labeled "private" for either the pseudo TFP or the genuine TFP), we see that the "macro" estimate is biased upward, although the movement over time is similar.

Table 8: "Macro" Growth Accounting

period	$\frac{Y_t}{N_t}$	A_t	$A_t^{1/(1-\theta)}$	$\frac{K_t}{Y_t}$	$\left(\frac{K_t}{Y_t}\right)^{\theta/(1-\theta)}$	$\frac{L_t}{N_t}$
1960-73	6.8	4.2 [4.1]	6.7	-0.1	-0.1	0.2
1973-84	2.5	1.1 [0.7]	1.8	2.2	1.2	-0.6
1984-90	3.4	1.9 [2.4]	3.0	0.4	0.2	0.2
1990-2000	0.5	0.4 [0.4]	0.6	2.3	1.3	-1.4
1990-95	0.1	0.1 [0.3]	0.2	3.3	1.9	-1.9
95-2000	0.9	0.7 [0.4]	1.1	1.2	0.7	-0.8

Note: Growth rates in annual percentages. N_t is the working-age population (number of persons aged 20-69). Y_t is chained real private GDP, L_t is total hours worked in the private sector, K_t is real capital stock, and A_t is "macro" TFP. See text for the precise definition of Y_t, K_t, L_t, A_t. $\theta = 0.362$. The numbers in brackets are the aggregate TFP growth rates in Hayashi and Prescott (2002), calculated from the worksheet downloadable from `http://www.e.u-tokyo.ac.jp/~hayashi/hp/FED_data.xls`.

4. The Two-Sector Growth Model with Consumer Durables

This section presents our theoretical model to be confronted with the data from the multi-sector accounting system. Main features of the model are the following.

- Consistent with the multi-sector accounting system, there are two market-provided goods (non-IT goods and IT goods) and two non-market goods (government services and household services). The IT goods are not consumed. Government services do not enter the household's utility function.

- The two market goods (non-IT and IT goods) are internationally tradable. We assume that the country is small enough not to influence the relative price of IT goods in terms of non-IT goods. This means that the relative price is exogenous to the model.

- Unlike in HP (Hayashi and Prescott (2002)), where the capital stock includes claims on the rest of the world, we separate external assets from domestic capital. The time path of external assets is treated as exogenous. This means that both net income from abroad and net exports are exogenous to the model.[14]

- Unlike in HP, labor supply is exogenous. The sectoral allocation of total labor, too, is exogenous. We are forced to make this assumption because the market equilibrium is one of near-complete specialization under the observed relative price if labor is allowed to move freely between sectors.

We now turn to a more detailed description of the model.

Households

The stand-in household's utility function is

$$\sum_{t=0}^{\infty} \beta^t N_t u(c_{1t}, d_t), \quad \beta \in (0, 1), \tag{4.1}$$

where N_t is working-age population, c_{1t} is per-worker consumption of good 1 (the non-IT good), and d_t is the service flow (from owner-occupied housing and consumer durables) produced by

[14] Recall from national income accounting that the net increase in external assets equals the current account and that the current account is the sum of next exports (the trade balance) and net income from abroad.

the household. If K_{it} is the quantity of private capital stock i obtained from investment in good i ($i = 1, 2$), the household sets aside $\mu_{it} N_t d_t$ of it as capital input for producing $N_t d_t$ units of household services. These capital input requirement coefficients (μ_{1t}, μ_{2t}) depend on the rental rates of capital (see below). We allow two distorting taxes, the consumption tax (the tax rate: τ_{ct}) and the tax on capital income (τ_{kt}). Labor supply is exogenous to the model, so the tax on labor is not distortionary and is lumped into the lump-sum tax τ_{ht}. The household's budget constraint is

$$\begin{aligned}(1+\tau_{ct})N_t c_{1t} &+ [K_{1,t+1} - (1-\delta_1)K_{1t}] + P_t[K_{2,t+1} - (1-\delta_2)K_{2t}] + (FA_{t+1} - FA_t) \\ &\leq w_{1t}L_{1t} + w_{2t}L_{2t} + w_{Gt}L_{Gt} + [r_{1t}(K_{1t} - \mu_{1t}N_t d_t) + P_t r_{2t}(K_{2t} - \mu_{2t}N_t d_t)] \\ &- \tau_{kt}[(r_{1t} - \delta_1)(K_{1t} - \mu_{1t}N_t d_t) + P_t(r_{2t} - \delta_2)(K_{2t} - \mu_{2t}N_t d_t)] - \tau_{ht} + NI_t,\end{aligned} \tag{4.2}$$

where P_t is the relative price (the price of good 2 in terms of good 1), δ_i is the depreciation rate of asset i, FA_t is foreign assets in terms of non-IT goods (good 1), w_{jt} is the wage rate measured in good 1 paid by sector j, L_{jt} is labor supply to sector j, r_{it} is the rental *rate* for asset i (so the rental price in terms of good 1 of asset 2 equals $P_t r_{2t}$), and NI_t is net income from abroad measured in good 1.[15]

In terms of the notation of Tables 1 and 6, $P_t = P_{2t}/P_{1t}$, $c_{1t} = C_{1Ht}/N_t$, $d_t = Y_{Ht}/N_t$, $w_{jt} = W_{jt}/P_{1t}$, $K_{i,t+1} - (1-\delta_i)K_{it} = I_{i1t} + I_{i2t} + I_{iHt}$ ($i = 1, 2$), and $\mu_{it} N_t d_t = K_{iHt}$ ($i = 1, 2$). In the data, the rental rate r_{ijt} depends on sector j because of the asset heterogeneity within the broader asset classes of non-IT and IT capital, but in the model, which does not recognize this heterogeneity, the rental rate does not depend on j.

