Information Technology and the Indian Economy

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

Jyoti Vig

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Terry Roe

March 2011

Acknowledgements

This dissertation owes its completion to many quarters...

In Dr Terry Roe, Dr V. V. Chari and Dr. Paul Glewwe, I was fortunate to have had access to a committee of outstanding and erudite researchers. Prof. Glewwe and Prof. Roe were very responsive to my work and gave excellent feedback for every chapter.

Dr. Roe was an excellent advisor, I cannot recall a single instance when Dr. Roe was not willing to review my work even when he was traveling. He allowed me to teach full time for a year and return and finish my thesis. For this I shall always be very grateful.

I would like to thank all the participants in the macro workshop organized by Prof. Terry Roe. I would like to thank Prof. Roe for giving us access to the GTAP database and for Cristina Vinas in helping me extract data for constructing the Social Accounting Matrix for India. Prof. Roe's book on Multi-sector growth Models was an excellent guide in understanding the minutia of modeling.

I would like to thank Prof. Paul Glewwe for reading and reviewing my work not once but many times. His insightful feedback and excellent guidance in my econometric chapter helped me refine my work and develop greater finesse in presentation.

I owe a special thanks to Prof. Simran Sahi, Director for Undergraduate Studies, Department of Economics, University of Minnesota for providing me with support and in encouraging me to pursue my research ideas.

I would also like to thank Dr. Andrew Odlyzko for including me in his research team on network neutrality from 2007-08. He was highly approachable and allowed all of us to work through our ideas and offered academic and financial support.

On the subject of stress, I must emphasize how vitally important it is to have a close group of friends to interact with during the graduate program, both professionally and for recreation. I was fortunate to have made many close friends during my stay in Minneapolis and I would be remiss if I did not acknowledge their role in overcoming my homesickness, in mitigating stress and for never allowing me to feel isolated. In particular I would like to thank Suhas, Eugenie, Uttam, Rosamma, Khusro, Michael Bar, Stanley Cho, Julian, Maria, Carlos, Sujeewa and Bilal for making my stay in Minneapolis as pleasant as it has been. Though they are all in different parts of the world pursuing their dreams, I wish them the very best for years to come.

Dedication

I dedicate this dissertation to my grandmother Vidya Taneja, the greatest feminist I know.

Abstract

Using a multi-sector growth model this thesis attempts to capture the impact of the information technology sector on the growth of the Indian economy. I focus attention on three structural features. Specifically a movement towards services and a decrease in agriculture as a share of GDP, a sharp increase in merchandise and services trade and a sharp increase in GDP growth rate from the period 2004 to 2009. I ask the question whether the four sector Ramsey model can capture these structural features?

An important input into the growth model is the econometric work on firm level panel data. Using firm level data obtained from NASSCOM and the CMIE database I carry out production function estimation and create an aggregate productivity index using the Bailey, Hulten and Campbell or the BHC index. The parameters or coefficients of capital, labor and intermediate goods are obtained using the Levinsohn-Petrin method in order to obtain consistent estimates and to account for the endogeneity problem arising from OLS estimates. These coefficients are then used to evaluate aggregate levels of capital and labor used in the IT sector. These aggregate measures of inputs are used in the social accounting matrix constructed using the GTAP database for India for the base year 2001.

The growth model is characterized by three final goods agriculture, manufacturing and services and one intermediate good stylized as information technology. Using a social accounting matrix (from GTAP) for the base year 2001

as input into the growth model, we compare the output of the baseline to WDI data.

We observe a close fit of GDP and sectoral output for the period 1991 to 2003, however the model output severally undershoots thereafter. We apply a parametric experiment on our original baseline model and observe a similar trend. This shows that information technology accounts for growth trends for the period 1991 to 2003 but cannot account for the sharp acceleration in the GDP growth rate for the period thereafter.

The model however does account for the increase in services as a share of GDP, an increase in the contribution of services in the growth of GDP and the sharp increase in exports of IT. Using firm level panel data we simulate shocks to the TFP parameter and observe the above trends repeating for every case.

Table of Contents

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

List of Tables

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Preface

The three distinguishing features of any general purpose technology include: Pervasiveness: A GPT should have an impact on technical change and productivity growth across a large number of industries. Improvement: A GPT should experience continuous improvement leading to sustained productivity growth and cost reductions in its own industry. Innovation spawning: A GPT should lead to product and process innovation in application sectors (Bresnahan and Trajtenberg 1995, Jovaovic (2001), Jovaovic and Rousseau 2005). On all the above accounts information technology serves as a GPT.

Information technology served as an important driver of the growth resurgence experienced by the US economy during the period 1996-2000. Prior to this period work by Jorgenson and Stiroh (1999) shows a sharp increase in both consumption and investment of information technology (refer to table 1.1) throughout all sectors of the US economy. Further constant productivity increments in this sector resulted in an increase in rates of productivity growth throughout the US economy (Jorgenson 2000). However as with any GPT it happened with a lag so that TFP changes in the period 1976-90 did not reflect the increased absorption of information technology. The period thereafter shows a sharp rise in TFP as can be seen in table 1.1.

This thesis is unique as it attempts to understand the impact of information technology on the Indian economy both at the micro level of the firm by using firm level data (CMIE/NASSCOM) to assess growth and productivity variation and at the macro level by asking if the growth of this sector can explain the growth trends of individual sectors and in the aggregate.

Chapter 1 reviews the literature marking the rise of information technology as a general purpose technology and its impact on growth in the technology center i.e. the US. Jorgenson (1999, 2000) focuses on specific features that emerge in the US data such as an increase in capital intensity across sectors that absorb IT intensively and the increase in their productivity. In this chapter I also focus on the growth of IT in three centers outside the US i.e. the 3I's India, Ireland and Israel. These tree countries have emerged as main suppliers of intermediate goods to the technology center.

Using firm level data obtained from NASSCOM and CMIE databases, chapter 2 focuses on the growth and evolution of Indian IT industry. The chapter investigates the nature of growth in relation to firm size. I further investigate the productivity variation of the industry by constructing the Bailey, Hulten and Campbell Index (BHC Index) of Industry level TFP. Over the period 2002-2007 aggregate industry productivity is found to increase. I use the production function coefficients to find aggregate levels of capital and labor for a social accounting matrix which is then used in the following chapter.

The following chapter analyzes the contribution of the information technology sector in the acceleration in growth rate of the Indian economy during the period 1991-2009 using an applied general equilibrium model. Using a multi-sector Ramsey growth model with IT stylized as an intermediate good I study how well the model captures the growth trends during 1991 to 2009. I mimic the impact of a greater absorption of IT in the Indian economy by allowing the relative price of IT to fall and by increasing the capital coefficients in all sectors. I also induce TFP shocks on the information technology sector to mimic the sharp increase in the aggregate productivity index obtained from the firm level database. The latter three changes I term as the "Jorgenson Effect". The simulations derived from our original baseline model and the Jorgenson effect show a rising share of services as a fraction of the GDP and a rising contribution of services in the growth of GDP. The model is however not able to explain the sharp rise in the growth rate from 2003-2009. We assume this implies there are forces working in the Indian economy which are not captured by our theoretical construct.

An important feature of the Indian software industry which might explain the above observation differs is the relatively lower share of domestic absorption. There is however an increase in domestic absorption in absolute terms hence we do expect IT to behave as a GPT in the Indian economy but the effect is likely to not be as pronounced as in the US economy.

We predict that the rise in the aggregate TFP level of this industry (refer to table is transmitted to final good producers in the US and the EU where most of the sales revenue is derived. However this does speak volumes of the potential of this sector to increase productivity growth throughout the Indian economy in the medium and long run. As Ruttan (2007) points out the public sector played a key role in spreading IT throughout the US economy. A similar public policy initiative can be adopted to reap the benefits of IT in the domestic Indian market.

Chapter 1

Information Technology Revolution

Information technology played a key role in the American growth resurgence in the late 1990's. The growth resurgence is characterized by a rapid rise in growth of output, labor productivity and total factor productivity. Jorgenson quantifies the sources of growth for the period 1948-1999 with special emphasis on the role of information technology.

Jorgenson uses the production possibility curve as the methodology to evaluate the impact and cost of using information technology in the US economy. Apart from describing efficient combinations for outputs and inputs for the economy, the PPF allows one to incorporate the costs of adjustment when increasing output of any one commodity.

At the firm level an example in the literature is on firms employing complementary inputs and restructuring organization to effectively use and employ information technology (Bresnahan, Brynjolfsson QJE 2002). This implies a cost in the initial phase of implementation followed by a long term gain of efficiency.

At the macro level the cost of adjustment would account for the decrease in the output of consumption and non IT investment goods to allow for an increase in the output of IT investment. Either way employing a general purpose technology is typically occurs in two phases. In phase one due to diversion of complementary resources there is an initial slowdown followed by a productivity upsurge when the efficiency of the GPT is realized.

Aggregate output Y consists of output of investment and consumption goods, these outputs are produced using capital and labor services. Productivity is "Hicks neutral" augmentation of aggregate input.

$$Y(I_n,I_c,I_s,I_t,C_n,C_c)=A.X(K_n,K_c,K_s,K_t,L)$$

The outputs include non-IT investment goods (I_n) and investment in computers (I_c), software (I_S) communication equipment (I_t) as well as non IT consumption goods and services (C_n) and IT capital services to households ad governments (C_c). Inputs include non IT-capital services (K_n) and the services of computers (K_c), software (K_s) and telecommunication equipment (K_t), as well as labor input L. Total factor productivity (TFP) is denoted by A.

Under the assumption that product and factor markets are competitive, producer equilibrium implies that the share weighted growth of output is the sum of the share weighted growth of inputs and growth in total factor productivity.

$$\alpha_1 \Delta \ln I_n + \alpha_2 \Delta \ln I_c + \alpha_3 \Delta \ln I_s + \alpha_4 \Delta \ln I_t + \alpha_5 \Delta \ln C_n + \alpha_6 \Delta \ln C_c = \beta_1 \Delta \ln K_n + \beta_2 \Delta \ln K_c + \beta_3 \Delta \ln Ks + \beta_4 \Delta \ln K_t + \beta_5 \Delta \ln L + \Delta \ln A.$$

where $\Sigma\alpha_i = 1$, $\Sigma\beta_i = 1$

The above equation makes it possible to measure contribution to outputs and inputs to US economic growth. The term ΔlnA captures the contribution to growth arising from factors other than changes in output and inputs such as technical change. It can be further simplified to the following form to present results in terms of average labor productivity. y=Y/H, the ratio of output Y to hours worked H, k=K/H is the ratio of capital services K to hours worked:

Growth Accounting for the US Economy

	Growth rates		
Source	**1943-73**	**1973-90**	**1990-96**
Total Output	4.02	2.86	2.363
I) Non computers	4.978	2.650	1.980
II) Computers	0.042	0.270	0.384
i) Investment (I_c)	0.042	0.171	0.258
ii) Consumption (C_c)	0.000	0.024	0.086
iii) Consumer Durable services (S_c)	0.000	0.012	0.040
Inputs			
I) Capital Services (K)	1.073	0.954	0.632
i) Non computers (K_n)	1.049	0.845	0.510
ii) Computers (K_c)	0.025	0.109	0.123
II) Consumer Durable services (D)	0.550	0.426	0.282
i) Non computers (D_n)	0.550	0.414	0.242
ii) Computers (D_c)	0.000	0.012	0.040
Aggregate Total factor Productivity Growth	1.391	0.335	0.231

Table 1.1: Source: Jorgenson and Stiroh "Information Technology and Growth"

$$\Delta \ln y = \beta_k \Delta \ln K + \beta_L(\Delta \ln L - \Delta \ln H) + \Delta \ln A.$$

The above equation allocates average labor productivity growth in to three sources: capital deepening, the growth of capital input per hour reflecting capital labor substitution, improvement in labor quality captured by the rising proportion of workers working longer hours with higher marginal products. The third is TFP growth which contributes point to point to ALP growth.

The growth rates in the above table are average annual percentages and the contribution to inputs and outputs are real growth rates weighted by average nominal shares. The estimate of the sources of growth for the U.S. private domestic economy for 1948-1996 is broken into three sub-periods: 1948-1973, 1973-1990, and 1990-1996.

For the entire period (1948-1996), output grew 4.4 percent per year. Capital and consumers' durables services were the most important source of growth, accounting for 43 percent of the total, while labor accounted for 32 percent, and the TFP residual accounted for the remaining 25 percent. The growth of output and TFP slowed sharply after 1973, and there has been another, smaller, decline since 1990. The growth rate of output for 1990-1996 was 2.4 percent per year, almost half a percentage point less than the average for 1973-1990 of 2.9 percent annually.

Jorgenson further breaks out the contribution of the three types of computer outputs (investment, consumption purchases, and consumers' durable services) and combines all other outputs into a single index of "non-computer outputs."

The data shows that computers are most important as an investment good, contributing 0.26 percentage points to growth for 1990-1996. Purchases of computing equipment by households and the service flow from this equipment contributed an additional 0.13 percentage points to growth, about half as much.

Although computers contributed virtually nothing to growth prior to 1973, nearly one- sixth of the 2.4-percent output growth for 1990-1996 can be attributed to computer outputs. Alternatively, we can express output growth as the sum of the contributions of the growth of capital services, consumers' durable services, labor inputs, and the TFP residual.

Jorgenson replicates the above exercise for the G7 group of countries. The following table illustrates the growth accounting exercise for the G7. In the context of the above growth accounting exercise the sum of capital expenditures on computers, software and communication equipment constitutes ICT i.e. $K_c+K_s+K_t=K_{ICT.}$ Following our definition of labor productivity we analyze contribution of labor input in terms on labor hours and productivity or quality.

The G7 and IT: Contribution of ICT and Non ICT capital in Growth Accounting (% points per annum)

Contribution of Capital						
Economy	**1989-95**		**1995-2000**		**2000-04**	
	NON ICT	**ICT**	**Non ICT**	**ICT**	**Non ICT**	**ICT**
Canada	0.27	0.49	0.77	0.94	0.67	0.45
France	0.92	0.20	0.81	0.39	0.29	0.37
Germany	1.03	0.28	0.92	0.44	-0.20	0.34
Italy	0.85	0.26	1.00	0.48	0.66	0.36
Japan	1.16	0.31	0.38	0.78	0.21	0.31
United Kingdom	1.67	0.29	0.20	0.79	0.54	0.57
United States	0.71	0.49	1.11	1.02	0.86	0.57
All group	0.89	0.39	0.87	0.82	0.58	0.47

Table 1.2: Contribution of ICT and Non ICT capital in Growth Accounting (G7) (% points per annum)

Source: Jorgenson "Information Technology and World Growth Resurgence" German Economic Review 2007, pg. 125-145

Contribution of ICT and Non ICT capital in Growth Accounting
Developing Countries:
(% points per annum)

Sources of Output Growth by period						
Contribution of Capital						
Economy	**1989-95**		**1995-2000**		**2000-04**	
	Non ICT	**ICT**	**Non ICT**	**ICT**	**Non ICT**	**ICT**
Brazil	0.22	0.07	0.21	0.25	0.05	0.27
China	2.21	0.17	2.69	0.48	2.73	0.63
India	1.12	0.08	1.39	0.17	1.39	0.26
Indonesia	1.42	0.07	1.10	0.06	0.50	0.08
Mexico	1.03	0.25	1.32	0.29	1.63	0.28
S. Korea	2.02	0.21	1.30	0.34	0.84	0.39
All group	1.22	0.12	1.46	0.31	1.56	0.41

Table 1.3 Contribution of ICT and Non ICT capital in Growth Accounting (Developing countries)

Source: Jorgenson "Information Technology and World Growth Resurgence" German Economic Review 2007, 125-145

Table 1.3 shows the contribution of capital input to economic growth for the G7 economies. Capital input is divided between IT and non IT capital. Capital input was the most important source of growth before and after 1995.

The contribution of capital input before 1995 was 1.28 or almost three fifths of the G7 growth rate of 2.19 percent. The capital contribution of 1.69 percent from 1995 to 2000 was 52 percent of the higher growth rate of 4.25 percent. After 2000 the capital contribution fell to 1.05 or 47.7 percent of the substantially lower G7 growth rate of 2.20 percent.

Sources of Output Growth by period Contribution of Labor (% points per annum)						
	1989-95		1995-2000		2000-04	
Country	**Hours**	**Quality**	**Hours**	**Quality**	**Hours**	**Quality**
Canada	0.08	0.55	1.08	0.21	1.29	0.15
France	-0.17	0.61	0.45	0.35	0.64	-0.08
Germany	-0.41	0.33	-0.03	0.21	0.09	0.18
Italy	-0.35	0.38	0.55	0.46	0.75	0.21
Japan	-0.39	0.54	-0.42	0.26	-0.32	0.21
United Kingdom	-0.72	0.49	0.61	0.33	0.65	0.27
United States	0.57	0.37	1.12	0.19	-0.16	0.40
All group	0.07	0.43	0.63	0.24	0.08	0.28

Table 1.4 Contribution of Labor in Growth Accounting (The G7)

Source: Jorgenson "Information Technology and World Growth Resurgence" German Economic Review 2007, 125-145

Table 1.4 shows the contribution of labor in the growth accounting exercise. Labor input growth contributed 0.50 percent to growth of the G7 economies before 1995, 0.87 percent in 1995-2000, but only 0.36 percent after 2000. Hours predominated during 1995-2000, growing at 0.63 percent while labor quality rose at 0.24 percent.

The sharp increase in IT investment in the US after 1995 is mirrored in a sharp increase in the growth rates of IT capital throughout the G7. The above table shows that contribution of IT capital input for the G7 more than doubled from 0.39 during the period 1989-95 to 0.82 per cent during 1995-2004 before receding to 0.47 percent after 2000. The contribution of non IT capital predominated in all three sub periods but fell steadily throughout 1989-2004. This reflects the rapid substitution of IT capital input for non IT capital input in response to declining prices of IT equipment and software after 1995.

In developing Asia the contribution of capital input increased from 18.1 percent before 1995 to 2.22 percent in 1995-2000 and rose again to 2.27 percent after 2000. The contribution of labor input fell from 2.33 percent during 1989-95 to 1.64 percent during 1995-2000 and recovered slightly to 1.68 percent after 2000. The decline in the Asian growth rate from 7.54 percent before 1995 to 5.91 percent during 1995-2000 can be traced to a sharp decline in productivity growth from 4.41 percent to 2.04 percent.

The above data shows a steady increase in the contribution of investment in IT equipment and software to economic growth. Contribution of IT investment doubled from 0.14 percent before 1995 to 0.33 percent during 1995-2000 to 0.44 percent after 2000. IT investment was especially large in China rising from 0.17 percent before 1995 to 0.48 percent during 1995-2000 increasing again to 0.63 percent after 2000. India lagged behind China and the rest of developing Asia. Indonesia was the only country to experience a decline in the contribution of both IT and non IT investment during 1995-2000.