Let $\beta^t \Lambda_t^{-1}$ be the Lagrange multiplier. Being the reciprocal of the shadow price of the budget constraint, Λ_t measures the wealth of the household. The FOCs (first-order conditions) for

[15]This budget constraint implies that the household does not pay the consumption tax on purchases of non-IT and IT goods to be used for household production. If this counterfactual assumption is to be avoided, we would have to treat those flow of durables purchases separately from investments in the capital stock to be rented out to firms, but that adds another co-state variable to the system. Our numerical procedure for computing the perfect foresight equilibrium path cannot handle more than one co-state variable.

optimality are:

$$u_{c_1}(c_{1t}, d_t) = (1 + \tau_{ct})\Lambda_t^{-1}, \tag{4.3}$$

$$u_d(c_{1t}, d_t) = P_{dt}\Lambda_t^{-1}, \tag{4.4}$$

$$\beta[1 + (1 - \tau_{k,t+1})(r_{1,t+1} - \delta_1)] = \frac{\Lambda_{t+1}}{\Lambda_t}, \tag{4.5}$$

$$\beta[1 + (1 - \tau_{k,t+1})(r_{2,t+1} - \delta_2)] = \frac{P_t}{P_{t+1}}\frac{\Lambda_{t+1}}{\Lambda_t}, \tag{4.6}$$

where

$$P_{dt} \equiv [(1 - \tau_{kt})r_{1t} + \tau_{kt}\delta_1]\mu_{1t} + P_t[(1 - \tau_{kt})r_{2t} + \tau_{kt}\delta_2]\mu_{2t} \tag{4.7}$$

is the imputed price of household services in terms of sector 1 output.[16] The user costs are $(1 - \tau_{kt})r_{it} + \tau_{kt}\delta_i$ rather than r_{it}, because household production is not taxed.

(4.5) and (4.6) yield

$$\text{(Euler equation)} \qquad \frac{\Lambda_{t+1}}{\Lambda_t} = \beta[1 + (1 - \tau_{k,t+1})(r_{1,t+1} - \delta_1)], \tag{4.8}$$

$$\text{(arbitrage)} \qquad \frac{P_{t+1}}{P_t} = \frac{1 + (1 - \tau_{k,t+1})(r_{1,t+1} - \delta_1)}{1 + (1 - \tau_{k,t+1})(r_{2,t+1} - \delta_2)}. \tag{4.9}$$

The first of these two equations will be referred to as the *Euler equation* because it describes how the household wealth Λ_t evolves over time. The second equation will be called the *arbitrage condition* governing the portfolio of the two assets K_{1t} and K_{2t}.

We can solve (4.3) and (4.4) for (c_{1t}, d_t) as a function of the consumption tax rate τ_{ct}, the imputed price (P_{dt}), and the shadow price Λ_t:

$$\text{(Frisch demands)} \qquad c_{1t} = c_1(\tau_{ct}, P_{dt}, \Lambda_t), \;\; d_t = d(\tau_{ct}, P_{dt}, \Lambda_t). \tag{4.10}$$

This demand system, with the shadow price Λ replacing income, is called "Frisch demands". Use of Frisch demands enforces the household FOCs (4.3) and (4.4) in the equilibrium conditions.

The input requirement coefficients (μ_{1t}, μ_{2t}) for producing household services can be made endogenous, as the solution to the cost minimizing problem:[17]

$$\min_{\mu_{1t},\mu_{2t}} P_{dt} \;\text{ s.t. }\; F_d(\varphi_{Ht}Q^K_{1Ht}\,\mu_{1t}, Q^K_{2Ht}\,\mu_{2t}) = 1, \tag{4.11}$$

[16] It equals P_{Ht}/P_{1t} in the notation of Section 2.

[17] The constraint in the problem can also be written as $F_d(\varphi_{Ht}Q^K_{1Ht}\,\mu_{1t}N_td_t, Q^K_{2Ht}\,\mu_{2t}N_td_t) = N_td_t$ due to constant returns to scale.

where F_d is a linear homogeneous production function for household services, Q^K_{iHt} $(i = 1, 2)$ is the capital quality defined in Section 2 to capture the asset heterogeneity, and φ_{Ht} is the factor accounting for land in asset 1. By definition, there is no TFP growth in household production, so the production function is stationary. We write the solution as

$$\mu_{1t} = \mu_1\left(\frac{(1-\tau_{kt})r_{1t} + \tau_{kt}\delta_1}{P_t[(1-\tau_{kt})r_{2t} + \tau_{kt}\delta_2]}\right)/(\varphi_{Ht}Q^K_{1Ht}),\ \ \mu_{2t} = \mu_2\left(\frac{(1-\tau_{kt})r_{1t} + \tau_{kt}\delta_1}{P_t[(1-\tau_{kt})r_{2t} + \tau_{kt}\delta_2]}\right)/Q^K_{2Ht}. \tag{4.12}$$

Firms

The technology of the two market sectors is described by the constant-returns-to-scale production functions

$$Y_{1t} = Y_1(\varphi_{1t}Q^K_{11t}K_{11t}, Q^K_{21t}K_{21t}, Q^L_{1t}L_{1t}; A^*_{1t}), \tag{4.13}$$

$$Y_{2t} = Y_2(\varphi_{2t}Q^K_{12t}K_{12t}, Q^K_{22t}K_{22t}, Q^L_{2t}L_{2t}; A^*_{2t}), \tag{4.14}$$

where K_{ijt} is the amount of privately-held asset i rented by sector j in date t and A^*_{jt} is the level of technology. The capital quality Q^K_{ijt} converts the capital stock into capital services, Q^L_{jt} measures the quality of labor in sector j, and the factor φ_{jt} accounts for land. The FOCs are

$$r_{1t} = \frac{\partial Y_{1t}}{\partial K_{11t}},\ P_t r_{2t} = \frac{\partial Y_{1t}}{\partial K_{21t}},\ r_{1t} = P_t\frac{\partial Y_{2t}}{\partial K_{12t}},\ r_{2t} = \frac{\partial Y_{2t}}{\partial K_{22t}},\ w_{1t} = \frac{\partial Y_{1t}}{\partial L_{1t}},\ w_{2t} = P_t\frac{\partial Y_{2t}}{\partial L_{2t}}. \tag{4.15}$$

The Government

The government collects taxes to finance government expenditure in goods and services (the sum of government consumption and investment) in two goods, G_{1t} and G_{2t}, and payments to hire labor L_{Gt} used for producing government services. The lump-sum tax τ_{ht} is adjusted to meet the government budget constraint. In terms of the notation of Table 6, $G_{1t} = C_{1Gt} + I_{1Gt}$ and $G_{2t} = I_{2Gt}$. Neither the government production function nor breakdown of government expenditure between consumption and investment needs to be specified, because it does not affect the equilibrium of the private sector.

Market Equilibrium

The market equilibrium conditions are:

$$\text{(asset 1)} \qquad K_{11t} + K_{12t} + \mu_{1t}N_t d_t = K_{1t}, \tag{4.16}$$

$$\text{(asset 2)} \qquad K_{21t} + K_{22t} + \mu_{2t}N_t d_t = K_{2t}, \tag{4.17}$$

$$\begin{aligned}\text{(RC)} \qquad N_t c_{1t} + [K_{1,t+1} - (1-\delta_1)K_{1t}] + P_t[K_{2,t+1} - (1-\delta_2)K_{2t}]& \\ = (Y_{1t} - G_{1t}) + P_t(Y_{2t} - G_{2t}) - NX_t.&\end{aligned} \tag{4.18}$$

Here, the label "RC" stands for resource constraint and NX_t is net exports in terms of good 1.

Equilibrium

We can now define competitive equilibrium. Take as given:

- a government policy $\{K_{1Gt}, K_{2Gt}, L_{Gt}, G_{1t}, G_{2t}, \tau_{ct}, \tau_{kt}\}_{t=0}^{\infty}$,
- labor supply to each sector $\{L_{1t}, L_{2t}\}_{t=0}^{\infty}$,
- external assets $\{FA_t\}_{t=0}^{\infty}$ and net exports $\{NX_t\}_{t=0}^{\infty}$,
- the relative price $\{P_t\}_{t=0}^{\infty}$,
- the capital and labor quality and the land conversion factor $\{Q_{ijt}^K, Q_{jt}^L, \varphi_{jt}\}_{t=0}^{\infty}$ ($i = 1,2$; $j = 1,2,\mathrm{H},\mathrm{G}$),
- the technology level $\{A_{1t}^*, A_{2t}^*\}_{t=0}^{\infty}$.

A *competitive equilibrium* given an initial condition (K_{10}, K_{20}) is a sequence of factor prices, $\{r_{1t}, r_{2t}, w_{1t}, w_{2t}\}_{t=0}^{\infty}$, the household wealth $\{\Lambda_t\}_{t=0}^{\infty}$, and associated quantities, $\{K_{1,t+1}, K_{2,t+1}, K_{11t}, K_{12t}, K_{21t}, K_{22t}\}_{t=0}^{\infty}$, such that the Euler equation (4.8), the arbitrage condition (4.9), the firm's FOCs (4.15), the market equilibrium conditions ((4.16)-(4.18)) are satisfied, where (Y_{1t}, Y_{2t}) in those conditions are given by (4.13) and (4.14), c_{1t} in the RC (resource constraint) and d_t in the asset market equilibrium condition are given by (4.10), and (μ_{1t}, μ_{2t}) in the asset market equilibrium condition are given by (4.12).

In this definition, the government budget constraint is not an equilibrium condition, because the lump-sum tax τ_{ht} is assumed to meet the constraint. The household budget constraint is not included, because it is implied by the government budget constraint, the factor exhaustion condition that value added equals factor payments (an implication of the linear homogeneity of the production function and the marginal productivity conditions), the market equilibrium conditions, and the identity that the increase in external assets, $FA_{t+1} - FA_t$, equals net exports NX_t plus net income from abroad NI_t.

Implications of The Cobb-Douglas Technology

In what follows, we assume the Cobb-Douglas form for the production functions. So (4.13) and (4.14) can be written as

$$Y_{1t} = A_{1t}^* \left(\varphi_{1t}\, Q_{11t}^K K_{11t}\right)^{\theta_{11}} \left(Q_{21t}^K K_{21t}\right)^{\theta_{21}} \left(Q_{1t}^L L_{1t}\right)^{1-\theta_{11}-\theta_{21}} = A_{1t}\, K_{11t}^{\theta_{11}}\, K_{21t}^{\theta_{21}}\, L_{1t}^{1-\theta_{11}-\theta_{21}}, \tag{4.19}$$

$$Y_{2t} = A_{2t}^* \left(\varphi_{2t}\, Q_{12t}^K K_{12t}\right)^{\theta_{12}} \left(Q_{22t}^K K_{22t}\right)^{\theta_{22}} \left(Q_{2t}^L L_{2t}\right)^{1-\theta_{12}-\theta_{22}} = A_{2t}\, K_{12t}^{\theta_{12}}\, K_{22t}^{\theta_{22}}\, L_{2t}^{1-\theta_{12}-\theta_{22}}, \tag{4.20}$$

where

$$A_{jt} \equiv A_{jt}^* \ \left(\varphi_{jt}\, Q_{1jt}^K\right)^{\theta_{1j}} \ \left(Q_{2jt}^K\right)^{\theta_{2j}} \ \left(Q_{jt}^L\right)^{1-\theta_{1j}-\theta_{2j}}, \ \ j = 1, 2. \tag{4.21}$$

This shows that, for the Cobb-Douglas technology, the production function can be defined for the capital *stocks*, with an appropriate re-definition of the TFP term. The growth rate of A_{jt}^* is the "genuine" TFP growth rate, v_{jt}^{T*}, of Section 2. The above expression of the production function makes it clear that what matters for equilibrium is the "pseudo" TFP growth rate, v_{jt}^T, which equals the growth rate of A_{jt} defined here.

We will also assume the Cobb-Douglas form for the household production function F_d in (4.11):

$$F_d(\varphi_{Ht} Q_{1Ht}^K\, K_{1Ht}, Q_{2Ht}^K\, K_{2Ht}) = A_H^* \ \left(\varphi_{Ht} Q_{1Ht}^K, K_{1Ht}\right)^{\gamma} \left(Q_{2Ht}^K\, K_{2Ht}\right)^{1-\gamma} = A_{Ht}\, K_{1Ht}^{\gamma}\, K_{2Ht}^{1-\gamma}, \tag{4.22}$$

where

$$A_{Ht} = A_H^* \left(\varphi_{Ht} Q_{1Ht}^K\right)^{\gamma} \left(Q_{2Ht}^K\right)^{1-\gamma}. \tag{4.23}$$