The growth in IT investment in equipment and software is a global phenomenon and the variation in the contribution of this investment has grown considerably since 1995. The moderation in IT investment in the G7 after the dot com crash was accompanied by an expansion in the contribution of IT in the developing world. The contribution of IT investment more than doubled after

1995 in Developing Asia, Latin America, Eastern Europe, North Africa, Middle East and the Sub Saharan Africa.

The Software Industry: International Comparison Software Industry in Brazil, China, Ireland, Israel and India in comparison with the US, Japan and Germany

Countries	Sales ($ bn)	Employment ('000)	Sales / Employment (000)	Software sales/GDP (%)	Software Development Index
Brazil	7.7	160	45.5	1.5	0.22
China	14.3	190	37.6	1.1	0.23
India	12.5	230	54.3	2.5	0.96
Ireland	12.3	15.3	804.9	10.1	0.34
Israel	4.1	15	274.3	4.7	0.17
United States	200	1024	195.3	2	0.05
Japan	85	534	159.2	2	0.08
Germany	39.8	300	132.7	2.2	0.09

Table 1.5 The Software Industry: International Comparisons

Source: Arora and Gambardella "Bridging the Gap"

The above table further provides a summary of software industry in five emerging countries in relation to the three leading software producers i.e. the United States, Germany and Japan. We observe that the software industry in each of the five emerging economies has comparable size. In 2002 the Irish Software industry reached a size of $14.9 bn in total sales of which $12.3 bn was due to multinationals and $1.5 bn was due to indigenous companies. The size of Indian and Chinese industries was $12.5bn and $14.3bn respectively while the figures for Brazil and Israel for 2001 are $7.7bn and $4.1bn respectively.

Consider also the difference in employment base across the five countries. According to NASSCOM (National Association of Software and Service

Companies) the estimates of software professionals in India is over 230,000 in March 2004. The 2000 figures for China and Brazil are respectively 160,000 and 190,000. The 2002 figure of employment in Ireland was 28,000 while in 2001 figure for the Israeli industry was 15,000. An interesting observation is the contribution of this industry to the GDP in all the above countries. For each of the five countries we observe a ratio of software sales to employment exceeding 1%, a figure typical for developed markets such as France, the United Kingdom and Italy. The ratio is highest for India and Israel and is comparable with ratios in developed markets.

The software development index is measured by dividing the software sales per GDP to the GDP per capita of the country. This index gives the size of the software industry in relation to the country's level of development. India, Israel and Ireland have the highest value for this index. Moreover given that India has the lowest capita per GDP the ratio is the highest 0.96. It is thus an outlier and this industry represents a success story in an underdeveloped country.

Software Industry Growth, GDP growth and Software Export Growth

Countries	Average Growth of Software sales in the 1990's	Average growth of GDP in the 1990's (%)	Software Exports as % of sales (2002 or latest available year)
Brazil	20	2.5	1-2
China	>35	9.8	11
India	40	4.4	80
Ireland	20	7	85
Israel	20	7.4	70

Table 1.6, Emerging Economies and the Software Industry

Source: Arora and Gambardella "Bridging the Gap"

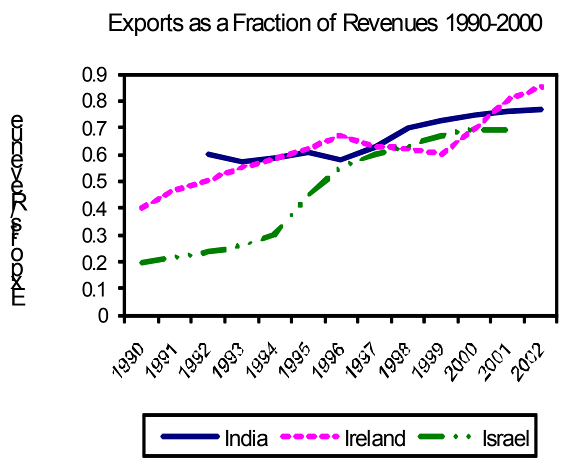


Fig. 1.1 3I's and Software Industry, Exports as a fraction of revenues

Source: Arora and Gamberdella "From Underdogs to Tigers" (2005)

We observe that in terms of size as well as export orientation India, Israel and Ireland are similar. The predominance of exports marks the Indian software industry as an export led industry different from its counterparts in the developing world such as Brazil and China. When compared with equivalent exporters like Israel and Ireland Indian Software growth manifests differences. Unlike the Israeli Industry the Irish and the Indian industry are built around services rather than products.

During the period of rapid expansion of the IT sector the Indian economy was undergoing changes in its macroeconomic policy towards trade, internal liberalization and capital market reforms. There are three key features that I would like to draw attention to. The first is the structural break in the growth rate of GDP circa 1980. As Wallack (2004) points out the most significant structural break between 1950-2004 occurred in 1980.

Sector/Period	1950-51 to 1979-80	1980-81 to 2004-05	1980-81 to 1990-91	1991-92 to 2004-05
Primary sector	2.2	2.9	4.1	2.5
Secondary	5.3	6.1	6.7	6.0
Tertiary sector	4.5	7.1	6.6	7.8
GDP total	4.5	5.6	5.4	5.9
GDP per capita	1.4	4.6	4.2	4.1

Table 1.7 Sectoral and Aggregate Economic Growth in India 1950-51 to 2004-05, Source: Bosworth and Collins (2003)

The period 1950-51 to 2004-05 shows a significant structural break in growth rate circa 1980[5]. This growth was impressive in terms of growth in the OECD, transition economies and most emerging economies. The only country with comparable growth rates during the same period was China.

This period can be further subdivided in to two periods 1980-91 and 1991-2005. The 1980-1991 period was characterized by debt financing of growth. The increase in aggregate demand was fueled by expansion of public expenditure on consumption and investment. Given unemployed resources in the economy expansionary fiscal policies did raise output but were not fiscally sustainable and led to a balance of payments (BOP) crises (1991). The country underwent a structural adjustment program within the purview of the IMF where the emphasis was on privatization of public assets, devaluation of the currency, trade liberalization and internal deregulation. The period 1991-2005 was characterized by a continuation in higher growth rates but under a drastically different policy regime. Effective average tariff rates fell from 120 percent to less than 40 percent.

Volatility of Growth Rates

India	1960-70	1970-80	1980-90	1990-00
Mean	1.91	0.77	4.91	4.22
Std Dev	4.24	4.16	1.87	2.05
Coefficient of variation	1.69	5.40	0.48	0.64

Table 1.8 Volatility in growth rates

Source: Bosworth and Collins (2003)

Kruger points out that trade reforms have only a level effect on growth rate not an accelerating impact, hence the sharp rise in growth rate (1985-2000) cannot be attributed to trade reforms. However firm level studies like Topolova (2005) explore the impact of trade liberalization on productivity in manufacturing whereas Sharma (2006) highlights the differential impact of trade liberalization on sectors of the economy which were underwent domestic deregulation. The findings are suggestive of productivity improvements in manufacturing arising from trade liberalization. The following table shows the impact of trade liberalization in terms of average decline in effective rate of protection and other parameters.

India: Measures of Trade Protection

All Industries	1980-85	1986-90	1991-95	1996-00
Average effective rate of protection	115.1	125.9	80.2	40.4
Import coverage ratio	97.6	91.6	38	24.8
Import penetration ratio	10	11	12	16

Table 1.9 Measures of Trade protection

Source: Bosworth and Collins (2003)

The following table points out another interesting feature of growth in India. Consider a comparison of cross national data for contribution of capital accumulation and total factor productivity growth to overall labor productivity growth. Prior to 1980 the contribution of TFP growth to overall labor productivity at 10% was lower in India than in any other region, except the Middle East: even Sub Saharan Africa fared better. Since 1980 India tops the list for TFP contribution to overall growth. The Indian TFP performance in 1980-99 surpasses that of East Asia even in the first 20 years of the East Asian miracle. India relied less on savings and more on productivity growth to motor growth even compared to the fast growing countries of East Asia.

Region	Output	Output per Worker	Physical Capital	Education	Factor productivity	Contribution of Factor Productivity (%)	Contribution of Physical Capital. (%)
China							
1960-80	4.04	1.83	0.76	0.43	0.64	35%	41%
1980-99	9.75	7.85	2.63	0.36	4.71	60%	33%
1960-99	6.78	4.72	1.66	0.39	2.60	55%	35%
India							
1960-80	4.41	1.28	0.72	0.43	0.12	9%	56%
1980-99	5.73	4.60	1.18	0.33	2.05	57%	33%
1960-99	4.53	2.40	0.95	0.38	1.06	44%	39%

Table 1.10 Growth Accounting

Source: Bosworth and Collins (2003)

Consider output Y and the size of the labor supply L.

$Y/L= (Y_a/L_a)*(La/L)+(Y_m/L_m)*(L_m/L)+(Y_s/L_s)*(L_s/L)$

Increase in aggregate productivity occurs due to two main reasons. A shift in labor shares away from lower productivity agriculture towards higher productivity manufacturing and finally services. An increase in labor productivity can also occur due to increase in productivity coefficients Y_i/L_i for i=a,m,s. The rise in Y/L occurs due to both the above effects. There has been a structural change in the labor force employed in the three sectors. Labor in agriculture declined by 10 percent (1975 to 1995) and has been partially offset by an increase in share of services (7.5 percent) and industry (2.5 percent). However this shift in labor shares explains a very small fraction less than 10 percent of the economy wide productivity. For example at fixed labor shares the increase in productivity growth in the 1980's is 2.6 to 2.9 percent, and the deceleration in the 1990's is about 0.4-0.6 percentage points.

Panagariya asserts that though growth picked up in the 1980's it was highly fragile and had much higher variance than the growth in the 1990's. He attributes the reforms specifically external reforms as responsible for the increase in growth rate of GDP and a decrease in volatility or variance in growth rates. Consider the following periods and the ratio of variance relative to the 1990's.

Average Annual Growth rates during selected period

Period	Variance	Ratio of Variance in the 1990's
1981-82 to 1991-92	6.1	4.1
1980-81 to 1990-91	4.6	4.1
1981-82 to 1990-91	4.8	4.3
1977-78 to 1990-91	12.5	8.5
1992-93 to 2002-03	1.5	-

Table 1.11 Annual average growth rates

Source: Panagariya EPW (2004)

Another interesting feature of the Indian economy is the structural change that accompanied the rise in growth rate. The decline in the share of agriculture is accompanied by a rise in the share of services as a share of GDP. This structural change is also accompanied by a sharp increase in the exports of services. This feature is peculiar for a developing country as ninety percent of trade in services takes place between the OECD (WTO website).

Years	**Agriculture**	**Industry (Mgf)**	**Services**
1970-71	46	22 (13)	32
1980-81	40	24 (14)	37
1990-91	32	27 (17)	41
2000-01	24	27 (17)	49
2004-05	21	27 (17)	52

Table 1.13 Sectoral Composition, WDI

Echivarria (1995, 1997, 2000) and Gollin (2004) in a series of papers develop neoclassical growth models in which agriculture and a home good are used to show how sectoral composition of an economy explains an important part of the variation in growth rates across countries. Our model with homothetic preferences in a multi-sector framework is able to show the same sectoral transformation for the Indian economy.

My thesis captures the impact of the information technology as an intermediate good sector within the context of the above macroeconomic changes taking place in the Indian economy. Specifically using an open economy four sector Ramsey growth model we stylize the IT sector as an intermediate good in manufacturing and services. We use the production function coefficients obtained from the study of TFP to estimate capital and labor shares in the output of the IT sector in a social accounting matrix (SAM) derived from the GTAP.

Chapter 2

Growth and Evolution of Firms

The Indian software industry has greatly benefitted from outsourcing and initially specialized in labor intensive stages of testing and support of various software applications. Over time firms have climbed the quality ladder and have acquired ISO/CMM certifications and have gradually moved away from client specific to process and product specific applications.

Outsourcing is an act of transferring some of the firms recurring internal activities and decision rights to outside providers as set in a contract. Outsourcing can be categorized into four types based on location and control/ownership as distinguishing criteria i.e. captive outsourcing, non captive onshore outsourcing, captive off-shoring and non captive off-shoring.

Captive onshore outsourcing implies a shift in intra firm supplies to an affiliated firm in the home economy of the parent firm. If the shift in sourcing of supplies benefits a non-affiliated firm in the home economy one can describe it as **non-captive onshore outsourcing**. The term “onshore” can be replaced in both cases by “local” or domestic”.

Captive off-shoring describes a situation in which future supplies are sourced from an affiliated firm abroad. The fourth type refers to **non-captive off-shoring** and responds to the case when the new supplier is non-affiliated firm located abroad. The following table illustrates the four types of outsourcing. In the context of the Indian software industry captive and non-captive off-shoring are of particular interest.

		Located in home country	Located abroad
Shifting intra-firm inputs/supplies to	Non-Affiliated firm	Local/Domestic	Offshore Outsourcing = Offshoring
	Affiliated Firm	Captive onshore outsourcing	Captive offshore Outsourcing = Captive Offshoring

Table 2.1 Source: World Trade Report 2005, OECD (2005a)

A problem with the definitions above is that they do not accord well with officially collected economic data. Outsourcing decisions are made at the micro level of plants and firms while official data are collected at the sector and national level. An absence of links between statistical concepts such as import statistics and a management decision to substitute a product or a service in house makes it difficult to track imported intermediates.

In contrast to merchandize trade, service trade flows recorded in the balance of payments are not broken down by region and country this prevents a detailed geographical analysis of services off-shoring. A further difficulty arises due to the large internal service transactions of multinational firms. Many of these internal cross border transactions go unreported.

Trade and Market Thickness

Forces of comparative advantage and intra-industry trade drive off-shoring in the same way as these two forces drive trade in general. Comparative advantage and intra-industry are complementary forces. Trade between countries that are significantly different when it comes to relative factor endowments is driven by comparative advantage. Trade between similar countries is motivated by the desire for a broader variety of goods and services ("love for variety" encompassed in Dixit-Stiglitz preferences). Off-shoring allows countries to exploit comparative advantage and obtain a greater variety through trade at the same time.

Off-shoring of IT services and business process outsourcing can be characterized as vertical specialization. Off-shored services are usually less skill intensive and less capital intensive than those retained in the home country and trade is driven by comparative advantage (Feenstra 2005).

McLaren (2000, 2003) studies the impact of removing trade barriers or globalization on the market for inputs i.e. globalization increases the number of buyers available for each seller and the number of sellers available for each buyer, thereby raising the market "thickness". This effect of trade openness is distinct from the increase in competition which is often sighted as giving rise to gains from trade. Instead this phenomenon arises due to the increase in probability of a final good producer to find within any given length of time a suitable upstream intermediate good producer from whom to source inputs. This effect of market thickness affects the nature of organizational structure of the firm, the emphasis being to compare the case of an integrated equilibrium to one of "arms length transaction" or non-captive outsourcing.

Removal of trade barriers apart from increasing the total size of the market can also introduce technologies that lower search costs enabling final good producers to accurately locate a technologically compatible supplier. The author calls this an improvement in search efficiency. Increase in market thickness can also arise due a rise in the fraction of given sellers or buyers increasing the range of goods they can produce i.e. increased variety which is the intensive margin in trade relative to increase in number of alternate producers or the extensive margin of trade.

A final good producer also referred to as the downstream firm has a choice between merging with the upstream input supplier leading to an integrated equilibrium or engaging in arms length engagement i.e. non captive outsourcing. In the integrated equilibrium the firm incurs a rise in governance cost due to a larger organizational structure. In the non integrated solution the input supplier undertakes a relationship specific investment which leads to a sunk cost. The more specific the input is to a particular final good producer (downstream firm) the greater is the surplus that gets transferred to the final good producer in the event of a transaction. This is the classic Williamson holdup problem.

In the above context a thicker market allows more flexibility for the input supplier on finding an alternate buyer. This increases the bargaining position of the intermediate good supplier (upstream firm) and allows a more efficient outcome in the event of a transaction.

Note that thinner is the market for inputs the greater is the holdup problem for input suppliers. Thus the market has to be thick enough for the arms length outcome to be socially efficient. The author argues that there will be essentially two equilibria, one where all firms are integrated where market thickness is severely limited and the second more efficient equilibrium where all firms are non-integrated. In this context the sharp increase in the number of firms in the Indian software industry is an example of an increase in market thickness which has resulted in a greater number of arms-length arrangements.

Reputation and Contracting

Banerjee and Duflo (2000) provide crucial insights into how reputation affects contractual negotiations between the client and the outsourced firm. Outsourcing by its very nature invites holdup costs. Drawing a contract that defines precisely the needs of the client firm and the necessary man-hours required to fulfill the task by the software firm is thereby crucial. However typically as it's a service based industry the initial contract is nebulous in the precise details of the end product but is specific in its desired functionality. This allows disputes to arise in case the final product does not meet all the specifications of the client and results in a cost overrun which is significantly higher than the initial estimate.

The overrun can be either due to the non-performance of the client in accurately describing the desired end product or the inability of the software firm to achieve cost containment in creating the final product. While adjudicating in these contractual disputes the legal system finds it impossible to ascertain or assess the contribution of the cost overrun on either party. Two forms of contracts predominate in the Indian software industry, a fixed price contract where the software firm absorbs the entire overrun and a time and materials contract where the client pays for the entire cost overrun. Given the inability of the client firm to ascertain the particular 'type' of the software firm explains why most of the contracts are fixed price contracts. In this context the authors point out that reputation is a strategy employed by the software firm to signal their worth or reliability to the client firms.

The authors measure reputation as arising from three features. The first is the age of the firm. The age of the firm signifies a selection process at work where it's assumed that the older the firm the longer it has been with its partners and the greater its reliability in terms of honoring its contractual commitments. Process and product certifications are the other two sources of reputation.

Consider a contract where the final product is worth 'V' to the client. In a world of perfect information where the client and the firm have all the information about the nature of the product there would be no overrun in costs. Let the cost overruns be y_f and y_c for the firm and the client respectively i.e. the total overrun is given by $y = y_f + y_c$. Note that in a world of perfect information $y=0$. In case of positive $y > 0$, courts can only observe y and not y_f or y_c. Further we assume two types of firms and two types of clients i.e. high and low overrun type agents.

Software firms are either high overrun i.e. $\overline{y_f}$ or low overrun $\underline{y_f}$ type. Similarly clients are either high $\overline{y_c}$ or low over-run type $\underline{y_c}$. The reduction of overrun can be achieved by the client firm by taking effort to help in product development and by working closely with the firm and in precisely describing the nature of the product desired. Firms can in turn reduce their overruns by putting in more effort in understanding the particular product. The extra cost to the client and the firm from choosing a low level of overrun is given by B_C and B_F such that it's always optimal to minimize overruns.

$$\overline{y_f} - \underline{y_f} > B_F$$

$$\overline{y_C} - \underline{y_C} > B_C$$

Further let this be a world of imperfect information. Let θ_C represent the probability that the firm attaches to the client of being the low overrun type, similarly let θ_F be the probability attached by the client to the firm that it's a low overrun type. A pooling equilibrium occurs when there is matching of low and high overrun types. Contractual disputes typically arise when there occurs a separating equilibrium i.e. either party makes a mistake in selecting a type.