The utility function $u(c_{1t}, d_t)$ is linear logarithmic:

$$u(c_{1t}, d_t) = \mu \log(c_{1t}) + (1-\mu) \log(d_t). \tag{4.24}$$

With these functional-form assumptions for household, the Frisch demands (4.10) and the demand for capital inputs for household production (4.12) become

$$\text{(Frisch demands)} \qquad c_{1t} = \frac{\mu \Lambda_t}{1 + \tau_{ct}}, \; d_t = \frac{(1-\mu)\Lambda_t}{P_{dt}}, \tag{4.25}$$

$$P_{dt} = \gamma^{-\gamma} \, (1-\gamma)^{-(1-\gamma)} \, ((1-\tau_{kt})r_{1t} + \tau_{kt}\delta_1)^{\gamma} \, (P_t[(1-\tau_{kt})r_{2t} + \tau_{kt}\delta_2])^{1-\gamma} \, / A_{Ht}, \tag{4.26}$$

$$\begin{aligned} K_{1Ht} &\equiv \mu_{1t} N_t d_t = \frac{\gamma}{(1-\tau_{kt})r_{1t} + \tau_{kt}\delta_1} \, (1-\mu) N_t \Lambda_t, \\ K_{2Ht} &\equiv \mu_{2t} N_t d_t = \frac{1-\gamma}{P_t[(1-\tau_{kt})r_{2t} + \tau_{kt}\delta_2]} \, (1-\mu) N_t \Lambda_t. \end{aligned} \tag{4.27}$$

Thanks to the unit elasticity in both the demand for and the supply of household services, a change in A_{Ht} does not affect the demand for assets $\mu_{it} N_t d_t$ in household production. Combining (4.22), (4.26), and (4.27), we obtain

$$P_{dt} Y_{Ht} = P_{dt} \, A_{Ht} \, K_{1Ht}^{\gamma} \, K_{2Ht}^{1-\gamma} = (1-\mu) N_t \Lambda_t, \tag{4.28}$$

which states that the value (in terms of good 1) of household production does not depend on the pseudo TFP A_{Ht}.

Detrending

With the Cobb-Douglas technology and the linear-logarithmic preferences, it is possible to transform the system so that it involves only the growth rates, but not the levels, of the TFPs. To this end, define two trends:

$$X_{1t} \equiv A_{1t}^{\frac{1-\theta_{22}}{v}} \, A_{2t}^{\frac{\theta_{21}}{v}} \, N_t, \; X_{2t} \equiv A_{1t}^{\frac{\theta_{12}}{v}} \, A_{2t}^{\frac{1-\theta_{11}}{v}} \, N_t \;\; \text{with} \;\; v \equiv 1 - \theta_{11} - \theta_{22} + \theta_{11}\theta_{22} - \theta_{12}\theta_{21}. \tag{4.29}$$

Define also lower-case letters as ratios to these trends:

$$\begin{aligned} &k_{it} \equiv \frac{K_{it}}{X_{it}} \;\; (i = 1,2), \;\; k_{ijt} \equiv \frac{K_{ijt}}{X_{it}} \;\; (i,j = 1,2), \;\; \ell_{jt} \equiv \frac{L_{jt}}{N_t} \;\; (j = 1,2), \;\; y_{jt} \equiv \frac{Y_{jt}}{X_{jt}} \;\; (j = 1,2), \\ &p_t \equiv \frac{P_t}{\left(\frac{X_{1t}}{X_{2t}}\right)}, \;\; \lambda_t \equiv \frac{\Lambda_t}{\left(\frac{X_{1t}}{N_t}\right)}. \end{aligned} \tag{4.30}$$

A very tedious algebra shows that the equilibrium conditions in terms of these detrended variables can be reduced to the following set of equations.

$$\text{(Euler)} \qquad \frac{\lambda_{t+1}\left(\frac{X_{1,t+1}}{X_{1t}}\right)}{\lambda_t\left(\frac{N_{t+1}}{N_t}\right)} = \beta\ \left[1 + (1 - \tau_{k,t+1})(r_{1,t+1} - \delta_1)\right], \tag{4.31}$$

$$\text{(arbitrage)} \qquad \frac{p_{t+1}\left(\frac{X_{1,t+1}}{X_{1t}}\right)}{p_t\left(\frac{X_{2,t+1}}{X_{2t}}\right)} = \frac{1 + (1 - \tau_{k,t+1})(r_{1,t+1} - \delta_1)}{1 + (1 - \tau_{k,t+1})(r_{2,t+1} - \delta_2)}, \tag{4.32}$$

$$\begin{aligned} \text{(production FOCs)} \qquad & r_{1t} = \theta_{11}\,\frac{y_{1t}}{k_{11t}},\ p_t r_{2t} = \theta_{21}\,\frac{y_{1t}}{k_{21t}},\ r_{1t} = \theta_{12}\,p_t\,\frac{y_{2t}}{k_{12t}},\ r_{2t} = \theta_{22}\,\frac{y_{2t}}{k_{22t}}, \\ & y_{1t} = k_{11t}^{\theta_{11}}\,k_{21t}^{\theta_{21}}\,\ell_{1t}^{1-\theta_{11}-\theta_{21}},\ y_{2t} = k_{12t}^{\theta_{12}}\,k_{22t}^{\theta_{22}}\,\ell_{2t}^{1-\theta_{12}-\theta_{22}}, \end{aligned} \tag{4.33}$$

$$\text{(asset 1)} \qquad k_{11t} + k_{12t} + \frac{\gamma}{(1-\tau_{kt})r_{1t} + \tau_{kt}\delta_1}\,(1-\mu)\lambda_t = k_{1t}, \tag{4.34}$$

$$\text{(asset 2)} \qquad k_{21t} + k_{22t} + \frac{1-\gamma}{p_t[(1-\tau_{kt})r_{2t} + \tau_{kt}\delta_2]}\,(1-\mu)\lambda_t = k_{2t}, \tag{4.35}$$

$$(z \text{ defined}) \qquad z_{t+1} \equiv k_{1,t+1} + p_t\frac{\left(\frac{X_{1t}}{X_{1,t+1}}\right)}{\left(\frac{X_{2t}}{X_{2,t+1}}\right)}\,k_{2,t+1}, \tag{4.36}$$

$$\begin{aligned} \text{(RC)} \qquad & \frac{X_{1,t+1}}{X_{1t}}\,z_{t+1} \\ & = (1-\psi_{1t})y_{1t} + p_t(1-\psi_{2t})y_{2t} - \frac{\mu}{1+\tau_{ct}}\,\lambda_t + (1-\delta_1)k_{1t} + (1-\delta_2)p_t k_{2t} - \nu_t(y_{1t} + p_t y_{2t}). \end{aligned} \tag{4.37}$$

Here, (ψ_{1t}, ψ_{2t}) is the government share of output for each good and ν_t is net exports-to-GDP (excluding household production) ratio:

$$\psi_{it} \equiv \frac{G_{it}}{Y_{it}}\ \ (i = 1, 2) \quad \text{and} \quad \nu_t \equiv NX_t/(Y_{1t} + P_t Y_{2t}). \tag{4.38}$$

The Transition Path and the Steady State

From this set of equations, we can define a first-order dynamical system (k_1, k_2, λ), namely a mapping from $(k_{1t}, k_{2t}, \lambda_t)$ to $(k_{1,t+1}, k_{2,t+1}, \lambda_{t+1})$, as follows.

i) Given $(k_{1t}, k_{2t}, \lambda_t)$, use eight equations, (4.33)-(4.35) to solve for eight unknowns $(r_{1t}, r_{2t}, k_{11t}, k_{21t}, k_{12t}, k_{22t}, y_{1t}, y_{2t})$. Intuitively, this enforces that the country's marginal rate of transformation between the two goods be equated to the world relative price. This step also gives (r_{1t}, r_{2t}) as functions of $(k_{1t}, k_{2t}, \lambda_t)$. Write them as: $r_{it} = r_i(k_{1t}, k_{2t}, \lambda_t)$ $(i = 1, 2)$.

ii) Given $(k_{1t}, k_{2t}, \lambda_t, y_{1t}, y_{2t})$, use (4.37) to calculate z_{t+1}.

iii) Substitute $r_{i,t+1} = r_i(k_{1,t+1}, k_{2,t+1}, \lambda_{t+1})$ into (4.31) and (4.32). Given the value of z_{t+1} obtained in the previous step, three equations — (4.31), (4.32), and (4.36) — can be solved for $(k_{1,t+1}, k_{2,t+1}, \lambda_{t+1})$.

The initial condition for the system is that the initial values for the two state variables (k_{1t}, k_{2t}) are given. Given an appropriate initial value for the co-state variable λ_t, we can generate the solution path using this mapping from $(k_{1t}, k_{2t}, \lambda_t)$ to $(k_{1,t+1}, k_{2,t+1}, \lambda_{t+1})$.

This dynamical system is autonomous (i.e., the mapping from $(k_{1t}, k_{2t}, \lambda_t)$ to $(k_{1,t+1}, k_{2,t+1}, \lambda_{t+1})$ is stationary or time-invariant) if the forcing or exogenous variables — ℓ_{1t}, ℓ_{2t}, $X_{1,t+1}/X_{1t}$, $X_{2,t+1}/X_{2t}$, N_{t+1}/N_t, τ_{kt}, τ_{ct}, ψ_{1t}, ψ_{2t}, p_t, and ν_t — are constant over time. The steady state or the equilibrium of this autonomous system can be determined uniquely from the above equations by dropping the time subscript, as follows. Dropping the time subscript in (4.31) pins down r_1, the steady-state value of r_{1t}. Given r_1, use the steady-state version of (4.32) to obtain r_2. Given r_1 and r_2, use (4.33) to calculate $(k_{11}, k_{21}, k_{12}, k_{22}, y_1, y_2)$. Use the rest of the equations, (4.34)-(4.37) to pin down (k_1, k_2, z, λ).

When we simulate the model in the next section, we will assume that the exogenous variables become constant either asymptotically (for $\ell_{1t}, \ell_{2t}, \nu_t$) or after some fixed date (which is year 2000 in the simulation below), so the detrended system is asymptotically autonomous. The appropriate initial value of the co-state λ_t is the one that guides the detrended system to approach the steady state in the long run (as time goes to infinity). This particular solution path satisfies relevant transversality conditions.

Given the solution path for the detrended system, we can back out the equilibrium of the model before detrending using (4.30). This determines:

$$Y_{1t}, Y_{2t}, K_{1t}, K_{2t}, K_{11t}, K_{12t}, K_{21t}, K_{22t}, r_{1t}, r_{2t}, \Lambda_t.$$

The value of household production, $P_{dt}Y_{Ht}$, can be determined from this by (4.28). All these endogenous variables are determined independent of the psudo TFP for the household sector, A_{Ht}. The breakdown of $P_{dt}Y_{Ht}$ between price and quantity does depend on A_{Ht} and can be obtained from (4.26).

The steady-state or the balanced growth path associated with the steady-state or the equilibrium of the detrended system has the following features.

- The sectoral allocation of capital for each asset i ($i = 1, 2$) is constant, because the trend in K_{ijt} does not depend on j.

- Obviously,

$$Y_{1t} \propto X_{1t},\ Y_{2t} \propto X_{2t},\ \ P_t\ (\equiv \frac{P_{2t}}{P_{1t}}) \propto \frac{X_{1t}}{X_{2t}},\ \ N_t\Lambda_t \propto X_{1t}. \tag{4.39}$$

  Thus if, as is the case in the calibrated model below, X_{2t} grows much faster than X_{1t} thanks to the rapid IT productivity growth, the relative price of IT goods declines rapidly and the growth of relative output level Y_{2t}/Y_{1t} is as rapid as the decline in the relative price.

- The sectoral nominal value-added shares in private GDP

$$v_{jt}^Y = \frac{P_{jt}Y_{jt}}{P_{1t}Y_{1t} + P_{2t}Y_{2t} + P_{Ht}Y_{Ht}} = \begin{cases} \frac{Y_{1t}}{Y_{1t}+P_tY_{2t}+P_{dt}Y_{Ht}} & (\text{for } j = 1), \\ \frac{P_tY_{2t}}{Y_{1t}+P_tY_{2t}+P_{dt}Y_{Ht}} & (\text{for } j = 2), \\ \frac{P_{dt}Y_{Ht}}{Y_{1t}+P_tY_{2t}+P_{dt}Y_{Ht}} & (\text{for } j = \text{H}), \end{cases} \tag{4.40}$$

  are constant. This is because, in addition to (4.39), we have $P_{dt}Y_{Ht} \propto X_{1t}$ by (4.28).

- It then follows from (4.26) that

$$Y_{Ht} \propto X_{1t}^{\gamma} X_{2t}^{1-\gamma} A_{Ht},\ \ P_{dt}\ (\equiv \frac{P_{Ht}}{P_{1t}}) \propto \left(\frac{X_{1t}}{X_{2t}}\right)^{1-\gamma} A_{Ht}^{-1}. \tag{4.41}$$

  Let Y_t be the translog index of real private GDP constructed from (P_{jt}, Y_{jt}) ($j = 1, 2, \text{H}$) with $P_{2t} = P_{1t}P_t$ and $P_{Ht} = P_{dt}P_t$ for some arbitrary path of P_{1t} (which doesn't affect the index), and let v_j^Y be the steady-state value of the value-added shares discussed above. Then the steady-state growth rate of real private GDP is given by

$$v_1^Y \times g_{X1} + v_2^Y \times g_{X2} + (1 - v_1^Y - v_2^Y) \times (\gamma g_{X1} + (1-\gamma) g_{X2} + g_H), \tag{4.42}$$

  where g_{Xj} is the long-run growth rate of X_{jt} and g_H is the long-run growth rate of A_{Ht}.