The authors consider only contracts where the client pays the firm as amount $P + (1-s)(y_f+y_c)$ where P is the pre-specified fixed payment and s is the share of the overrun borne by the firm i.e. $s \varepsilon [0,1]$. Note that 's' gives incentive to both parties where a high 's' gives incentives to the firm and a low 's' gives incentive to the client. Note that the authors have chosen linear contracts with discrete choices for s.

Using detailed information on 230 projects carried out by 125 software firms they investigate if reputation can determine contractual outcomes.

The contribution of this paper is to use a discrete choice model to answer two central questions:

a) What factors affect the choice of a contract fixed price versus time and materials contract?

b) What is the effect of reputation on the share of the overrun paid by the firm?

The first regression model is as follows:

$$C_{ic}= \alpha R_{ic} + \beta X_{ic} + \gamma Z_{ic} + \delta M_{ic} + v_i + \omega_{ic}$$

C_{ic} denotes the type of contract obtained by firm i in contract c, by R_{ic} the vector of reputation variables, by X_{ic}, the project characteristics by Z_{ic} the firms characteristics and by M_{ic} the client's characteristics.

Results suggest that controlling for client and firm size, project size young firms are more likely to have a fixed price contract. ISO certified firms are also more likely to have a fixed price contract. Both these results are not significant. Neither client size or project characteristics have any impact on the choice of the contract. To answer the second question the authors estimate using coefficients in a random effects regression model which includes C_{ic} and then excludes C_{ic}.

$$S_{ic}= \alpha R_{ic} + \beta X_{ic} + \gamma Z_{ic} + \delta M_{ic}+\lambda C_{ic} + v_i+\omega_{ic}$$

In the above model the dependent variable is measured only when there is an overrun. Conditional on the type of contract younger firms pay more of the overrun (nine percent) but the difference is not significant. The age effect gets diminished when we condition on the type of the contract. Clients that have had a good experience with a firm are more likely to behave reliably since they want to retain the firm hence the impact on repeat contracts.

Empirics: Growth of Firms

To understand the reasons behind the emergence of three the 3I's (Ireland, India and Israel) as three key centers for the growth of software services consider related evidence on the emergence of three US industries studied extensively in the literature i.e. television receivers, automobiles and automobile tires. Each of these industries experienced an initial rise in the number of producers. In each industry the sharp rise in the number of firms is followed a period of consolidation where the number of firms falls dramatically eventually declining to 20 percent of the peak number (Steven Klepper (2001, 2002)).

All three US industries evolved to be oligopolies. The heritage of firms was also studied and how the heritage of firms conditioned the evolution of the industry. Entrants were classified as diversifiers, firms founded by heads of firms in related industries, spin-offs defined as firms with one or more founders that had previously worked in a related sector. In the context of software it could be Electronics or Engineering. In the Indian context firms like Tata Steel come to mind. The final category of firms constitutes startup firms.

In the following section we analyze firm level data with relevance to the Indian software industry. We trace the increase in the total number of firms and the entry rate over time. In this section using data collected from NASSCOM directories we further study the relation between size and growth of firm i.e. Gibrat's law. Using the CMIE database we carry out production function estimation in order to find firm level TFP and build an aggregate index (BHC index) by means of which we trace industry level TFP and study productivity variation in the industry.

Data Description

The two firm level databases that contribute to this study are the NASSCOM database and the CMIE/PROWESS database. The CMIE/PROWESS database under the industry heading of information technology characterizes firms by industry according to the 4 digit NIC code. The firm level panel data set is derived from income and balance sheets of companies and covers the period 1999-2007.

The second source of data for this study is the 'IT Software and Services Directories' published biannually by the India's National Association of Software and Service Companies (NASSCOM) from 1992 to 2004. This dataset allows one to study the growth of the total number of firms and the entry rate of firms over time. As a private industry organization NASSCOM membership has grown from 38 firms representing 65% of total revenue to over 1200 firms representing over 95% of total revenue. NASSCOM membership is highly diverse and represents a cross section of firms in the industry. The ownership varies from public firms, private firms, subsidiaries, proprietorships, company and joint ventures.

The NASSCOM database has certain key limitations. In any given year member firms have the choice to reveal or not reveal their accounts. For the purpose of building a panel dataset firms listed in the directories can be classified into three categories. The first category consisted of firms with data available on exports, revenue and employment as well qualitative information on the level of technical skill such as certification and technical specialization. I will call this set of firms as 'observed'. The second category consisted of firms for which information was incomplete i.e. either revenue, exports or employment is not missing. The last category consisted of firms which are listed as members but which do not reveal any data. These were not included in the panel. A large proportion of firms in the third category are subsidiaries of foreign multinational firms. I will call the last category of firms as being 'unobserved'.

Over the years member firms changed status from being unobserved to becoming an observed member and vice versa i.e. there are years for which data is missing for certain firms. This dataset is thus more useful for studying variations in distributions of variables such as revenue, size & exports instead of following individual firms over the time span. However to study the relation of growth versus size of firms I use this database extensively as data for sales was available for a large percentage of these firms. The unbalanced panel constructed consists of revenue, software exports, software employment and non-technical employment for the years 1990, 1994-2002.

Year	**Total Sample(A)**	**Exporters (B)**	**B/A**	**Total Member Firms**
1990	76	60	79	94
1994	182	138	76	212
1995	175	131	75	262
1996	295	231	78	356
1997	343	273	79	402
1998	372	309	83	464
1999	488	407	83	520
2000	620	527	85	680
2001	457	402	87	810

Table 2.2 Composition of NASSCOM dataset

Given that the data is not representative of multinational subsidiaries it speaks more clearly about the growth of indigenous firms and their response to changes in domestic policy and increase in world demand for software. Further the industry retains a highly competitive structure with the top five firms accounting for roughly only a quarter of all industry revenues. I also use the second dataset to crosscheck variables in the CMIE/PROWESS database.

Year	Number of Firms	Number of Entrants
1989	36	
1991	94	58
1993	172	78
1995	212	40
1997	356	144
1999	520	164
2001	600	80
2002	800	200
2004	892	92
2006	1138	246
2007	1285	147
2008	1246	-39
2009	1237	-9

Table 2.3, NASSCOM Dataset: Entrants

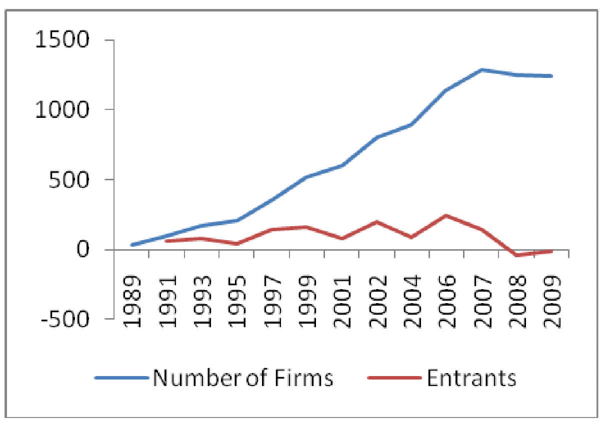


Fig. 2.1 Entrants, Source: NASSCOM

As studies by Klepper (2001) suggest this nascent industry experienced a sharp increase in the total number of firms followed by the current period of 'shakeout' or consolidation. We can also empirically evaluate the entry rate which can be measured by the following formula where N_t refers to the total number of firms in period t and N_{t-1} refers to number of firms in the previous period or data point.

$$e_t = \frac{N_t - N_{t-1}}{N_{t-1}}$$

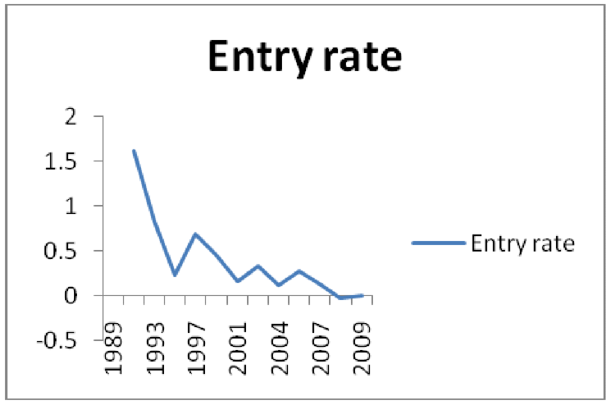


Fig. 2.2 Entry rate, Source: NASSCOM

We observe from the above how the entry rate falls gradually over time until it becomes negative. This again substantiates findings by Klepper. Consider next the size orientation of these firms. It is observed that only 8 percent of these firms are large companies, 10 percent constitute medium sized firms while 73 percent comprise small firms. A minor 9 percent consist of institutional firms. Given that it is a skilled labor based industry, economies of scale and large initial capital investments do not hinder the growth of this industry.

The study of current literature on firms and export markets such as 'Plants and Productivity in International Trade' by Bernard, Jensen, Kortum and Eaton (2003) and 'An Anatomy of International Trade: Evidence from French Firms' (2005) by Kortum and Kramarz suggests the following three stylized facts about firm behavior in export markets.

a) Exporters are a small fraction of all producers in an industry.

b) Exporters earn a small share of revenue from exports.

c) Exporters are more productive than non-exporters**.**

From the NASSCOM dataset it is observed that the above stylized facts do not hold. Revenue per worker is taken as a proxy for productivity of an individual firm. The median value of revenue per worker divides high from low productivity firms in each year. Distribution of exports by revenue shows that low productivity firms are exporting as much a proportion of their revenue as the high productivity firms. This can be attributed to the nature of the good as being services, where services can vary from low level data entry and customer service to skilled software design. Given that the nature of the good allows for a broad range of skill levels this seems like a logical outcome.

The data further reveals most firms to be exporting software and software services. This is in direct contradiction to the findings of firm behavior in export markets where only a small proportion of highly productive firms are found to be exporting.

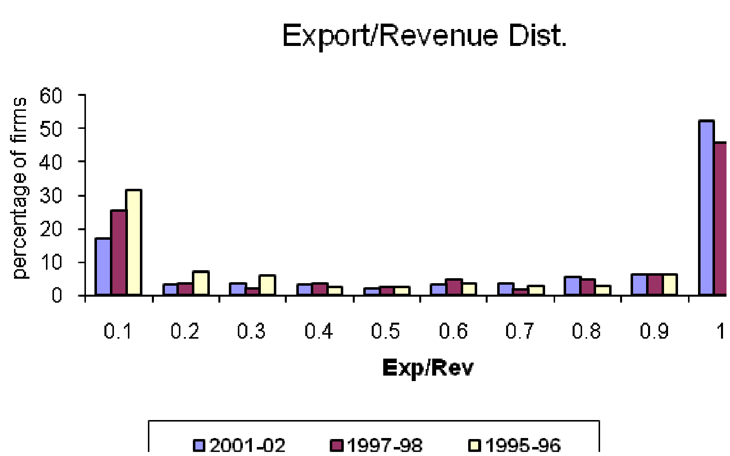


Fig. 2.3 Export Intensity, NASSCOM Database

The above graph shows the distribution of revenues derived from exports. It shows that a large proportion of firms in each year recorded exports worth more than 50% of output. Further this proportion increased over the three years. Consider further the same distribution across low and high productivity firms over 1990-91, 1994-95 and 2001-02.

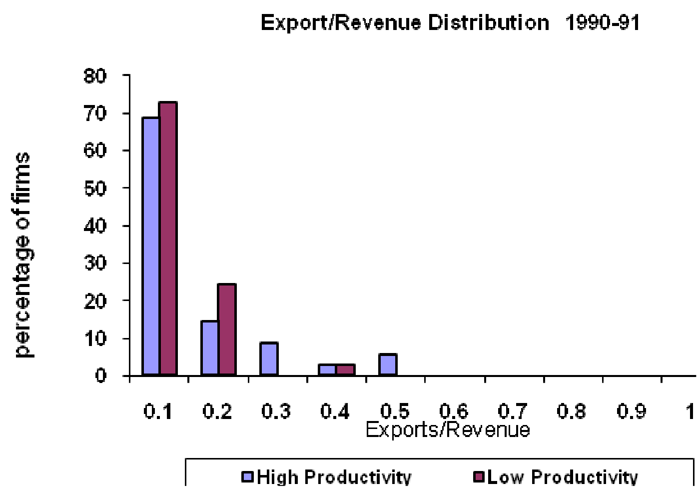


Fig. 2.4 Export Intensity 1990-91, NASSCOM

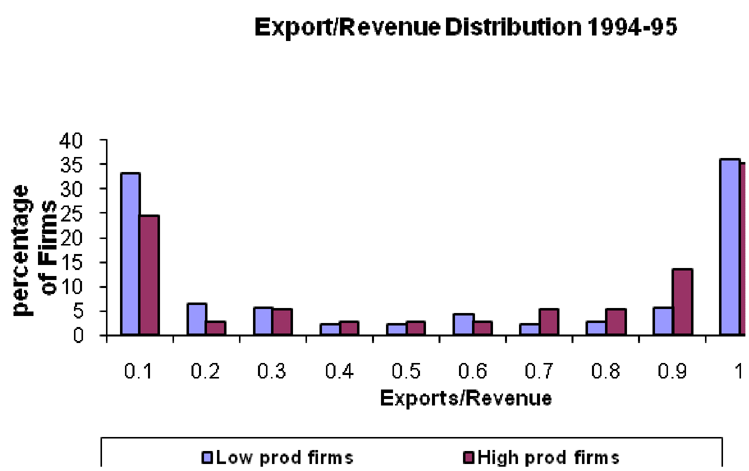


Fig. 2.5 Exports Intensity 1994-95, NASSCOM

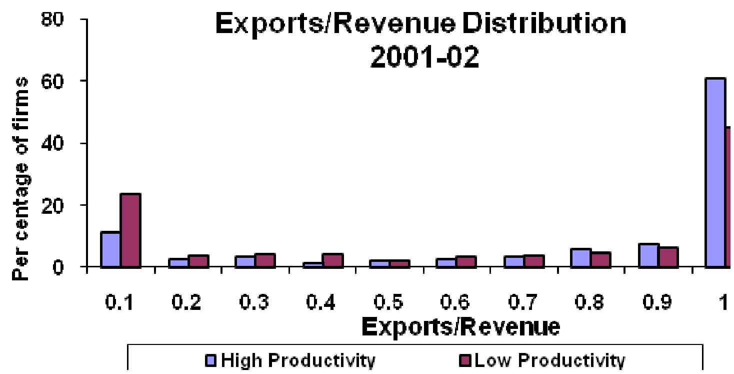


Fig. 2.6 Export Intensity 2001-02, NASSCOM

Note how the distribution shows a sharp change in 1994-95 relative to 1990-91. I attribute this shift in greater entry of domestic and foreign firms in response to trade liberalization and domestic reform. More so given the limited size of the domestic market most entrants focused on expanding in the international software market. Hence export orientation was the modus operandi for continued expansion. Consider productivity distribution of exporters from 1990-91 to 2001. It is observe that the productivity distribution shifts towards the right. Also exporters are more productive than non exporters. The distribution of exporters is skewed to the left relative to the non exporters. Also observe that it is the relatively large firms which are more productive.

In the following graphs we observe similarity or overlap between the distributions of exporters and non exporters in 1990-91. However as the years proceed we observe the exporters distribution shifting towards the left. This might be attributed to the impact of trade liberalization and its schumpeterian impact on firm survival. Further large firms appear to be more productive relative to smaller firms.

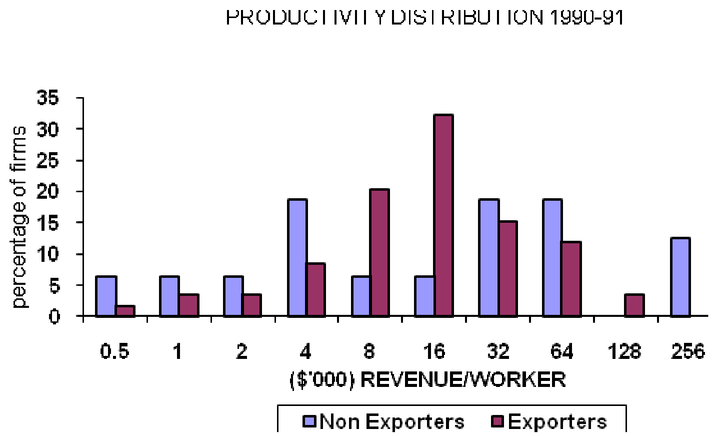


Fig. 2.7, Productivity Distribution, 1990-91, NASSCOM

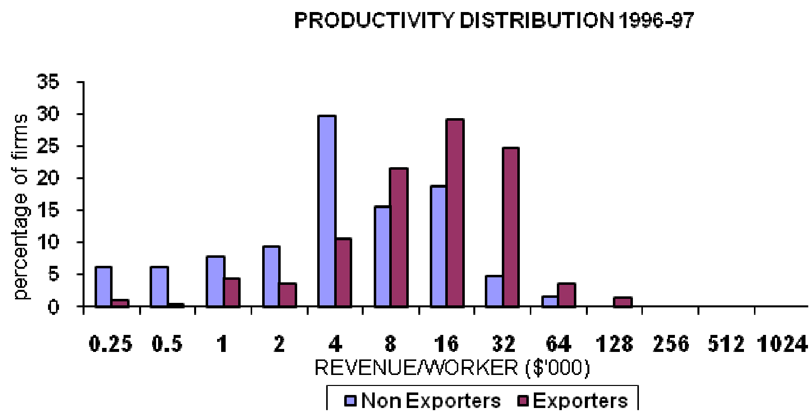


Fig. 2.8, Productivity Distribution, 1996-97, NASSCOM

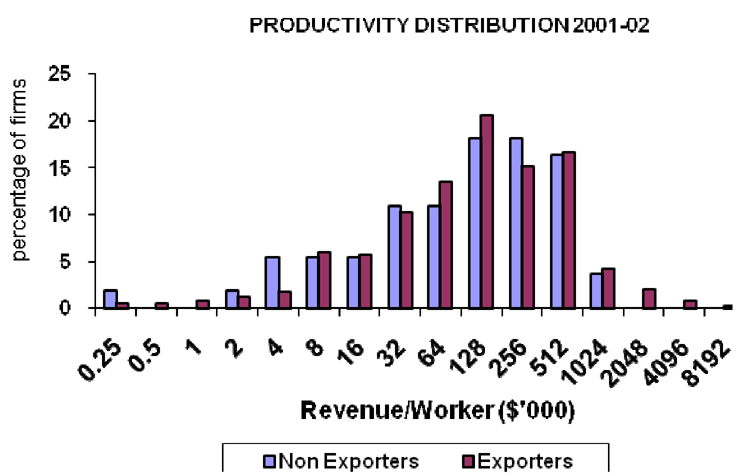


Fig. 2.9, Productivity Distribution, 2001-02, NASSCOM

The next section further explores the pattern of firm growth of this industry i.e. the relation between growth rate and size of firms or Gibrat's Law. The following section carries out detailed tfp evaluation using production function estimation. In the process we aggregate firm level tfp estimates and evaluate industry level productivity over time. This will allow us to find capital and labor coefficients and use them in the process of evaluating the Social Accounting matrix for the macro model which follows.

Growth of Firms: Size versus Growth

Validity of Gibrat's Law

Robert Gibrat's book *"Inegalites Economiques"* published in 1931 presented the first formal model of the dynamics of firm size and industry structure. The origins of his thinking can be traced back to Jacobus Kaptyne, an astronomer who became interested in the appearance of skewed distributions in various settings. It was assumed that underlying these distributions was a guassian process i.e. a large number of small additive influences operating independently of each other generating a normally distributed variate z. An observed skewed distribution could then be modeled by positing that some underlying function of x was normally distributed. A formal statement of the argument can be stated as follows. Let x_t denoted the size of the firm at time t and let ε_t be the random variable denoting the proportionate rate of growth between t-1 and t.

$$x_t - x_{t-1} = \varepsilon_t x_{t-1}$$

$$x_t = (1+\varepsilon_t)x_{t-1} = x_0(1+\varepsilon_1)(1+\varepsilon_2)(1+\varepsilon_3)\ldots\ldots(1+\varepsilon_t)$$

Consider choosing a short time period where we can regard ε_t to be small.

Approximating $\log(1+\varepsilon_t) \approx \varepsilon_t$

Taking logs we get $\log x_t \approx \log x_0 + \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots\ldots + \varepsilon_t$

Assuming the increments ε_t to be independent variates with mean m and variance σ^2, as $t \rightarrow \infty$ the term $\log x_0$ will be small compared to $\log x_t$. The distribution of $\log x_t$ can be approximated by a normal distribution with mean m_t and variance $\sigma^2{}_t$. Hence the limiting distribution of x_t is lognormal.

Gibrat looked for the above statistical regularity in a broad range of data. From income distributions and plant sizes in manufacturing, the goodness of fit obtained was striking. He carried out this analysis between broad sectors of the economy such as agriculture and commerce to narrowly defined industries such as electro-chemicals and metallurgy.

The 1950's and 60's saw reluctance to accept the uniformity of Gibrat's law, as greater attention was being paid to plant level heterogeneity. Greater interest in how industrial structure differed across industries with factors such as economies of scale and R&D was the focus of research. Joe Bain, Frederick Pryor and Louis Philips showed how ranking of industries persisted from country to another suggesting basic industry characteristics determines market structure.

In Sutton (1997) Gibrat's law is considered to be a misnomer. The initial assumption that the probability of the "next opportunity is taken up by any particular active firm is proportional to the current size of the firm". A simple restatement of this proportional effect states that growth rates should be independent of initial size. Mansfield (1962) characterized this as "the probability change in size during a specific period is the same for all firms in the industry-regardless of their size at the beginning of the period".

Mansfield interpreted Gibrat's Law applied in three versions. The first postulates that the law holds for firms that exited the industry as well as firms that survived. The second version states that the law holds for only for firms that survived over the relevant time period (Hart and Prais 1956). The third main version applies to firms large enough to exceed minimum efficient scale level of output (Simon and Bonini 1958).

The new literature of the 80's spanned a broad range of countries on both small as well as large enterprises resulting in a stylized result i.e. growth rates decrease with increasing firm size. The three survey articles Cave (1998), Sutton (1997), Geroski (1995) focus on studies based on manufacturing. The three surveys suggest that what holds for manufacturing will also hold for services. If this was not true then manufacturing would be special case. Given that services represent the fastest growing sector in the OECD and in many developing countries the question merits special attention. Whether services have similar firm dynamics relative to manufacturing has significant policy implications. The following section examines a few theoretical reasons why we can expect behavior between firm size and growth rates in services to be different from that in manufacturing.

Services: Gibrat's Law Revisited

Various empirical studies show that while Gibrat's law does not hold for large samples of manufacturing firms it does hold for smaller sub samples such as large established firms. The discrepancy between arises due to two assumptions underlying the law. The "next opportunity taken up by any particular firm is proportional to the current size of the firm" does not necessarily imply that firm growth is independent of initial size unless there is no correlation between size and survival of the firm. If opportunities are stochastically distributed and proportional to firm size, the expected growth rates are same for all firms. If likelihood of survival is independent of firm size Gibrat's law can be expected to hold for any large sample.

If the probability of survival is related to firm size, the observed growth rates are no longer normally distributed for each firm size or size class. This implies that the consequence of negative growth becomes asymmetrical across firm size classes. Negative growth for small firms implies a lower probability of survival relative to a large firm experiencing the same. Even lack of growth or insufficient growth for a small firm will mean that the firm has a lower probability of survival. Given the higher propensity on part of small firms to exit the sample relative to low growth large firms serves to bias the sample towards higher growth firms. The consequence of not obtaining a high growth opportunity differs between large and small firms. Gibrat's law will tend to hold for large firms but not for smaller enterprises. The lower survival probability for small firms is not constant from industry to industry and varies systematically across industries.

Methodology

Using the methodology developed by Chesher (1979) we test the hypothesis that firm growth is independent of size.

$z_t=\beta z_{t-1}+ \varepsilon_{it}$ (1

Where "t" is an index for time, "i" is an index of firm and z_{it} is the deviation of the logarithm of the size of the firm "i" at time "t" from the mean of the logarithms of the sizes of companies at time t (z_{it-1} analogously defined). "β" is the parameter to be estimated and ε_{it} is a disturbance. A value of β close to unity is evidence that the law is in operation at the time of observation as long as the errors are independently distributed over time. When beta is less than one sizes regress away from the mean i.e for $\beta <1$ the larger the firm the less it may expect to grow.

Exponentiation of (1) yields equation (2).

$S_{t,i}-S_{t-1,i}=\{\exp(\varepsilon_{it})S_{t-1,i}{}^{\beta-1}-1\}S_{t-1,i}=g_{t,i}S_{t-1,i}$

Where $g_{t,i}$ is the proportion referred to in the statement of the law.

However if β is unity the law will not be in operation if the error terms are serially correlated, for then also the $g_{t,i}$ and $S_{t-1,i}$ are dependent. Serial correlation in proportionate growth rates can be ascribed to persistence of chance factors which make a firm grow abnormally fast or abnormally slow i.e. "size encourages growth". Serial correlation in growth rates implies "growth encourages growth". Serial correlation in disturbances induces dependence between $z_{t-1,i}$ and ε_{it} which render least square estimators of β inconsistent, even though estimation proceeds using cross sectional data.

Assuming a first order autoregressive process for the disturbance ε_{it}

$$\varepsilon_{it}=\rho\ \varepsilon_{it-1} + \nu_{it}$$

where ν_{it} is assumed to be non serially correlated. Substituting the above in the original specification we obtain.

$$z_{it}=\gamma_1 z_{it-1}+\gamma_2\ z_{it-2} +\nu_{it}$$

$$\text{where } \gamma= \beta + \rho\ ,\ \gamma=\beta\rho$$

The operation of OLS on $z_{t,i}$ $z_{t-1,i}$ and $z_{t-2,i}$ can expect to yield consistent estimates of β and ρ given

$$(\beta,\rho)= [1/2\{\gamma_1+ (\gamma_1^2+4\gamma_2)^{1/2}\},\ 1/2\{\gamma_1-(\gamma_1^2+4\gamma_2)^{1/2}\}]$$

Sample information does not reveal which estimate is β and which is ρ. The identification problem is resolved by referring to the literature where it is argued that β is close to unity even if the law of proportionate effect is not in operation. The estimate closest to unity is denoted as $\tilde{\beta}$ and the other as $\tilde{\rho}$. The null hypothesis that the law of proportionate effect is in operation is tested against the alternative that $\beta\neq1$ and/or the disturbances ε_{it} are first order auto-correlated by testing:

$$H_o: (\gamma_1,\gamma_2) = (1\ 0)$$

$$\text{vs. }\ H_1: (\gamma_1,\gamma_2) \neq (1\ 0)$$

Assuming that the OLS estimators of γ_1 and γ_2 are asymptotically normally distributed the classical test statistic for simple hypothesis concerning subsets of coefficients in a linear regression model maybe constructed. With a sufficiently large sample this statistic will be approximately a chi-squared variate with two degrees of freedom.

Results:

Carrying out the regression on the CMIE data set (1999-2005) we obtain the following estimates for γ_1 and γ_2 for different years in the data. Recalling our original model we consider the results from the regression as follows:

$$z_{it}=\gamma_1 z_{it-1}+\gamma_2 z_{it-2} +\nu_{it}$$

$$\text{where } \gamma= \beta+\rho \text{ , } \gamma=\beta\rho$$

Year (t)	γ1	γ2	ρ	β	F Test For Joint Hypothesis	Hypothesis H(γ1,γ2)= (1,0)
1999	0.99711	-0.0079	1.00504	-0.008	F(2,44)=112, Prob>F=0.00	Reject
2000	0.4422	0.3086	Not defined	Not defined	F(2,127)=57.2, Prob>F=0.000	Reject
2001	0.8395	0.08735	0.71781	0.12169	F(2,170)=4.9, Prob>F=0.02	Reject
2002	0.9822	-0.0197	1.0019	-0.0197	F(2,207)=0.73,Prob>F=0.483	Reject
2003	0.9678	0.02036	0.9463	0.02152	F(2,221)=0.29,Prob>F=0.748	Accept
2004	0.95878	0.03969	0.91542	0.04336	F(2,228)=0.14,Prob>F=0.866	Accept
2005	1.2255	-0.2100	1.37791	-0.1524	F(2,204)=8.85,Prob>F=0.0002	Reject

Table 2.4 Gibrat's Law: All Firms

The above table shows that when we take the entire sample into account the null hypothesis is rejected. Dividing up the sample by size of the firms into large, medium and small sized firms we observe that in each category the null hypothesis can be rejected. In order to test for proportionate effect we need to observe that our linear model fits not only for one particular year but that we observe a fit over a few years either before t or after t otherwise our conclusion will be inconclusive. The size of firms is determined by sales.

We observe that in large sized firms the null hypothesis is rejected for all but one of the years. Hence our central proposition that the law of proportionate effect holds for large sized service firms can be rejected. For medium sized firms we observe that our model fits for the year 1999 to 2001 but is rejected thereafter. Small sized firms show a similar trend but the years for which the model is a positive fit are not contiguous and hence raise doubts about the conclusion.

Year	γ_1	γ_2	β	ρ	F test	Result (0.01)
1999	0.960891	0.003047	0.964051	-0.00316	F(2,18)=0.15,Pr>F=0.8651	Accept
2000	0.262433	0.44785	0.813176	-0.55074	F(2,59)=86.0, Pr>F=0.000	Reject
2001	0.71135	0.055516	0.782314	-0.07096	F(2,76)=15.6, Pr>f=0.000	Reject
2002	0.971299	-0.05497	0.910958	0.060341	F(2,87)=5.37,Pr>F=0.0063	Reject
2003	1.194488	-0.23915	0.940106	0.254382	F(2,88)=6.53,Pr>F=0.0023	Reject
2004	1.151512	-0.20741	0.928008	0.223504	F(2,100)=9.38,Pr>F=0.0002	Reject
2005	1.273694	-0.32459	0.921421	0.352273	F(2,108)=10.39,Pr>F=0.000	Reject

Table 2.5 Large firms Source: CMIE/PROWESS Dataset

Year	γ_1	γ_2	β	ρ	F test	Result (0.01)
1999	0.8553	0.00652	0.862807	-0.00756	F(2,7)=0.99, Prb>F=0.4189	Accept
2000	0.431	0.22042	0.732085	-0.30109	F(2,20)=4.24,Prb>F=0.0603	Accept
2001	0.7163	0.12115	0.857531	-0.14128	F(2,24)=2.20,Prob>F=0.1323	Accept
2002	0.7361	-0.04993	0.660506	0.075594	F(2,37)=7.99,Prb>F=0.0013	Reject
2003	0.4745	0.24055	0.782042	-0.30759	F(2,36)=6.02,Prob>=0.0055	Reject
2004	0.319	0.1738	0.605863	-0.28686	F(2,38)=20.26,Prb>F=0.0000	Reject
2005	0.4235	-0.10467	#NUM!	#NUM!	F(2,45)=37.24,Prob>F=0.0000	Reject

Table 2.6 Medium Sized Firms, Source: CMIE/PROWESS Dataset

Year t	γ_1	γ_2	β	ρ	F test	Result (0.01)
1999	1.0797	-0.22352	0.80051	0.27922	F(2,13)=0.24,Pr>F=0.7865	Accept
2000	0.713	0.03102	0.75470	-0.04111	F(2,64)=2.21,Pr>F=0.1177	Accept
2001	0.762	0.2055	0.97365	-0.21106	F(2,43)=7.57,Pr>F=0.0015	Reject
2002	0.764	0.03102	0.80265	-0.03865	F(2,77)=4.20,Pr>F=0.0186	Accept
2003	0.819	0.01752	0.84064	-0.02084	F(2,91)=6.42,Pr>F=0.0025	Reject
2004	0.688	0.1641	0.87594	-0.18734	F(2,85)=4.92,Pr>F=0.0235	Accept
2005	0.8548	-0.2366	#NUM!	#NUM!	F(2,46)=11.06,Pr>F=0.0001	Reject

Table 2.7, Small Sized Firms, Source: CMIE/PROWESS Dataset

Consider analyzing the data for size, age and growth effects (Tables 2.1 to 2.4). The size of the firm can be measured by sales or employment. In either case we observe that smaller firms have higher rates of growth relative to medium and large scale firms. However for smaller firms the result is driven by outliers as indicated by standard deviation. This is concomitant with our observation that in the event of a negative productivity shock the survival probabilities of firms is size dependent so that smaller firms go out of business whereas large and medium sized firms survive with a greater probability.

We also observe that if we keep size fixed as age of the firm increases the average rate of growth decreases. This is an interesting observation which we observe repeated throughout the sample. We observe a similar trend when we measure size using employment (Appendix chapter 2).

Chapter 3

Measuring Productivity

Introduction

The efficiency of a firm as measured by total factor productivity or labor productivity is considered the foremost indicator of a firm's competitiveness in both domestic and international markets. An increase in TFP is indicative of larger quantities of output being produced with either the same or lesser amount of inputs. This is typically due to a more efficient utilization of inputs based on more productive use of existing technology and/or technical change.

The production function provides the basis for evaluating TFP of each plant in our sample. The literature suggests two alternative ways of calculating the TFP. Consider using the Cobb Douglas production function, taking logs of inputs we obtain a linear estimation equation.

$$Y_{it}=A_{it}\, K_{it}^{\beta k}\, L_{it}^{\beta l}\, M_{it}^{\beta m}$$

$$\ln TFP_{it}= \ln Y_{it} - \beta_k \ln K_{it} - \beta_l \ln L_{it} - \beta_m \ln M_{it}$$

Where Y_{it} represents physical output of firm "i" in period t, K_{it}, L_{it}, and M_{it} are inputs of capital, labor and materials respectively, A_{it} is the Hicksian neutral efficiency level of firm "i" in period t. Industry level productivity in year t can be represented by the following index:

$$\ln(TFP_t)= \Sigma\theta_{it} \ln TFP_{it}$$

where θ_{it} is the share of the i_{th} plant in industry output. In the above measurement of TFP individual input levels are deflated using changes in the price of inputs.

An alternative way to calculate TFP is by relating deviation of plant output and factor inputs from the industry means:

$$\ln TFP_{it} = (\ln Y_{it} - \ln \mathbf{Y}_t) - \beta_k(\ln K_{it} - \ln \mathbf{K}_t) - \beta_l(\ln Lit - \ln \mathbf{L}_t) - \beta_m(\ln M_{it} - \ln \mathbf{M}_t)$$

In the above equation the bold letters indicate industry mean levels of output and inputs. The relative TFP index is adjusted to have mean zero for each industry. The first method allows one to calculate TFP for industry growth analysis while the second method allows one to focus on relative productivities of plants in an industry in a given year.

The important property of relative productivity rankings is that they do not depend on the output deflator. In a given year output is measured in the same units in all plants. This even extends to inter-temporal comparisons. We can observe how plants move in rankings from one period to the next without introducing errors in the output deflator. The deflators become important when comparing inter-temporal variations in productivity growth over time.

Estimation of TFP Coefficients

OLS: Biased and Inconsistent Estimators

The production function estimates obtained via OLS are biased and inconsistent. Consider the following:

$y_i = x'_i \beta + u_i$ or $y_i = x_i'\beta + u_i$ or $Y = X\beta + U$

unlike the usual OLS assumptions we assume

$E[u_i|x_i] \neq 0$ and $\frac{1}{N}\sum_{1}^{N} x_i u_i \xrightarrow{p} E[x_i u_i] \neq 0$

$$\frac{1}{N}\sum_{1}^{N} x_i x'_i \xrightarrow{P} E[x_i x'_i]$$

Applying the law of iterated expectations we can see the OLS estimator is biased,

$$\hat{\beta}_{OLS} = (X'X)^{-1}X'Y = (X'X)^{-1}X'(X'\beta + U) = \beta + (X'X)^{-1}X'U$$

$$E[\hat{\beta}_{OLS}] = \beta + E_{X,U}[(X'X)^{-1}X'U] = \beta + E_X[E_u\big|_x[(X'X)^{-1}X'U\big|X]]$$

$$= \beta + E_{X,U}[(X'X)^{-1}X'U] = \beta + E_X[(X'X)^{-1}X'\underbrace{E_{U|X}[U\big|X]]}_{\neq 0} \neq 0$$

Large sample properties reflect the inconsistency of the estimator.

$$\hat{\beta}_{OLS} = (X'X)^{-1}X'Y = (\frac{1}{N}\sum_{1}^{N} x_i x'_i)^{-1}\frac{1}{N}\sum_{1}^{N} x_i y_i = (\frac{1}{N}\sum_{1}^{N} x_i x'_i)^{-1}\frac{1}{N}\sum_{1}^{N} x_i(x'_i\beta + u_i)$$

$$= \beta + (\frac{1}{N}\sum_{1}^{n} x_i x'_i)^{-1}\frac{1}{N}\sum_{1}^{n} x_i u_i$$

and

$$p\lim \hat{\beta}_{OLS} = p\lim[\beta + (\frac{1}{N}\sum_{1}^{n} x_i x'_i)^{-1}\frac{1}{N}\sum_{1}^{n} x_i u_i]$$

$$= \beta + E[x_i u_i]^{-1}.E[x_i u_i] \neq \beta$$

Hence the estimator is also inconsistent. The next section discusses the use of fixed effect and instrumental variables to mitigate the above two properties.