- From the firm's marginal productivity conditions, the wage ratio w_{1t}/w_{2t} under the Cobb-Douglas technology equals $\frac{1-\theta_{11}-\theta_{21}}{1-\theta_{21}-\theta_{22}} \frac{Y_{1t}/L_{1t}}{P_tY_{2t}/L_{2t}}$ for all t. In the steady state, it equals

$$\frac{w_{1t}}{w_{2t}} \text{ in the steady state } = \frac{1-\theta_{11}-\theta_{21}}{1-\theta_{21}-\theta_{22}} \frac{y_1/\ell_1}{py_2/\ell_2}, \tag{4.43}$$

  where (p, ℓ_1, ℓ_2) are the constant long-run values of $(p_t, \ell_{1t}, \ell_{2t})$. It can be easily seen from tracing out the procedure for calculating the steady state explained above that y_1/ℓ_1 and y_2/ℓ_2

do not depend on (ℓ_1, ℓ_2) (an implication of the constant-returns-to-scale technology and the small country assumption). Thus the steady-state wage ratio between non-IT and IT sectors does not depend on the allocation of labor between the two sectors.

We close this section by commenting on our assumption that the relative price ($P_t \equiv P_{2t}/P_{1t}$), which is internationally given, is projected to grow at precisely the rate given by X_{1t}/X_{2t}, which is determined by the domestic TFP growth rates in non-IT and IT sectors (see (4.29)). This is not as far-fetched as it might seem. As Jorgenson (2003) finds, the rapid decline in IT prices is common to G7 countries. If, as Jorgenson and Nomura (2005) argue, this relentless decline is rooted in developments in technology (primarily in semiconductors) that are widely understood by technologists and economists, it would not be too unrealistic to assume that the TFP growth rate in the IT sector in Japan is as high as it is elsewhere in the world.

5. Calibration and Results

The detrended dynamical system described in the previous section has a set of parameters and exogenous variables. In this section, we calibrate the detrended system and specify the paths of exogenous variables. We will then discuss the steady-state properties of the system. The equilibrium of the model in levels can be obtained by solving the detrended system and then multiplying the solution by appropriate time trends. The last part of this section examines the transition dynamics thus calculated. As in Hayashi and Prescott (2002), the calibration is based on data for 1984-1989 in principle, and the transition dynamics is set off from 1990. The presumption of this simulation exercise is that the representative agent learns, all of a sudden in 1990, about the paths of the exogenous variable from 1990 on. The prior expectations about the exogenous variable from 1990 on are whatever is consistent with the 1984-89 values of the endogenous variables of the model.

Calibration

The detrended dynamical system has nine parameters $(\beta, \mu, \gamma, \delta_1, \delta_2, \theta_{11}, \theta_{21}, \theta_{12}, \theta_{22})$. These parameters are calibrated as follows.

θ_{ij} $(i, j = 1, 2)$: These are capital shares, whose values for selected years are reported in Table 3 for the non-IT and IT sectors. Given that β is estimated from the 1984-1989 data (see below), we should use the 1984-1989 averages. However, as seen from the Table, the factor shares of IT assets tend to increase in the 1990s. For this reason, we use the 1990-2000 averages.

γ: It is non-IT capital's (asset 1's) share in household production. Its values for selected years are reported in Table 3 for the household sector. We use the 1990-2000 average.

μ: From the parameterized Frisch demands (4.25), μ equals $(1 + \tau_{ct})P_{1t}Y_{Ht}/((1 + \tau_{ct})P_{1t}C_{1Ht} + P_{Ht}Y_{Ht})$. We use the 1990-2000 average; the 1984-89 average is similar.

δ_i $(i = 1, 2)$: The depreciation rate for each asset differs slightly across sectors in data, as shown in Table 7. For each asset and for each year, we take the weighted average of the depreciation rates over three sectors, $j = 1, 2, \mathrm{H}$, with the capital stocks of that asset in three sectors as weights. We then use their 1990-2000 averages for δ_i $(i = 1, 2)$. The calibrated values thus calculated are: $\delta_1 = 6.8\%$ and $\delta_2 = 30.5\%$. The IT capital depreciates much faster. Again, their 1984-89 averages are similar.

β: From the Euler equation (4.8), the parameterized Frisch demands (4.25), and the marginal productivity condition for asset 1 in sector 1 under the Cobb-Douglas production function, we can derive

$$\frac{\Lambda_{t+1}}{\Lambda_t} = \beta[1 + (1 - \tau_{k,t+1})(\theta_{11}\frac{Y_{1t}}{K_{11t}} - \delta_1)] \quad \text{with} \quad \Lambda_t = \frac{(1 + \tau_{ct})P_{1t}C_{1Ht} + P_{Ht}Y_{Ht}}{P_{1t}N_t}. \tag{5.1}$$

Following Hayashi and Prescott (2002), we take the sample average over 1984-1989 of both sides of this Euler equation and then solve for β. In taking the sample averages, θ_{11} and δ_1 are year-dependent values in data, not the calibrated values of them.

There are eleven exogenous variables in the detrended system: the growth rates of (X_{1t}, X_{2t}, N_t), the relative price (p_t), the two tax rates (τ_{kt}, τ_{ct}), exogenous labor ratios (ℓ_{1t}, ℓ_{2t}) (where

$\ell_{jt} = L_{jt}/N_t$), the government-expenditure-to-GDP ratios (ψ_{1t}, ψ_{2t}), and the net export-to-GDP ratio (ν_t). Their values from year 1990 to 2000 are set to their actual values. Their paths beyond year 2000 are projected into the future as follows.