Consider the production function approach to measuring TFP.

$$y_{it}=\beta_o+\beta_k k_{it}+\beta_l l_{it}+\beta_m m_{it}+\varepsilon_{it}$$

Where β_o measures the mean efficiency level across firms and over time and ε_{it} is the time and producer specific deviation from the mean. Endogeniety arises as the error term is correlated with the choice of inputs k_{it} and l_{it}. The error term can be further decomposed into the correlated component and the uncorrelated i.i.d. component. This results in the following equation:

$$\varepsilon_{it} = \omega_{it} + u_{it}$$

$$y_{it} = \beta_o + \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + \omega_{it} + u_{it}$$

where w_{it} refers to firm level productivity which is observed by the firm but not by the econometrician and u_{it} represents the truly i.i.d. random component of the error term. After estimating the coefficients of the production function we can substitute and arrive at the following measure of the TFP.

$$\omega'_{it} = y_{it} - \beta'_k k_{it} - \beta_l' l_{it} - \beta_m' m_{it}$$

Productivity in levels can be obtained as the exponentiation of $\omega'_{it.}$ i.e. $\Omega_{it} = \exp(w'_{it})$. Weights used to aggregate firm-level TFP can be either firm level output shares as in Olley and Pakes or employment shares as in De Loecker and Konings (2006). The following three sections discuss methods in the literature which attempt to overcome the endogeneity problem discussed above. Ordinary least squares (OLS), fixed effects (FE), Olley and Pakes (OP) and Levinsohn Petrin (LP) are discussed. We compare OP and LP methods and discuss limitations of the same.

Fixed Effects Estimate

Fixed effects estimators have been used in the production literature (Mundlak, 1961; Hoch, 1962) for a long time. Using within firm variation in the sample, under certain assumptions the fixed effects estimator overcomes the simultaneity bias discussed in the previous section. It is based on the assumption that the correlated part of the error term is time invariant i.e. $\omega_{it} = \omega_{it-1} \ \forall\ t$.

Also given that exit decisions by firms might be driven by time invariant, firm specific affect "ω_{it}" and not by the time varying component "u_{it}" the fixed effects within estimator should give similar results for balanced or unbalanced sample.

The assumption of an unchanging productivity term is controversial when analyzing impact of policy changes on productivity over time e.g. Tybout, Pavcnik. A second way to deal with the endogeneity problem is to find appropriate instruments. The OP and LP methods are a form of instrumental variables approach and are discussed in the following sections.

Instrumental Variables:

Olley Pakes (OP) and The Levinsohn and Petrin (LP) Approach:

The Olley Pakes (1996) paper analyses the impact of technical change and deregulation on productivity dynamics in the tele-communications equipment industry. In the 1970's AT&T maintained exclusive monopoly in the provision of telecommunication services. By requiring all equipment attached to the Bell system network to be supplied by Western Electric, the manufacturing subsidiary of AT&T, the monopoly in the telecommunications industry was extended into the telecommunicating equipment market.

The change from electromechanical to electronic technology accompanied by a change in regulation opened the industry to competition by allowing entry of domestic and foreign firms. Following these changes the number of plants and firms doubled between 1967 and 1972. In spite of rapid entry, AT&T was able to maintain its monopoly in telecom services and hence also in the equipment industry. A decree was issued in 1982 breaking up the seven constituent regional bell companies along with a prohibition on the manufacturing of hardware equipment by these firms. This gradually decreased the monopoly of western electric in the equipment manufacturing industry.

Olley and Pakes (1996) attempt to analyze changes in the distribution of productivity that accompanied all the above exogenous changes in the telecommunications industry. The period 1967-1975 is characterized by entry and exit of firms and a rapid turnover rate. Using data relevant to the industry the authors address the twin estimation problems of selection and simultaneity. The selection problem is generated by the relationship between the unobserved productivity and the decision to either continue production or liquidate. The simultaneity problem has been discussed earlier and is based on the correlation of the unobserved productivity with the choice of inputs.

In order to understand the dynamic behavior of the firm with respect to both the selection and simultaneity/endogeneity problem consider the solution to the firm's dynamic optimization problem. Let the current period profits of the firm 'Π_{ijt}' be a function of the state variables i.e. unobserved productivity 'ω_{it}' and the capital stock 'k_{it}'.

$$\Pi_{ijt}(\omega_t,k_t)=f(\omega_{ijt},k_{ijt})$$

The profits of plant 'i' in industry 'j' at any time 't' are a function of its capital 'k_{ijt}' and the unobserved productivity 'ω_{ijt}'. The plant treats labor and intermediate goods as perfectly variable inputs, chosen at the time of production. Capital is treated as a fixed input determined in the previous period via the un-depreciated capital and investment. Incumbent firms have two decisions to make, to continue operation or exit the industry. In case of exit it receives liquidation or sell off value 'L_{it}'. In case it decides to continue production the choice of inputs dictates future profits. The individual plant 'i' is represented as solving the following value function:

$$V_t(\omega_t,k_t)=\max\{L_t, \sup \Pi_t(\omega_t,k_t)-c(i_t)+ \delta E[V_{t+1}(\omega_t,k_t)|\Omega_t]\}$$

s.t. $k_{t+1}=(1-\delta)k_t+i_t$

L_t: Liquidation value of the plant

$c(i_t)$: Cost of investment

δ: Discount factor

Solution to the above problem (Ericson and Pakes 1996) gives rise to a Markov Perfect Equilibrium. Plants remain open if the unobserved productivity remains above a certain threshold level.

<u>EXIT RULE</u>

$$X_t = \begin{cases} 1 & \text{if } \omega_t > \underline{\boldsymbol{\omega_t}} \\ 0 & \text{o.w.} \end{cases}$$

The plant stays in the market if $X_t=1$ otherwise the plant exits. The plants decision to invest depends upon its belief on future productivity and profitability. The following investment function is used to invert out the unknown productivity and solve the endogeneity problem.

<u>INVESTMENT RULE</u>

$$i_t= i_t(\omega_t,k_t)$$

In order to solve the simultaneity or endogeneity problem OP uses an investment function as an appropriate instrument. The assumption is that it is highly correlated to the unobserved productivity but not to the input choices. OP assumes that the firm's optimal investment decision "i_{it}" is a strictly increasing function of ω_{it}. Note that this function is identical for all firms in the sample i.e. changes in state variables affect all firms in the same way. The assumption of strictly increasing function assumes that the function is monotonic and hence can be inverted.

$$i_{it} = f_t(\omega_{it},k_{it})$$

$$\omega_{it} = f^{-1}{}_t(i_{it},k_{it})$$

Using the above assumptions we can substitute into the production function for "ω_{it}" and we obtain the following:

$$y_{it} = \beta_o + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + u_{it}$$

$$y_{it} = \beta_o + \beta_k k_{it} + \beta_l l_{it} + f^{-1}{}_t(i_{it},k_{it}) + u_{it}$$

In the above expression there is collinearity between ω_{it} and k_{it} hence we cannot identify β_k. We can however identify β_l and get an expression for the remaining terms say:

$$\varphi_{it} = \beta_k k_{it} + f^{-1}{}_t(i_{it},k_{it})$$

$$\omega_{it} = E[\omega_{it}|\omega_{it-1}] + \xi_{it}$$

Please note that the term ξ_{it} represents innovation effects that are uncorrelated to ω_{it-1} and is mean independent of capital in the same period. However this innovation term in productivity effects realization of labor in time 't' i.e. choice of labor in time 't' l_{it} is determined after realizing ξ_{it}. To identify β_k the authors make the crucial assumption that k_{it} is decided before the full realization of ω_{it}. This timing assumption is realized via the moment condition where ξ_{it} is orthogonal to k_{it}.

$$E[\xi_{it}|k_{it}]=0$$

This again allows us to justify the two stage estimation process. Also the above analysis is conditional on surviving firms. The selection issue is critical as only firms above a certain threshold of productivity survive i.e. $\underline{\boldsymbol{\omega}_t}$ for each ω_{it}. The above moment condition identifies β_k based on the assumption that k_{it} is decided before the realization of ω_{it}.

To operationalize the above moment condition consider the following:

$$\xi_{it}(\beta_k) = \omega_{it}-E[\omega_{it}|\omega_{it-1}]=(\varphi_{it}-\beta_k k_{it})-\psi(\beta_k)$$

Where $\psi(\beta_k)$ are predicted values from a non parametric regression of $(\varphi_{it}-\beta_k k_{it})$ on $(\varphi_{it-1}-\beta_k k_{it-1})$. In the present analysis we do not use Olley Pakes as we do not have investment data.

Levinsohn Petrin Method

The LP method uses an intermediate input demand function to invert or substitute out the unobserved productivity 'ω_{it}' in the production function. An advantage of this approach as mentioned earlier, is the ability to retain firms that do not report investment expenditure and overcome the problem of lumpy investment, i.e. investment expenditures either do not respond to productivity shocks or respond with a lag. Consider the following production function:

$$y_{it} = \beta_o + \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + \omega_{it} + u_{it}$$

In the above "m_{it}" represents intermediate inputs such as electricity, power and fuels. Assume that m_{it} is a function of the same state variables, i.e. capital k_{it} and the correlated productivity shock w_{it}.

$$m_{it} = f_t(k_{it},\omega_{it})$$

In the above functional form the choice of "m_{it}" is identical across firms but can change across time. In a way similar to the OP method, m_{it} is a monotonic function of $\omega_{it.}$ This allows one to invert the above function and substitute for ω_{it} out of the production function.

$$\omega_{it}=f^{-1}t(m_{it},k_{it})$$

$$i_t = \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it}+ f^{-1}t(m_{it},k_{it}) + u_{it}$$

Estimation of coefficients proceeds in two steps. In the first step, as in the OP method semi-parametric methods are used to approximate ($\beta_k k_{it} + \beta_m m_{it}+ f^{-1}t(m_{it},k_{it})$), which can be denoted as $\varphi(k_{it},m_{it})$. To identify β_k and β_m one can use two moment conditions.

$$E[\xi_{it}(\beta_k,\beta_m)|k_{it}]=0$$

Where $\xi_{it}(\beta_k,\beta_m)=w_{it}-E[\omega_{it}|\omega_{it-1}]=(\varphi_{it}-\beta_k k_{it}-\beta_m m_{it})-\psi_{it}(\beta_k,\beta_m)$

Where $\psi_{it}(\beta_k,\beta_m)$ are predicted values from a non-parametric regression of $(\psi_{it}(\beta_k,\beta_m)- \beta_k k_{it}-\beta_m m_{it})$ on $(\psi_{it-1}(\beta_k,\beta_m)- \beta_k k_{it-1}-\beta_m m_{it-1})$.

To estimate the third coefficient β_m the authors use the following moment condition.

$$E[\xi_{it}(\beta_k,\beta_m)|m_{it-1}]=0$$

The innovation in productivity ξ_{it} is not orthogonal to m_{it}. This is because "w_{it}" is observed at the time "m_{it}" is chosen. ξ_{it} should be uncorrelated with m_{it-1}. To estimate β_k and β_m consider the following assumption. Let ξ_{it} constitute innovations in the productivity uncorrelated with past values or "current period innovations".

$$w_{it}=E[w_{it} \mid w_{it-1}]+\xi_{it}$$

where $E[\xi_{it} | k_{it}]=0$ and $E[\xi_{it} | m_{it-1}]=0$

LP argue the following:

$y^*_{it}=y_{it}-\beta_2 l_{it}$ or $y^*_{it}=\beta_0 + \beta_k k_{it}+ \beta_m m_{it}+ w_{it} (m_{it},k_{it})+ \varepsilon_{it}$

$= \beta_0 + \beta_k k_{it}+ \beta_m m_{it}+ E[w_{it} | w_{it-1}]+ \varepsilon^*_{it}$

Where $\varepsilon^*_{it}=\varepsilon_{it}+ \xi_{it}$

Further $E[w_{it} | w_{it-1}]=f(k_{it-1},m_{it-1})$ where m_{it-1} is uncorrelated with ξ_{it}..

Discussion of OP and LP

Both the OP and LP rely on certain key structural assumptions. A key assumption in both papers is strict monotonicity assumptions i.e. for OP investment must be strictly monotonic in w_{it} while for LP intermediate input demand must be strictly monotonic in w_{it}. The monotonicity allows the inversion of w_{it} and allows completely removing the endogeneity problem.

The second assumption is that w_{it} is the only unobservable entering the functions for investment or the intermediate input. Measurement and optimization error gets ruled out.

Timing of input choices is a key assumption in both the models. Timing is with respect to the process governing wit. In OP and LP the investment process ensures that k_{it} is chosen at t-1. This ensures the orthogonality of k_{it} to w_{it}.

Labor as an input is considered perfectly variable i.e. it is chosen after the productivity shock is realized. This allows labor to have no dynamic implication thereby allows for the identification of the labor coefficient in the first stage of estimation. In LP the choice of intermediate inputs m_{it} is also made after the productivity shock and is independent of the choice of labor precisely because the choice of labor follows the shock and allows the choice of m_{it} to be independent of the choice of l_{it}.

Productivity Analyses

To capture the impact of exit and entry I use an unbalanced panel for estimation. To test for robustness the sample consists of only firms for which data are available for all years. The aim is to capture productivity by creating an index and tracing its evolution over the given time period. The index is a weighted TFP index where TFP of individual firms is aggregated using share of sales or employment. The following table illustrates the OLS, FE and LP coefficients.

	OLS	**FE**	**LP**
K	0.3631 (0.02217)	0.3278 (0.03064)	0.35 (0.10967)
L	0.4362 (0.02298)	0.3776 (0.0270)	0.4703 (0.03455)
PF	0.1982 (0.02933)	0.2394 (0.03476)	0.63 (0.1769)
D99	dropped	0.1557 (0.0697)	
D00	-0.08198 (0.0653)	0.0779 (0.0351)	
D01	0.01225 (0.0658)	0.1848 (0.0336)	
D02	-0.2348 (0.0646)	-0.0635 (0.0285)	
D03	-0.2375 (0.0644)	-0.0662 (0.0281)	
D04	-0.2243 (0.0645)	-0.0461 (0.0271)	
D05	-0.2057 (0.0652)	-0.0288 (0.0268)	
D06	-0.1930 (0.0658)	-0.0101 (0.0256)	

D07	-0.1871 (0.0669)	Dropped	
R-sq	0.8038 (overall)	0.8034 (overall)	

Table 3.1 Production Function Coefficients OLS, FE, LP

As we can see in the table 2.16 the coefficient for power and fuels is much higher in the LP estimation relative to LS and FE. Consider the results for the balanced panel of firms. The balanced panel shows results very similar to the unbalanced panel, which shows some robustness of the results.

	OLS	FE	LP
K	0.3822 (0.02292)	0.34698 (0.0314)	0.38 (0.1189)
L	0.42531 (0.02316)	0.3751 (0.0272)	0.4609 (0.0433)
PF	0.1836 (0.02953)	0.2344 (0.0348)	0.63 (0.1777)
N	1895 (472)	1895 (472)	1895 (472)
D99	0.1124 (0.0311)	0.1455 (0.0712)	
D00	dropped	0.0826 (0.0353)	
D01	0.2131 (0.0313)	0.1724 (0.0338)	
D02	-0.0486 (0.0268)	-0.0658 (0.0286)	
D03	-0.0489 (0.264)	-0.0702 (0.0283)	
D04	-0.0321 (0.0258)	-0.0513 (0.0274)	
D05	-0.0206 (0.0258)	-0.0274 (0.0271)	
D06	-0.0064 (0.0253)	-0.0127 (0.0260)	

D07	dropped	dropped
R-sq	0.8053	0.8005
F test		F(429,1373)=8.58 Prob>0.000
Wald Chi(2)10	3650.37 Prob>chi2 =0.0000	

Table 3.2 Production Function Coefficients OLS, FE, LP (Balanced panel)

Analyzing the above results, the OLS and FE estimates are similar in magnitude and have relatively low standard errors. The Levinsohn-Petrin (LP) coefficients for capital and labor are similar to those from OLS and FE estimates for labor and capital. The coefficient for power and fuels in LP differs markedly from OLS and FE estimates. The table below shows the TFP BHC index as defined earlier. Consider the following graphical variation in aggregate productivity over time. We observe that productivity index increases steadily after for the period 2003-07 independent of the coefficients used to measure them

Aggregate Productivity Index

Year	OLS	FE	LP
2002	0.8014	0.993	0.796
2003	0.8142	1.013	0.806
2004	0.806	1.022	0.811
2005	0.867	1.115	0.842
2006	0.893	1.153	0.865
2007	0.921	1.197	0.892

Table 3.4 Aggregate Productivity Variation

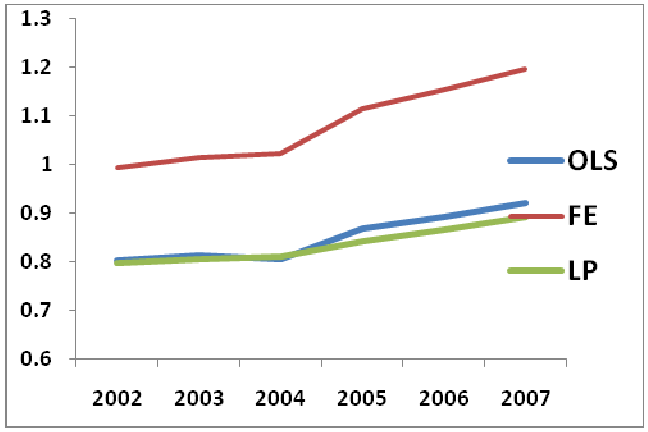


Fig.3.1 Variation of TFP Index 2002-2008.

The graph above shows the similarity of the index based on OLS and FE estimates and the difference of the index based on the LP coefficients. The sharp drop in the LP index is much sharper than the fall in the OLS or FE coefficients. Table 2.19 shows the percentage change in the TFP BHC index.

Conclusion:

The analysis of firm level data allows us to understand the nature of growth of firms and their productivity variation over time. The gradual rise in aggregate TFP is independent of the measure of TFP used, i.e. OLS, FE, LP. Given that technical change in this industry is relatively faster than in other high technology industries such as Biotechnology which apart from being highly capital intensive suffers from a very long gestation period for marketing innovation the rise in TFP can be interpreted as arising from the pace of technical change and increased competition due to growth in new indigenous firms.

The coefficients obtained from our estimation are used in the four sector macro model to calculate total labor and capital inputs for the Indian IT sector. Consider the social accounting matrix used to input data in the macro model.