ℓ_{jt} (allocation of hours): We consider two scenarios for the labor ratios $\ell_{1t} \equiv L_{1t}/N_t$ and $\ell_{2t} \equiv L_{2t}/N_t$. In either scenario, the total hours devoted to the private sector, $\ell_{1t} + \ell_{2t} = \frac{L_{1t}+L_{2t}}{N_t}$, are as in the data for $t = 1990, 1991, ..., 2000$, and remains at its year 2000 value for $t > 2000$. The two scenarios differ in the allocation of *private* total hours between non-IT and IT, $\frac{\ell_{jt}}{\ell_{1t}+\ell_{2t}} = \frac{L_{jt}}{L_{1t}+L_{2t}}$ ($j = 1, 2$), for $t = 2001, 2002, ...$

Scenario A The allocation is the same as in 2000. That is, $\frac{L_{1t}}{L_{1t}+L_{2t}} = \frac{L_{1,2000}}{L_{1,2000}+L_{2,2000}}$ for $t = 2001, 2002, ...$ As shown in Table 4, the ratio in 2000 is 97.2% for non-IT and 2.8% for IT.

Scenario B The allocation gradually converge from (97.2%, 2.8%) to (90%, 10%). More specifically, for $t = 2001, 2002, ...,$

$$\ell_{2t} - \ell_{2,t-1} = 0.1 \times \left(0.9 \times \frac{L_{1,2000} + L_{2,2000}}{N_{2000}} - \ell_{1,t-1}\right), \quad \ell_{1t} = \frac{L_{1,2000} + L_{2,2000}}{N_{2000}} - \ell_{2t}.$$

The steady-state distribution of 90% of private total hours for non-IT and 10% for IT is chosen because it implies a steady-state real private GDP growth of about 2.0%.

N_t (working-age population): We assume zero growth, so $N_t = N(2000)$ for $t = 2001, 2002, ...$

X_{1t} and X_{2t}: They are the time trends defined in (4.29) and depend on the "pseudo" TFP levels, A_{1t} and A_{2t} defined in (4.21). For the non-IT sector ($j = 1$), we assume no productivity growth, so $A_{1t} = A_{1,2000}$ for $t = 2001, 2002, ...$ For the IT sector, we set the growth rate of A_{2t} after 2000 to the average growth rate in 1995-2000. As Dale Jorgenson forcefully argues in his recent writings (see, e.g., Jorgenson (2003) for G7 countries, Jorgenson and Nomura (2005) for Japan in particular) and as verified in Table 5 and Figure 2, the TFP growth in the IT sector has accelerated after 1995. We are thus assuming that this acceleration after 1995 was anticipated in 1990 and that the enhanced IT growth is expected to continue into the future.

τ_{kt} (tax rate on capital): Its conceptually appropriate definition is the so-called *effective tax rate on income from capital*, which includes taxes on capital at both the corporate and personal levels and incorporates various other features of the tax code such as accelerated depreciation, tax-free reserves. As mentioned in footnote 7, this tax rate was calculated in Nomura (2004a). The value beyond 2000 is set equal to its 2000 value of 50.0%, which is close to the crude estimate of 48% used in Hayashi and Prescott (2002).

τ_{ct} (consumption tax rate): Its measurement was already discussed in Section 2. The value beyond 2000 is its 2000 value (9.8%). The tax rate is higher than the statutory rate of 5% because the tax base is assumed to be $P_{1t}C_{1Ht}$, which is narrower than the actual tax base.

ψ_{it} (government share of good i): The values beyond 2000 are the 2000 values.

p_t (the relative price): The detrended relative price in data does not show a trend since 1970. The value beyond 2000 is set at its average over 1990-2000. As discussed at the end of the previous section, this amounts to assuming that the differential in TFP growth between non-IT and IT is common to all countries in the world.

ν_t (net exports/GDP ratio): The country's foreign asset measured in non-IT goods, FA_t, evolves according to

$$FA_{t+1} = (1 + r_t)(FA_t - NX_t),$$

where r_t is the interest rate on foreign assets. Letting $fa_t \equiv FA_t/(Y_{1t} + P_t Y_{2t})$, this equation can be written as

$$\frac{1}{1+\tilde{r}_t} fa_{t+1} = fa_t - \nu_t, \quad 1 + \tilde{r}_t \equiv \frac{1 + r_t}{\frac{Y_{1,t+1} + P_{t+1} Y_{2,t+1}}{Y_{1t} + P_t Y_{2t}}}.$$

We assume that this $1 + \tilde{r}_t$ is constant and is equal to the ratio of 1.05 to 1.007 (one plus the long-run growth rate of X_{1t}). The value of ν_t beyond 2000 is set as:

$$\nu_t = -0.01 + x^{t-2000} \times (\nu_{2000} + 0.01) \ \text{ for } \ t = 2001, 2002, \ldots.$$

This x is set so that the present discounted value of ν_t ($t = 2000, 2001, \ldots$) with the discounting factor of $1/(1 + \tilde{r}_t)$ equals fa_{2000}. We take FA_{2000} to be the nation's external assets at the end of 1999 (84.735 trillion yen in nominal terms). x thus calculated equals 0.9422. Thus, the trade balance is assumed to gradually declines to -1% of GDP (excluding household production).

As explained in the previous section, the path of A_{Ht} (the pseudo TFP for household production) does not affect the detrended system, but it does affect the breakdown of $P_{dt}Y_{Ht}$ (value of household production in terms of good 1) between price and quantity. We assume no change in A_{Ht} beyond year 2000. The calibrated parameter values and projected growth rates are shown in Table 9.

Table 9: Calibrated Parameter Values and Projected Growth Rates

θ_{ij} (asset i's share in sector j)	$\theta_{11} = 0.326, \theta_{21} = 0.035, \theta_{12} = 0.285, \theta_{22} = 0.119$
γ (asset 1's share in household production)	0.985
μ (share of non-IT goods in consumption)	0.770
δ_i (depreciation rate for asset i)	$\delta_1 = 0.068, \delta_2 = 0.305$
β (discounting factor)	0.964
τ_{kt} (capital income tax rate) for $t > 2000$	its 2000 value of 50.0%
τ_{ct} (consumption tax rate) for $t > 2000$	its 2000 value of 9.8%
growth rate of N_t (working-age population) for $t > 2000$	0%
growth rate of A_{1t} (pseudo TFP in non-IT sector) for $t > 2000$	0%
growth rate of A_{2t} (pseudo TFP in IT sector) for $t > 2000$	12.4%
implied growth rate of X_{1t} for $t > 2000$	0.7%
implied growth rate of X_{2t} for $t > 2000$	14.5%
growth rate of A_{Ht} (pseudo TFP in household sector) for $t > 2000$	0%

Note: The pseudo TFPs, A_{1t} and A_{2t}, are defined in (4.21). A_{Ht} is defined in (4.23). The two trends, X_{1t} and X_{2t}, are defined in (4.29).