Expenditures		1. Activities				2. Commodoties				3. Factors				4. Institutions	5. Cap. Account	6. Foreign Trade	7. Total	
Receipts:		AT01 (AGR)	IT	AT02 (MFG)	AT03 (Services)	CT01	IT	CT02	CT03	K	L	T	Q	HH	KA	WT	TT	
1. Activities	AT01 (AGR)					102248.20										16275.67	118523.87	0.00
	IT						2538.99									7551.01	10090.00	0.00
	AT02 (MFG)							82256.33									82256.33	0.00
	AT03(SERVICES)								237583.97								237583.97	0.00
2. Commodities	CT01 (AGR)													102248.20			102248.20	0.00
	IT			836.05	1702.94												2538.99	0.00
	CT02 (MFG)													63710.46	42372.55		106083.01	0.00
	CT03 (Services)													237583.97			237583.97	0.00
3. Factors	K	24897.17	3430.60	49568.73	117962.83												195859.33	0.00
	L	48739.05	5406.22	31851.55	117918.20												203915.03	0.00
	T	44887.65	0.00	0.00	0.00												44887.65	0.00
	Q	0.00	1253.18	0.00	0.00												1253.18	0.00
4. Institutions	HH									195859.33	203915.03	44887.65	1253.18				445915.18	0.00
5. Cap. Account	KA													42372.55			42372.55	0.00
6. Foreign Trade	WT							23826.68									23826.68	0.00
7. Total	TT	118523.87	10090.00	82256.33	237583.97	102248.20	2538.99	106083.01	237583.97	195859.33	203915.03	44887.65	1253.18	445915.18	42372.55	23826.68		
[illegible]	VKB	89826.07																

Table 4.5 Social Accounting Matrix

Production function estimation apart from allowing us to trace aggregate industry productivity growth also allows us to evaluate capital and labor inputs given the gross output for the given sector in our case the information technology sector. This assumes that we use a constant returns production technology which allows all output to be distributed among inputs. Let G be the gross output of our sector and let a_k & a_L represent capital and labor coefficients obtained from production function estimation. Then the total input of capital and labor is measured by multiplying the coefficients with the aggregate gross output.

$$K_{IT} = a_K * G, \quad L_{IT} = a_L * G$$

We can thus use the inputs calculated to find capital and labor used in the respective sector. We thus allow our firm level data to inform the social accounting matrix which further feeds data in to the four sector Ramsey growth model. This ensures accurate micro-foundations to our analysis.

Chapter 4

An Applied General Equilibrium Model

Environment

This model depicts a small, open and perfectly competitive economy in which agents produce and consume three types of final goods, indexed j=manufacturing (m), services (s) and agriculture (a), at each instant in time at price p_j. In addition an intermediate good stylized as information technology (IT) is also produced. This intermediate good is produced using capital, labor and a fixed factor of production stylized as a sector specific resource Q.

The services of labor and capital are used in the production of all three final goods. Labor services are not traded internationally and domestic residents own the entire stock of domestic assets. Land is used as a sector specific factor in the production of agriculture, j = a. The intermediate good is not consumed as a final good but is used as a factor of production in manufacturing and services. The agricultural good is a pure consumption good that is traded. The home good or the services sector indexed j = s, is a pure consumption good.

Households earn income from providing labor services "L" in exchange for wages "w", earn interest income at rate "r" on capital assets K, and receive rents from agriculture sector specific resource and on the fixed factor in information technology Q. Labor services are not traded internationally and domestic residents own the entire stock of domestic assets.

Primitives: Given preferences, the representative household maximizes present discounted value of the inter-temporal utility function subject to a budget constraint defined over an infinite horizon.

$$\int_{t\in[0,\infty)} u(q_m(t), q_a(t), q_s(t))e^{(n-\rho)t}\,dt \qquad (4.1)$$

Or, equivalently

$$Max\int_0^t \frac{q^{1-\theta}-1}{1-\theta}e^{(n-\rho)t}\,dt$$

where $u\ :\ R^3_{++} -> R_+$ is an increasing and strictly concave function in q, where $q=u(q_m,q_a,q_s)$ is the consumption bundle. u(q) is everywhere continuous, twice differentiable and homothetic. Households discount future consumption at the rate $\rho > 0$.

Elasticity of inter-temporal substitution is given by $1/\theta$ and $\theta > 0$. The number of households is proportional to the growth of the population 'n' i.e. $L(t) = L(0)e^{nt}$. Households solve an intra-temporal problem given by the minimizing the expenditure 'ε' on the three final goods agriculture, manufacturing and services.

$$\varepsilon = E(p_a, p_m, p_s)q \equiv \min_{q_a, q_m, q_s}\left\{ \sum_{j=q_m, q_a, q_s} p_j q_j \mid q \leq u(q_a, q_m, q_s)\right\}$$

Where (p_m, p_a, p_s) are the respective prices of each good. At each instant in time, $E(p_a, p_m, p_s)$ represents the price (cost) of aggregate consumption q. The representative consumer's budget constraint is given by

$$\dot{k} = w + k(r^k - \delta - n) + \tilde{\pi}H + \tilde{\psi}Q - \varepsilon(p_a, p_m, p_s)q \quad (4.2)$$

where r^k=(r+δ) measures gross return to capital, $\tilde{\pi}$ and $\tilde{\psi}$ represents returns to fixed factors land and fixed factor in information technology, variables are normalized in units of labor eg. k=K(t)/L(t) capital per worker.

Euler Equation

The Euler equation is obtained by solving the inter-temporal maximization problem of the household problem using the present value Hamiltonian and substitution of first order conditions.

$$\frac{\dot{\varepsilon}}{\varepsilon} = \frac{1}{\theta}\left(r^k - \rho - \delta - \lambda_s \frac{\dot{p}_s}{p_s}\right) \quad (4.3)$$

where λ_s represents the share of total household expenditure spent on the home good.

FIRMS PROBLEM

Firms in each sector are atomistic and identical and have constant returns to scale technology. Unlike the household, firms solve an intra temporal cost minimization problem which is identical in every period subject to the following technologies

$$Y_a = B_a (e^{xt} L_a)^{\beta_1} K_a^{\beta_2} e^{(x+n)t} H^{\beta_3}, \sum \beta_i = 1, \beta_i > 0.$$

$$Y_{it} = B_{it} (e^{xt} L_{it})^{\alpha_1} K_{it}^{\alpha_2} e^{(x+n)t} Q^{\alpha 3}, \sum \alpha_i = 1, \alpha_i > 0.$$

$$Y_m = B_m (e^{xt} L_m)^{\delta_1} K_m^{\delta_2} IT_m^{\delta_3}, \sum \delta_i = 1, \delta_i > 0.$$

$$Y_s = B_s (e^{xt} L_s)^{\xi_1} K_s^{\xi_2} IT_s^{\xi_3}, \sum \xi_i = 1, \xi_i > 0.$$

The term ‘x’ represents the exogenous labor augmenting technological progress and 'n' represents the population growth hence the sum '(x+n)' represents the growth of effective economy wide worker. Firms in manufacturing and service sector minimize cost given technology. Expressed in units per effective economy wide worker the firm's problem can be represented by the following:

$$C^m(\hat{w}, r^k, p_{it})\hat{y}_m = \min_{l_m, \hat{k}_m, \hat{it}_m} \{\hat{w}l_m + r^k\hat{k}_m + p_{it}\hat{it}_m \;|\hat{y}_m \le B_m(l_m)^{\alpha_1}(\hat{k}_m)^{\alpha_2}(\hat{it}_m)^{\alpha_3}\}$$

$$C^s(\hat{w}, r^k, p_{it})\hat{y}_s = \min_{l_s, \hat{k}_s, \hat{it}_s} \{\hat{w}l_s + r^k\hat{k}_s + p_{it}\hat{it}_s \;|\hat{y}_s \le B_s(l_s)^{\beta_1}(\hat{k}_s)^{\beta_2}(\hat{it}_s)^{\beta_3}\}$$

In our model agriculture and information technology employ a sector specific factor which can be traded among firms within the sector only. The indirect profit functions for each sector are homogeneous of degree one in prices. In each case the envelope properties of the indirect profit function allow us to derive demand and supply functions for each sector. The resulting factor demands are homogeneous of degree zero. For example the agricultural supply and labor demand are given by Eqt 4.4 respectively.

$$\frac{\partial \pi(p_a, r^k, \hat{w})}{\partial p_a} = y_a(p_a, \hat{w}, r^k)$$

$$\frac{\partial \pi(p_a, r^k, \hat{w})}{\partial \hat{w}} = -x_a(p_a, \hat{w}, r^k) \tag{4.4}$$

Similarly, for the information technology sector the supply and factor demand is

$$\frac{\partial \psi(p_{it}, r^k, \hat{w})}{\partial p_{it}} = y_{it}(p_{it}, r^k, \hat{w})$$

$$\frac{\partial \psi(p_{it}, r^k, \hat{w})}{\partial \hat{w}} = -x_{it}(p_{it}, r^k, \hat{w}) \tag{4.5}$$

Equilibrium Characterization:

A competitive equilibrium is defined by positive prices $\{\hat{w}, r^k, p_s, p_{it}\}_{t\in[0,\infty)}$ of inputs and output Y_j, household consumption plans $\{q_a, q_m, q_s\}_{t\in[0,\infty)}$ and production plans $\{\hat{y}_m, \hat{y}_a, \hat{y}_{it}, \hat{y}_s, \hat{k}_m, \hat{k}_a, \hat{k}_{it}, \hat{k}_s, \hat{l}_a, \hat{l}_{it}, \hat{l}_m, \hat{l}_s, \hat{IT}_m, \hat{IT}_s\}$ given initial resources endowments {K(0),L(0),H,Q} such that the discounted present value of household utility is maximized, firms maximize profits subject to their technology at each instant of time t, and markets clear for all inputs and outputs. In addition the no-arbitrage condition between values of capital and land, and the transversality condition are satisfied. We consider cases where output of all sectors is positive or $Y_j>0$ for j = m, s, a.

Intra-Temporal Conditions:

Given the endogenous sequence of $\{\hat{k}, \hat{\varepsilon}\}$, the intra-temporal equilibrium is given by a five tuple sequence of positive values $\{\hat{w}, r^k, \hat{y}_m, \hat{y}_s, p_s\}$ which solve the following five intra temporal conditions. The first two constitute zero profit conditions for manufacturing and services followed by the labor, capital and home good market clearing equations.

We allow the price of manufactured goods to be the numeraire $p_m=1$, the zero profit conditions can be written as

$$\begin{aligned} 1 &= C^m(\hat{w}, r^k) \\ p_s &= C^s(\hat{w}, r^k) \end{aligned} \tag{4.6}$$

The zero profit conditions can be written in a reduced form as

$$\hat{w} = W(p_s); r^k = R(p_s) \tag{4.7}$$

Market Clearing Conditions

i) Labor Market Clearing

$$\sum_{j=m,s} \frac{\partial C^j(\hat{w}, r^k, p_{it})}{\partial w} \hat{y}_j - \frac{\partial \pi^a(p_{a,} \hat{w}, r^k)}{\partial w} H - \frac{\partial \psi(p_{it,} \hat{w}, r^k)}{\partial w} Q = 1$$

ii) Capital Market Clearing

$$\sum_{j=m,s} \frac{\partial C^j(\hat{w}, r^k, p_{it})}{\partial r^k} \hat{y}_j - \frac{\partial \pi^a(p_{a,} \hat{w}, r^k)}{\partial r^k} H - \frac{\partial \psi(p_{it,} \hat{w}, r^k)}{\partial r^k} Q = \hat{k}$$

iii) Home Good Market Clearing

$$\frac{\partial \hat{\varepsilon}}{\partial p_s} = y_s \Rightarrow \hat{\varepsilon} = \frac{1}{\lambda_s} p_s \hat{y}_s$$

Solving the above factor market conditions by substituting $W(p_s)$ and $R(p_s)$ we express the supply functions 'y_j' as functions of the home good price and capital, the endogenous variables i.e.

$$\hat{y}_j = Y^j(p_s, \hat{k}), \; j = m, s \tag{4.8}$$

$$\hat{\varepsilon} = \frac{1}{\lambda_s} p_s Y^s(p_s, \hat{k});$$

Substituting and restating the budget constraint we obtain

$$\dot{\hat{k}} = W(p_s) + \hat{k}(R(p_s) - \delta - n - x) + \overbrace{\pi^a(p_a, W(p_s), R(p_s))H}^{\equiv \tilde{\pi}^a(p_s)H}$$
$$+ \overbrace{\pi^{it}(W(p_s), R(p_s))Q}^{\equiv \tilde{\pi}^{it}(p_s)Q} - \frac{1}{\lambda_s} p_s Y^s(p_s, \hat{k}) \equiv \tilde{K}(p_s, \hat{k}) \tag{4.9}$$

Inter-temporal Equilibrium

If a steady state exists, we observe the following,

$$r^{k,ss} = \rho + \delta + \theta x,\ p_s^{ss} = R^{-1}\left(r^{k,ss}\right) \tag{4.10}$$

which permits specifying the budget constraint so that the root

$\hat{k}^{ss}$ satisfying $\widetilde{K}\left(p_s^{ss}, \hat{k}\right) = 0$

is the steady state capital stock.

Knowing $\left(p_s^{ss}, \hat{k}^{ss}\right)$ is sufficient to determine the remaining endogenous variables using the intra-temporal conditions only.

To derive the equations of motion for the home good price and the capital stock consider the following steps. We use two equations to derive the second equation of motion, they are $\frac{\dot{\hat{q}}}{\hat{q}} = \frac{1}{\theta}\left(r^k - \rho - \delta - \theta x - \lambda_s \frac{\dot{p}_s}{p_s}\right)$ and $\hat{\varepsilon} = \frac{1}{\lambda_s} p_s \hat{y}_s$.

Differentiating $\hat{\varepsilon} = \frac{1}{\lambda_s} p_s \hat{y}_s$ with respect to time t, we obtain

$$\dot{\hat{\varepsilon}} = \frac{1}{\lambda}\left(\dot{p}_s y^s\left(p_s, \hat{k}\right) + p_s y^s_{p_s}\left(p_s, \hat{k}\right)\dot{p}_s + p_s y^s_{\hat{k}}\left(p_s, \hat{k}\right)\dot{\hat{k}} \right) \tag{4.11}$$

In time derivatives $\dot{\hat{\varepsilon}}$ and $\frac{\dot{\hat{q}}}{\hat{q}}$ we substitute from the Euler equation and obtain (4.12).

Time differentiating the expenditure function:

$\hat{\varepsilon} = e\left(p_a, p_m, p_s\right)\hat{q}$

$$\frac{\dot{\hat{\varepsilon}}}{\hat{\varepsilon}} = \lambda_s \frac{\dot{p}_s}{p_s} + \frac{\dot{\hat{q}}}{\hat{q}} \Rightarrow$$

$$\frac{\dot{\hat{q}}}{\hat{q}} = \frac{\dot{q}}{q} - x$$

$$\frac{\dot{\hat{q}}}{\hat{q}} = \frac{\dot{\hat{\varepsilon}}}{\hat{\varepsilon}} - \lambda_s \frac{\dot{p}_s}{p_s}$$

Substituting for $\frac{\dot{\hat{q}}}{\hat{q}}$ from the Euler Equation we obtain:

$$\frac{\dot{\hat{\varepsilon}}}{\hat{\varepsilon}} - \lambda_s \frac{\dot{p}_s}{p_s} = \frac{1}{\theta}\left(r^k - \rho - \delta - \theta x - \lambda_s \frac{\dot{p}_s}{p_s} \right)$$

$$\frac{\dot{\hat{\varepsilon}}}{\hat{\varepsilon}} - \lambda_s \frac{\dot{p}_s}{p_s} = \frac{1}{\theta}\left(r^k - \rho - \delta - \theta x \right) - \frac{\lambda_s}{\theta} \frac{\dot{p}_s}{p_s} \Rightarrow$$

$$\frac{\dot{\hat{\varepsilon}}}{\hat{\varepsilon}} = \frac{1}{\theta}\left(r^k - \rho - \delta - \theta x + \lambda_s \frac{\dot{p}_s}{p_s}(\theta - 1) \right)$$

OR

$$\dot{\hat{\varepsilon}} = \frac{\hat{\varepsilon}}{\theta}\left(r^k - \rho - \delta - \theta x + \lambda_s \frac{\dot{p}_s}{p_s}(\theta - 1) \right) \qquad (4.12)$$

Substituting $\hat{\varepsilon} = \frac{1}{\lambda_s} p_s Y^s\left(p_s, \hat{k}\right)$ in the above

Replacing $\dot{\hat{\varepsilon}} = \frac{1}{\lambda}\left(\dot{p}_s y^s\left(p_s, \hat{k}\right) + p_s y^s_{p_s}\left(p_s, \hat{k}\right)\dot{p}_s + p_s y^s_{\hat{k}}\left(p_s, \hat{k}\right)\dot{\hat{k}} \right)$

to obtain $\frac{\frac{1}{\lambda_s} p_s Y^s\left(p_s, \hat{k}\right)}{\theta}\left(r^k - \rho - \delta - \theta x + \lambda_s \frac{\dot{p}_s}{p_s}(\theta - 1) \right) =>$

$$\frac{1}{\lambda}\left(\dot{p}_s y^s\left(p_s, \hat{k}\right) + p_s y^s_{p_s}\left(p_s, \hat{k}\right)\dot{p}_s + p_s y^s_{\hat{k}}\left(p_s, \hat{k}\right)\dot{\hat{k}} \right)$$

This is linear in $\dot{p}_s$ solving for this and substituting $\dot{\hat{k}} = \widetilde{K}(p_s, \hat{k},)$ for $\dot{\hat{k}}$.

Solving for the second equation of motion $\dot{p}_s = \widetilde{P}^s(p_s, \hat{k})$ (4.13)

Using (4.9) and (4.13) it is possible to solve for the sequence $(p_s(t), \hat{k}(t))_{t\varepsilon[0,\infty)}$ which then allows us to solve for the remaining endogenous variables.

<u>Selected Comparative Statics</u>

The comparative static properties of the model are similar to properties discussed in the two sector dynamic model of Roe, Smith and Saracoglu (2010). To illustrate how the static properties translate to our four sector model consider the case when all four sectors of the economy produce positive levels of output i.e. $Y_j > 0$ for all j. Consider the economy to be in transition growth where the initial capital stock is $k(\mathbf{0}) < \hat{k}^{ss}$. Capital accumulation allows k (.) to increase to the steady state level $\hat{k}^{ss}$.

Capital deepening results in a decrease in the marginal product of capital $\frac{\dot{r}^k}{r^k} \leq 0$. To understand the path of the endogenous home good price and the wage rate consider the following analysis. From the zero profit conditions in our model (Eqt 4.1) we can express returns to capital equation in terms of elasticity with respect to 'r' as follows:

$$\frac{\dot{r}^k}{r^k} = \boldsymbol{\varepsilon}_r \frac{\dot{p}_s}{p_s} \qquad (4.14)$$

Where 'ε_r' is the elasticity of the reduced function $R(p_s)$ with respect to p_s. With capital deepening the return to capital declines as follows:

$$\frac{\dot{r}^k}{r^k} \leq 0 \ , \frac{\dot{r}^k}{r^k} = \varepsilon_r \frac{\dot{p}_s}{p_s} \leq 0 \tag{4.15}$$

In case of our model the home good or service sector is more labor intensive relative to manufacturing $\varepsilon^r \leq 0$, hence Stolper-Samuelson theorem suggests that the relative price of the home good rises to its steady state value i.e. $\frac{\dot{p}_s}{p_s} \geq 0$. Similarly the transition path of wages in can be analyzed by expressing the zero profit conditions in terms of elasticity. Let the elasticity of $W(p_s)$ with respect to p be denoted by ε_W and takes the opposite sign to ε_r.

If the home goods sector is relatively more labor intensive than the manufacturing sector this implies $\frac{\dot{w}}{w} = \varepsilon_w \frac{\dot{p}_s}{p_s} \geq 0$. In cases where the home good sector is relatively more capital intensive relative to manufacturing, then ε_r is positive, ε_W is negative, this implies that $\frac{\dot{p}_s}{p_s} \leq 0$ hence $\frac{\dot{w}}{w} = \varepsilon_w \frac{\dot{p}_s}{p_s} \geq 0$. The wage rate converges to its steady state level w^{ss} from below. To study the transition dynamics of supply functions consider the output expressed in terms of elasticities with respect to the endogenous arguments of the supply function i.e. home good price and the capital stock.

$$\frac{\dot{\hat{Y}}_j}{\hat{Y}_j} = \varepsilon^j{}_{ps} \frac{\dot{p}_s}{p_s} + \varepsilon^j{}_{\hat{k}} \frac{\dot{\hat{k}}}{\hat{k}} \text{ for j=m, s, it ;}$$

$$\text{also } \frac{\dot{\hat{Y}}_j}{\hat{Y}_j} = \frac{\dot{Y}_j}{Y_j} - n - x \quad \text{and } \frac{\dot{\hat{k}}}{\hat{k}} = \frac{\dot{k}}{k} - x \tag{4.16}$$

$$\text{In steady state } \frac{\dot{\hat{k}}}{\hat{k}} = 0, \frac{\dot{\hat{Y}}_j}{\hat{Y}_j} = 0 \text{ hence } \frac{\dot{Y}_j}{Y_j} = \varepsilon^j{}_{ps} \frac{\dot{p}_s}{p_s} + \varepsilon^j{}_{\hat{k}} \frac{\dot{k}}{k} + (\text{x+n})$$

In the above equation note that $\varepsilon^j{}_{ps} < 0$ and the sign of $\varepsilon^j{}_{\hat{k}}$ depends upon the relative capital intensity of sector j. The reduced form factor rental equations are homogenous of degree one in output prices hence Stolper-Samuleson and Rybczynski theorems of a small open economy apply. Stolper Samuelson property states that if the price of a final good rises the returns to the factor employed intensively in that sector also rises, however it's not the case that that the rental rate of the factor will rise in a greater proportion than the initial increase in price of the final good. Further supply functions are homogeneous of degree zero in prices and of degree one in factor endowments.

As capital deepening proceeds, the unit cost of capital declines while the marginal product of labor rises in all sectors of the economy but relatively more so in the capital intensive sector. This sector experiences an increase in output while the sector employing labor intensively will experience a decline. However the proportional change in output may be less than the proportional change in capital stock. In the home good sector the domestic market clears. Capital deepening along with growth in factor incomes will cause this sector to compete for resources as labor gets pulled towards the traded goods sector. In response the price of the home good or the non traded sector will rise in order to compete for resources from the traded sector.

Fitting Model to Data

In order to calibrate our model and determine parameters specific to our country we carry out a detailed analysis exercise which involves determining capital stock by means of the perpetual inventory method and growth accounting. Other parameters in the model include the discount rate, the rate of depreciation, elasticity of inter-temporal substitution and the rate of population growth. The latter parameters are usually based on assumptions on earlier studies and lie within a certain range as suggested by the literature (Table 4.1). To study sensitivity of our model output we allow slight variation in these parameter values and observe how well the model fits the data.

Consider the method for determining the initial capital stock. Using the perpetual inventory method we use the capital accumulation equation.

$$K_{t-1}(1-\delta)+I_t=K_t$$

Capital stock in any period t is calculated by estimating an initial capital stock and by assuming a rate of depreciation and adding the flow of new investment. The flow of new investment or the net addition to the stock of fixed capital is measured by Gross fixed capital formation (GFCF). Time series of GFCF is used to study investment over time. Starting with an initial benchmark asset figure, the capital accumulation equation is used to estimate capital stock. This measure is very sensitive to the initial capital stock and the rate of depreciation. Initial capital stock is estimated using the following formula

$$K_0 = \frac{GFCF_o}{(\delta + \gamma)}$$

$$\gamma = \frac{\dot{GDP}}{GDP}$$

In the above formula the denominator is the sum of depreciation and the log term rate of growth of the GDP. GDP in constant local currency units (LCU) was obtained from WDI data and the average rate of growth of GDP over the long run (twenty five year period). As can be seen this is then used to determine capital stock in all succeeding periods using the accumulation.

Discount Rate	**Elasticity of Substitution**	**Depreciation Rate**	**Harrod Rate of Growth**	**Rate of growth in Population**	**Initial Capital Stock (Constant LCU Units)**
ρ	θ	δ_d	x	n	K(0)
0.035	1	0.01	0.0125	0.024	2×10^{13}

Table 4.1 Baseline Model Parameters (WDI)

$$Y = A(t)F(K(t), L(t))$$

$$\frac{\dot{Y}(t)}{Y(t)} = \frac{\dot{A}(t)}{A(t)} + \alpha \frac{\dot{K}(t)}{K(t)} + (1-\alpha)\frac{\dot{L}(t)}{L(t)}$$

Growth accounting of output is essential to determine the forces that drive growth especially during periods of sharp accelerations and decelerations in the growth rate. The total factor productivity is evaluated using estimates of capital share alpha which in the literature varies between 0.3 and 0.5. Value of TFP is sensitive to the value chosen for alpha. Interpretation of TFP growth also reflects diverse factors other than purely technical change such as increasing returns to scale, markup due to imperfect competition or gains from sector re-allocations. In the above exercise we use a Cobb Douglas production function to represent how inputs are combined to yield output. Using data on labor, capital stock from WDI we estimate the TFP contribution from each input, we obtain the following relative contributions.

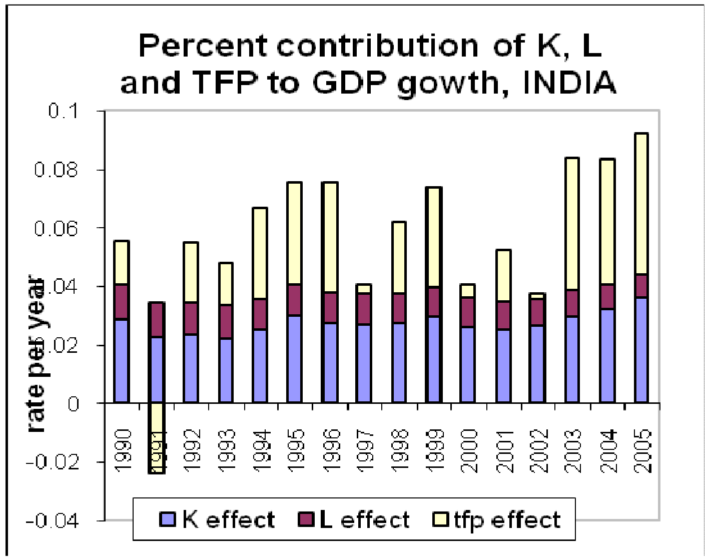


Fig. 4.1 Growth Accounting, WDI data

An interesting feature of the above graph is the sharp fall in TFP during the balance of payments crises in 1991. A rising contribution of TFP towards total output growth can be observed in the period following 2003 which is when the rate of growth of GDP accelerated from an average of 5.6 to 8 percent. This correlation between TFP variation and GDP growth rate variation can be seen in fig 4.2, an observation which is not country specific.

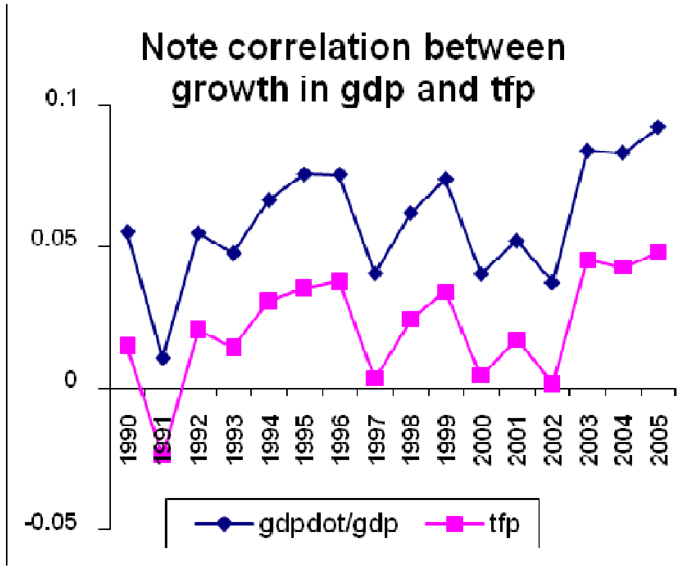


Fig. 4.2 TFP and Rate of GDP Growth, WDI Data

Another feature of the data that merits attention is the sectoral composition of the GDP. The following table uses data from the WDI on value added across different sectors in constant local currency units and illustrates the evolving shares of various sectors of the Indian economy.

Share of GDP	1989	1995	2000	2005
Agriculture	0.32	0.27	0.24	0.20
Industry	0.25	0.27	0.26	0.26
Services	0.43	0.46	0.50	0.54

Table 4.2 Sector shares, WDI data

Labor force growth rate and rate of capital depreciation are parameters of the model derived from World Development Indicators (WDI). This exercise gives insight into the economy's growth performance and suggests how far it is from its long run equilibrium growth rate. We assume that the economy is in long run equilibrium i.e. in the long run GDP or Y grows at the rate ‘x+n’ so does K, factor share contribution to growth are α and $(1-\alpha)$.

Table 4.2 and Fig.4.3 show that services is emerging as the dominant sector of the Indian economy while agriculture constitutes a decreasing share of total output. The role of information technology is crucial in this context in two ways. In itself this sector has grown at an annual rate of over forty percent over the period 1990-2000 thereby directly contributing to growth in services. The second effect is in its role as an intermediate good in manufacturing and services. Increases in its productivity are transferred by means of a decline in price. The four sector growth model attempts to capture the growth of this sector and its role in accelerating growth of manufacturing and services.

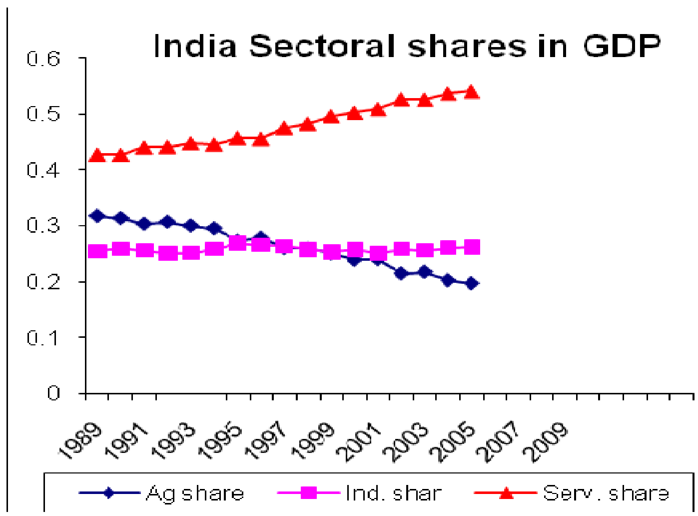


Fig.4.3 Sectoral Shares from Growth Accounting, WDI data

A snapshot of the economy, aggregated to the level of the model is presented in Table 4.4. Using the Global Trade Analysis Project (GTAP) database we construct a social accounting matrix (SAM) for India for the base year of 2001. Using firm level data from CMIE/Prowess and NASSCOM, we carry out production function estimation. We estimate the labor and capital coefficients. For a detailed discussion refer to conclusion in chapter two.

SAM2001 of INDIA (Consumptions by households and the government are aggregated.)																		
Expenditures:		1. Activities				2. Commodoties				3. Factors				4. Institu	5. Cap.	6. Forei	7. Total	
Receipts:		AT01 (AG	IT	T02 (MF(	3 (Servi	CT01	IT	CT02	CT03	K	L	T	Q	HH	KA	WT	TT	
1. Activ	AT01 (A					1E+05										16276	1E+05	0
	IT						2539									7551	10090	0
	AT02 (M							82256									82256	0
	AT03(S								2E+05								2E+05	0
2. Comr	CT01 (AGR)													1E+05			1E+05	0
	IT			836	1703												2539	0
	CT02 (MFG)													63710	42373		1E+05	0
	CT03 (Services)													2E+05			2E+05	0
3. Factc	K	24897	3431	49569	1E+05												2E+05	0
	L	48739	5406	31852	1E+05												2E+05	0
	T	44888	0	0	0												44888	0
	Q	0	1253	0	0												1253	0
4. Institu	HH									2E+05	2E+05	44888	1253				4E+05	0
5. Cap.	KA													42373			42373	0
6. Forei	WT							23827									23827	0
7. Total	TT	1E+05	10090	82256	2E+05	1E+05	2539	1E+05	2E+05	2E+05	2E+05	44888	1253	4E+05	42373	23827		
Capital !	VKB	89826																
Capital !	VDEP	3593															0.357	

Table 4.3 Social Accounting Matrix, GTAP

Factor Intensity

Sectors	**Capital Intensity**
Agriculture	0.5108
Information Technology	0.6345
Manufacturing	1.5562
Services	1.004

Table 4.4 Factor Intensity source: SAM 2001 India

The table above shows that manufacturing is the most capital intensive while agriculture is the least. These are derived from measuring the capital labor ratios from the social accounting matrix for India for the year 2001. The SAM was constructed using the GTAP database except for the information technology sector. In order to obtain labor and capital inputs used in information technology production function estimation was carried out using firm level data obtained from NASSCOM and CMIE database. Using a Cobb Douglas function and Levinsohn Petrin methodology to estimate capital and labor coefficients total labor and capital inputs were obtained. For further discussion refer to the conclusion in chapter two.

An interesting caveat is the fixed factor 'Q' in the production function of the information technology sector. I interpret this fixed factor as both knowledge and infrastructural capital necessary for producing IT service goods. This 'Q' includes increasing supply of skilled workforce, infrastructure which allows for connectivity to the internet via a broadband network and business acumen specific to this hi-tech sector which allows firms to compete internationally.

Information Technology sector with Q as the Fixed Factor

Inputs	**Production Function Coefficients**	**Total Value of Inputs (mn $)**
Capital (K)	0.34	3430.60
Labor (L)	0.54	5406.22
Fixed Factor (Q)	0.11	1254.18

Table 4.5 Production Function Estimation

With constant returns to scale technology, the parameters $\alpha1$, $\beta1$, $\delta1$and $\zeta1$ represents labor shares (refer to Table 4.13). Using our social accounting matrix we obtain estimates for 'wL_j' by dividing the labor row entry and divide it by total output of the sector Y_j. Calibration of labor input proceeds as follows:

$$l_1 = \frac{L1}{L} = \frac{48.74}{203.915} = 0.239$$
$$l_2 = \frac{L2}{L} = \frac{5.406}{203.915} = 0.0265$$
$$l_3 = \frac{L3}{L} = \frac{31.851}{203.915} = 0.562$$
$$l_4 = 1 - l_1 - l_2 - l_3$$

The normalized labor inputs (Eqt.4.15) in the four sectors represent share of wage payments to each sector. The value of '$L=\Sigma_j(wL_j)$' represents total wage payments to labor, dividing by L from normalization gives us the wage bill or $1= \Sigma_j(wL_j)/L=\Sigma_j[w(L_j/L)]= \Sigma_j[w(l_j)]$. Using the above normalized labor inputs we obtain the following scale parameters for the production function. Please note we can obtain the scaling parameter by solving the following formulae.

$A1= Y1 / ((L1/L)^{\beta 1}(K1/R)^{\beta 2}\ T^{\beta 3}) = 65.0992$

$A2= Y2 / ((L2/L)^{\alpha 1}(K2/R)^{\alpha 2}\ ((1)^{\alpha 3})) = 14.2652$

$A3= Y3 / ((L3/L)^{\delta 1}(K3/R)^{\delta 2}\ (IT3)^{\delta 3}) = 2.5652$

$A4= Y4 / ((L4/L)^{\zeta 1}(K4/R)^{\zeta 2}\ (IT4)^{\zeta 3}) = 5.4844$

Validation

In order to determine if our theoretical formulation is a viable approximation of reality we compare the output of the model with the actual data. Using predetermined parameters specific to our country and using 2001 as the base year as input, fig 4.4 to fig 4.6 compare the model output of agriculture, manufacturing and services to time series of output obtained from the WDI database.

This validation exercise is carried out to ascertain to what extent the baseline model captures key structural features of the Indian economy. Since no model can accurately replicate the actual economy the difference between the model output and the actual data can be attributed to factors outside the theoretical realm of the model formulation. Please note that each time series is normalized to the year 2001, this allows a relative comparison rather than an emphasis on absolute levels. Interestingly the WDI time series data does not compare identically with GTAP sector definitions so that sectoral GDP levels of the two series depart to some extent. We take the reference year as 2001 and compare model output to data ten years before and after the reference year.