Results

Under the calibrated parameter values and projected path of exogenous variables, we can numerically solve (i.e., simulate) the model as explained in detail in the previous section. We first examine the steady-state properties of the model solution. Table 10 reports our steady-state results under the two scenarios about the allocation of private total hours between non-IT and IT sectors. As explained in the previous section, the steady-state value of the wage ratio w_{1t}/w_{2t} does not depend on the allocation of private hours. Under our calibration of the model, it equals 0.9670. So there is no strong incentive for workers to emigrate between non-IT and IT sectors in the steady state. As shown in the table, the steady-state percapita GDP growth rate depends on the given allocation of labor. This is because the sectoral allocation of labor affects the sectoral allocation of value added. The "macro" capital-output ratio, on the other hand, is not sensitive to the labor allocation.

Table 10: Steady-State Labor Allocation and Growth: Two Scenarios

	Allocation of Hours Worked		Sectoral Value-added Shares				
	non-IT ($\frac{L_{1t}}{L_{1t}+L_{2t}}$)	IT ($\frac{L_{2t}}{L_{1t}+L_{2t}}$)	non-IT (v_1^Y)	IT (v_2^Y)	H (v_H^Y)	growth rate of Y/N	K/Y
scenario A	97.2	2.8	81.4	2.6	16.0	1.1	3.180
scenario B	90.0	10.0	74.8	9.2	16.0	2.0	3.173

Note: Shares and growth rates in percents. In both scenarios, 96.3% of total hours is in the private sector. L_{jt} is hours worked in sector j ($j = 1,2$). $L_{Ht} = 0$ by definition. Y is real private GDP, N is working-age population, and K/Y is the ratio of nominal private capital stock to nominal private GDP.

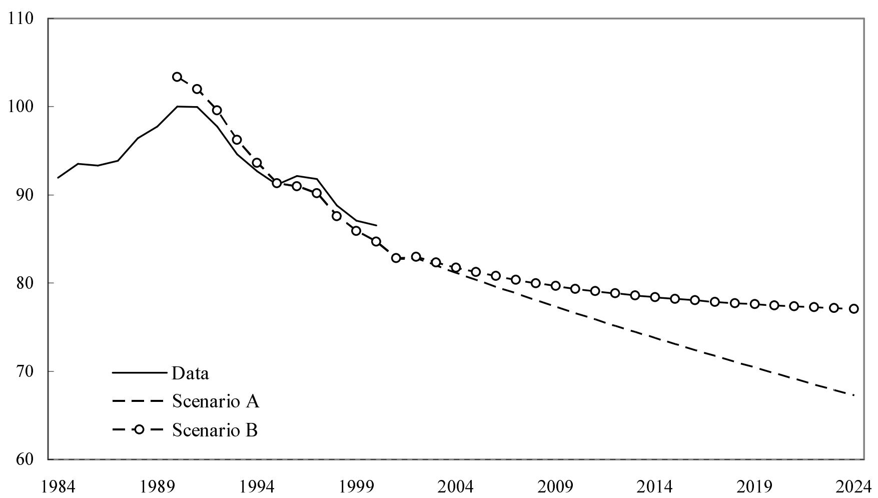

Figure 5: real GDP

Turning to the transition dynamics, under either scenario, the shooting algorithm finds that there is a unique initial value for the co-state, λ_{1990}, such that the system converges to the steady state. The transition paths under the two scenarios are graphed in Figure 5 for the detrended real GDP per worker and in Figure 6 for the "macro" capital-output ratio. Consistent with the

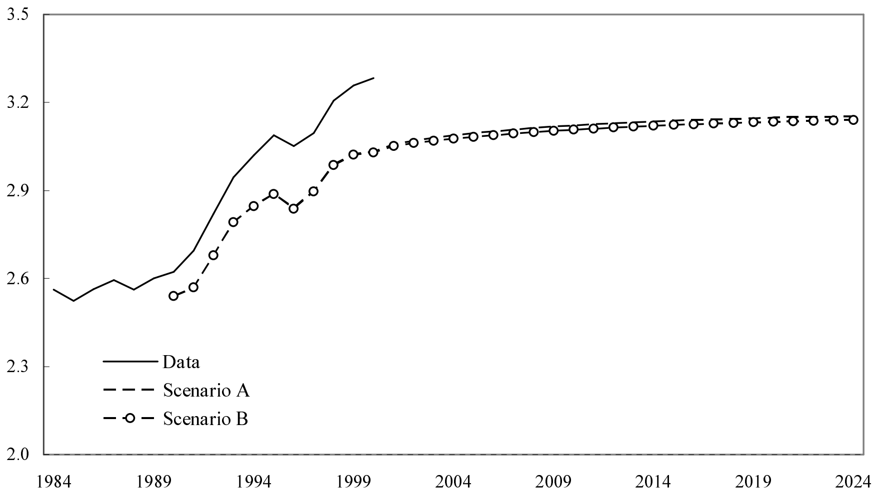

Figure 6: Capital-Output Ratio

different steady-state growth rates under the two scenarios, the detrended path of real GDP diverges eventually, as shown in the Figure, but the difference is not apparent until around 2003. For either scenario, the model's ability to track GDP is rather impressive. The model does far worse for the capital-output ratio (K/Y), as seen in Figure 6. The simulated K/Y under either scenario echoes the rapid rise in data, but the rise is not steep enough. Compared to the one-sector model of Hayashi and Prescott (2002), our multi-sector model is less able to account for K/Y. One possible reason is our assumption that labor allocation is exogenous. Shutting down the labor margin reduces returns from investment.

6. Conclusion

We have constructed a multi-sector growth model that takes explicit account of the differential TFP growth rates between non-IT and IT goods. Our model is capable of accounting for Japan's output slump in the 1990s, and is less successful than the one-sector model of Hayashi and Prescott (2002) in accounting for the sharp rise in the capital-output ratio in the 1990s.

Can IT be Japan's savior? What this paper has done is merely provide an accounting framework for answering the question. We have provided a mapping from the labor allocation and the relative price between non-IT and IT sectors to the long-run GDP growth rate. To endogenize the labor allocation and the relative price and to thereby determine the country's industry structure, one would need a dynamic Heckscher-Ohlin model composed open economies.

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