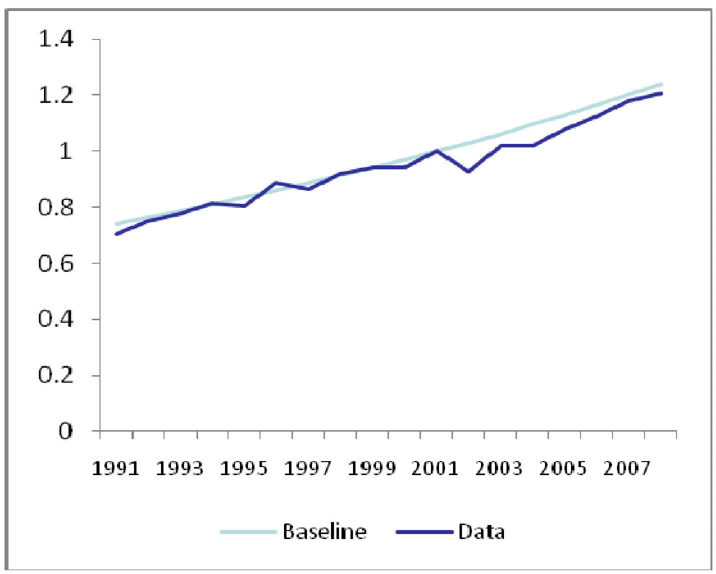


Fig. 4.4 Agricultural Sector (1991-2007)

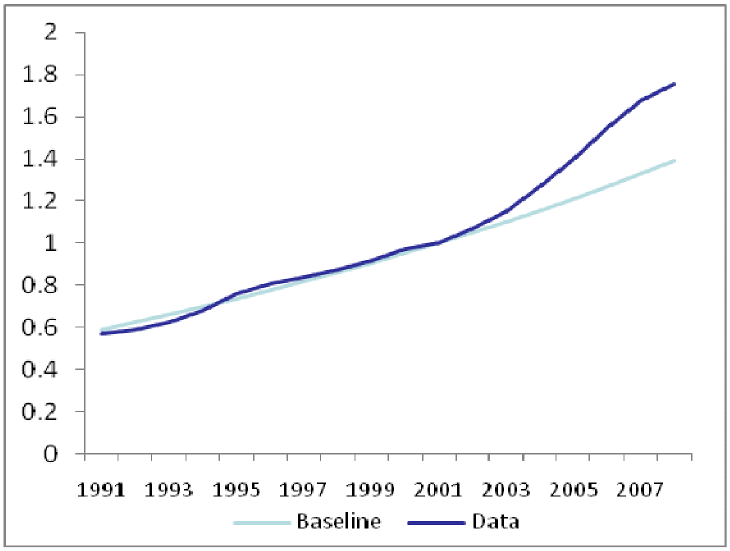


Fig. 4.5 Manufacturing Sector (1991-2007)

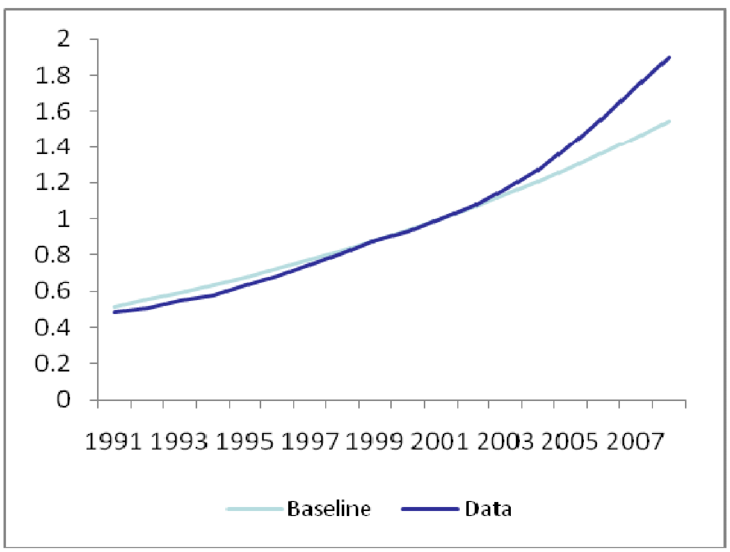


Fig. 4.6 Services Sector (1991-2007)

Fig 4.4 to fig 4.5 reveal that the time series generated by the model is an excellent fit to the data for the period 1991 to the base year 2001, however it undershoots for the period 2001 to 2008. This is an interesting observation as its true of manufacturing and services but not so for agriculture. The baseline model is able to account for data from 1991 to 2001 but not from 2001 onwards.

Baseline Model Results

To study the variation in sector shares of the baseline economy consider a few crucial results. Analyzing the total output or GDP in the baseline economy table 4.8 shows the components of GDP in terms of factor shares. The base year 2001 is characterized by capital having the largest share of GDP at 44.07 percent followed by wages at 42.23 percent. Agriculture profit and profit in the IT sector show a monotonic decline.

Year	Wages/GDP	AGR Profit/GDP	K/GDP	IT Profit/GDP
1991	0.4223	0.1400	0.4307	0.0069
2001	0.4229	0.1196	0.4525	0.0049
2011	0.4249	0.1048	0.4665	0.0037
2021	0.4277	0.0937	0.4756	0.0029
2031	0.4309	0.0852	0.4813	0.0024
2041	0.4345	0.0787	0.4848	0.00204
2051	0.4381	0.0734	0.4866	0.001761
2061	0.4418	0.0692	0.4874	0.001546
2071	0.4489	0.0657	0.4874	0.001379

Table 4.6 Factor shares in Output

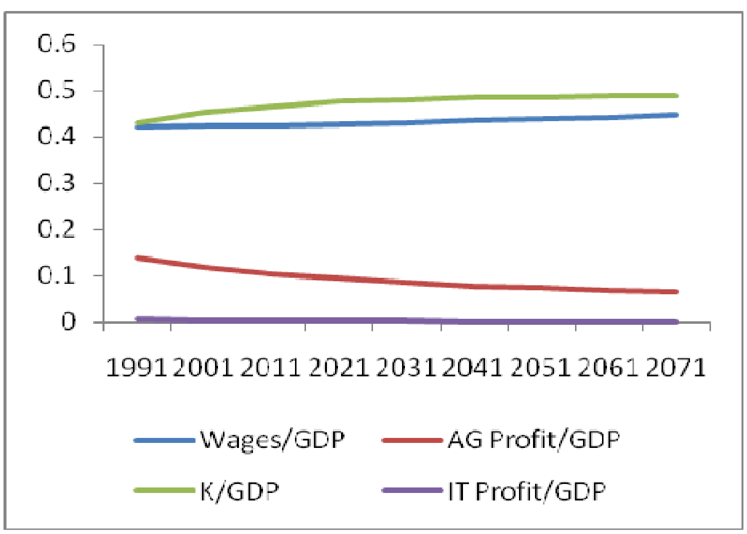


Fig 4.7 Factor Shares in Total Output

Transition Dynamics

Capital deepening occurs in every sector and this causes the marginal productivity of labor to rise in each sector. However the most capital intensive sector experiences the sharpest increase in the productivity of labor thereby pulling labor out of agriculture to manufacturing leading to a decrease in growth in agriculture and a rise in the rate of growth of manufacturing. The Rybczynski and Stolper Samuelson effects come into play and we observe the shift of labor across sectors as shown in table 4.9.

Year	**$L_m(t)$**	**$L_s(t)$**	**$L_{AGR}(t)$**	**$L_{IT}(t)$**
2001	0.4343	0.1649	0.3645	0.03628
2011	0.4815	0.1929	0.2982	0.02737
2021	0.5064	0.2190	0.2528	0.02171
2031	0.5185	0.2429	0.2205	0.01792
2041	0.5233	0.2646	0.1968	0.01528
2051	0.5236	0.2839	0.1790	0.01337
2061	0.5215	0.3012	0.1653	0.01196
2071	0.5181	0.3164	0.1546	0.01089
2081	0.5140	0.3297	0.1461	0.010061
2091	0.5098	0.3414	0.1393	0.00941

Table 4.7 Baseline Model: Variation of Labor Shares

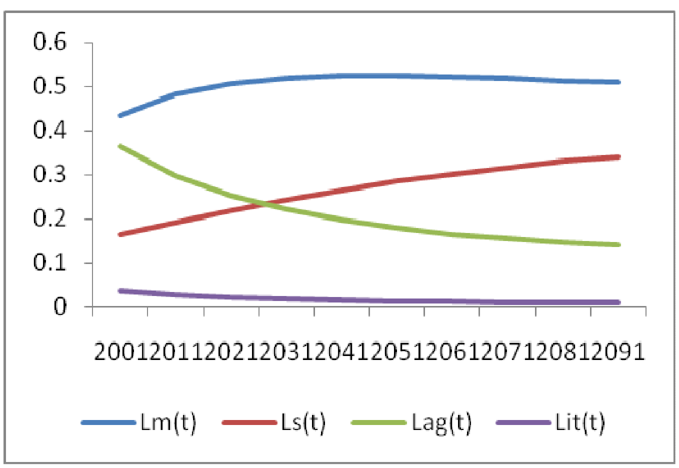


Fig. 4.8 Variation of Labor shares across sectors

Table 4.9 and Fig. 4.22 illustrate labor being pulled out of agriculture and IT and into manufacturing and services. What is interesting is the evolution of the baseline economy in terms of shares of various sectors in the economy. Sector shares and their variation (Table 4.7) show a decline in contribution of agriculture and a sharply rising share of services. Manufacturing as a share of GDP shows a non monotonic variation, it increases from 44.5 percent of total output to a maximum of 47.5 after which it declines over the next four decades.

Services show the sharpest growth in output emerging as the dominant sector. The base year is characterized by manufacturing as the dominant sector with 66.8 percent of GDP followed by agriculture with 36.9 percent and then services at 19.37 percent. Over the next six decades services overtakes manufacturing as the dominant sector. This trend resembles the WDI data on the Indian economy. However the IT sector decreases as a share of GDP and this trend does not match up to the actual data. Information Technology has emerged as the fastest growing sector in the Indian economy and its share in total output has increased from less than 0.5 percent in 1985 to over 7 percent in 2002.

Year	Agr/GDP	IT/GDP	Mfg/GDP	Ser/GDP
1991	0.3698	0.0555	0.4346	0.1575
2001	0.3157	0.0401	0.4683	0.1937
2011	0.2766	0.0304	0.4789	0.2314
2021	0.2475	0.0240	0.4749	0.2699
2031	0.2251	0.0196	0.4615	0.3086
2041	0.2077	0.0165	0.4419	0.3467
2051	0.1939	0.0142	0.4186	0.3839
2061	0.1827	0.0124	0.3931	0.4198
2071	0.1736	0.0111	0.3665	0.4541

Table 4.8 Baseline Model: Sector Shares

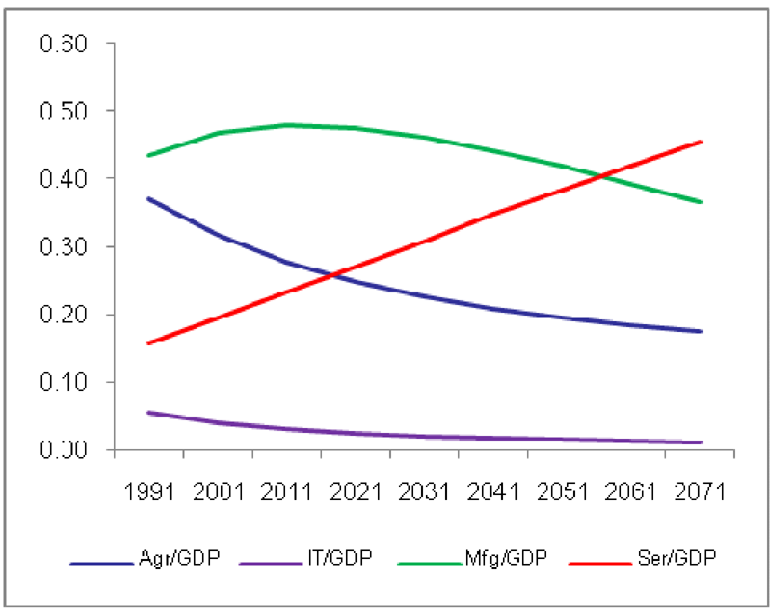


Fig 4.9 Baseline Model: Sector Shares

Transition Dynamics

In this section I perform a growth accounting exercise of each sector using their supply functions such as (4.8). This analysis shows the evolution of each sector and the contributing factors to growth. The agriculture sector is characterized by a fixed factor land and uses capital and labor as the two other inputs. The contribution towards growth of the agriculture supply function can be expressed as follows:

$$Y_a = Y^a\left(p_a, \hat{w}, r^k\right)e^{(x+n)}H \equiv \Pi_{p_a}\left(p_a, \hat{w}, r^k\right)e^{(x+n)}H$$

$$\frac{\dot{Y}_a}{Y_a} = \frac{\partial Y^a(\cdot)H}{\partial p_a}\frac{p_a}{Y_a}\frac{\dot{p}_a}{p_a} + \frac{\partial Y^a(\cdot)H}{\partial \hat{w}}\frac{\hat{w}}{Y_a}\frac{\dot{\hat{w}}}{\hat{w}} + \frac{\partial Y^a(\cdot)H}{\partial r^k}\frac{r^k}{Y_a}\frac{\dot{r}^k}{r^k} + (x+n)$$

$$\frac{\dot{Y}_a}{Y_a} = \varepsilon^{Y_a}_{p_a}\frac{\dot{p}_a}{p_a} + \varepsilon^{Y_a}_{\hat{w}}\frac{\dot{\hat{w}}}{\hat{w}} + \varepsilon^{Y_a}_{r^k}\frac{\dot{r}^k}{r^k} + (x+n)$$

$$\frac{\dot{Y}_a}{Y_a} = \varepsilon^{Y_a}_{p_a}\overbrace{\frac{\dot{p}_a}{p_a}}^{=0} + \overbrace{\varepsilon^{Y_a}_{w}}^{(-)}\overbrace{\frac{\dot{\hat{w}}}{\hat{w}}}^{(+)} + \overbrace{\varepsilon^{Y_a}_{r^k}}^{(-)}\overbrace{\frac{\dot{r}^k}{r^k}}^{(-)} + (x+n) \tag{4.17}$$

In the steady state

$$\frac{\dot{\hat{w}}}{\hat{w}} = 0, \frac{\dot{r}^k}{r^k} = 0$$

Hence, $\frac{\dot{Y}_a}{Y_a} = x+n$

'H' is the land endowment, normalized to unity so $(x+n)$ is the Harrod rate of exogenous technical change associated with land. For simplicity, we restrict this to the value $(x+n)$ to keep our equations autonomous. Whether $\hat{w}$ dominates the effects of changes in r^k depends upon relative factor intensities as measured by the elasticities. Consider the contribution of individual arguments of the agriculture supply function in contributing to the growth of the sector.

Year	w	r	H	tot
1991	-0.01081	0.003547	0.0365	0.02924
2001	-0.00926	0.003038	0.0365	0.030282
2011	-0.00796	0.002614	0.0365	0.031151
2021	-0.00688	0.002258	0.0365	0.0319
2031	-0.00597	0.001959	0.0365	0.032491
2041	-0.0052	0.001705	0.0365	0.03301
2051	-0.00454	0.001489	0.0365	0.033452
2061	-0.00397	0.001304	0.0365	0.033832
2071	-0.00348	0.001144	0.0365	0.03416

Table 4.9 Transition Dynamics Agriculture I

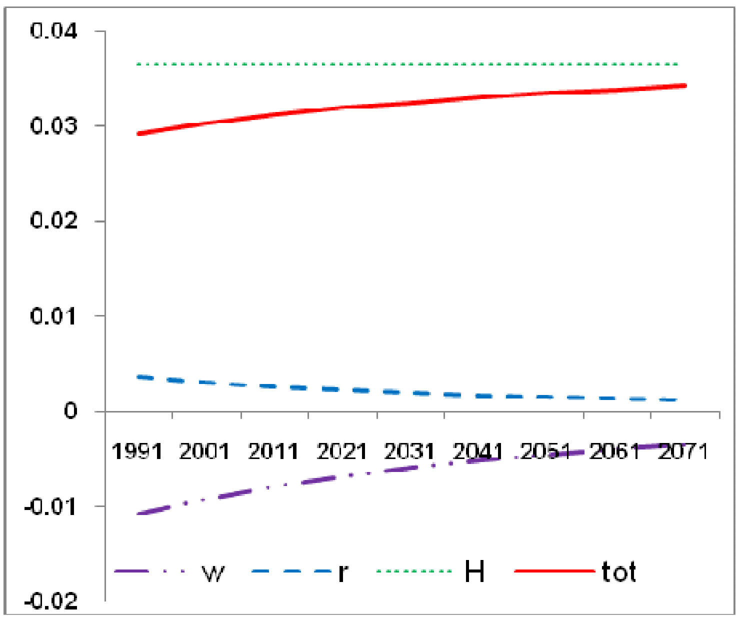


Fig 4.10 Transition Dynamics Agriculture I

Table 4.9 illustrates how factors contribute to the growth of agriculture on the transition path. Wages increase towards their steady state value from below as discussed earlier and due to capital deepening effect the rate of return on capital decreases towards its steady state value. The total growth of this sector tends towards a steady state value of 4.65 percent as that is the (x+n) discussed in the parameters of the baseline economy. Consider the growth of the information technology sector along the transition path. The supply function consists of labor, capital and a fixed factor Q.

$$Y_{it} = \psi\left(p_2, \hat{w}, r^k\right)\overbrace{e^{(x+n)}}^{Q} \equiv \Pi^{it}_{p_2}\left(p_2, \hat{w}, r^k\right)Q$$

$$Y_{it} = \psi\left(p_2, \hat{w}, r^k\right)Q \equiv \Pi_{p_2}\left(p_2, \hat{w}, r^k\right)Q$$

$$\frac{\dot{Y}_{it}}{Y_{it}} = \frac{\partial\psi(\cdot)H}{\partial p_2}\frac{p_2}{Y_{it}}\frac{\dot{p}_2}{p_2} + \frac{\partial\psi(\cdot)H}{\partial\hat{w}}\frac{\hat{w}}{Y_{it}}\frac{\dot{\hat{w}}}{\hat{w}} + \frac{\partial\psi(\cdot)H}{\partial r^k}\frac{r^k}{Y_{it}}\frac{\dot{r}^k}{r^k} + (x+n)$$

$$\frac{\dot{Y}_{it}}{Y_{it}} = \varepsilon^{Y_{it}}_{p_2}\frac{\dot{p}_2}{p_2} + \varepsilon^{Y_{it}}_{\hat{w}}\frac{\dot{\hat{w}}}{\hat{w}} + \varepsilon^{Y_{it}}_{r^k}\frac{\dot{r}^k}{r^k} + (x+n)$$

$$\frac{\dot{Y}_{it}}{Y_{it}} = \varepsilon^{Y_{it}}_{p_2}\frac{\overbrace{\dot{p}_2}^{=0}}{p_2} + \overbrace{\varepsilon^{Y_{it}}_{w}}^{(-)}\frac{\overbrace{\dot{\hat{w}}}^{(+)}}{\hat{w}} + \overbrace{\varepsilon^{Y_{it}}_{r^k}}^{(-)}\frac{\overbrace{\dot{r}^k}^{(-)}}{r^k} + (x+n) \qquad (4.18)$$

In the steady state

$$\frac{\dot{\hat{w}}}{\hat{w}} = 0, \frac{\dot{r}^k}{r^k} = 0$$

Hence, $\dfrac{\dot{Y}_{it}}{Y_{it}} = x + n$

Year	w	r	Q	tot
1991	-0.04294	0.017508	0.0365	0.01107
2001	-0.03678	0.014996	0.0365	0.01472
2011	-0.03164	0.012899	0.0365	0.017764
2021	-0.02733	0.011145	0.0365	0.020312
2031	-0.02371	0.009669	0.0365	0.022456
2041	-0.02064	0.008417	0.0365	0.024274
2051	-0.01893	0.00735	0.0365	0.025825
2061	-0.01578	0.006434	0.0365	0.027155
2071	-0.01384	0.005644	0.0365	0.028303

Table 4.10 Transition Dynamics Information Technology I

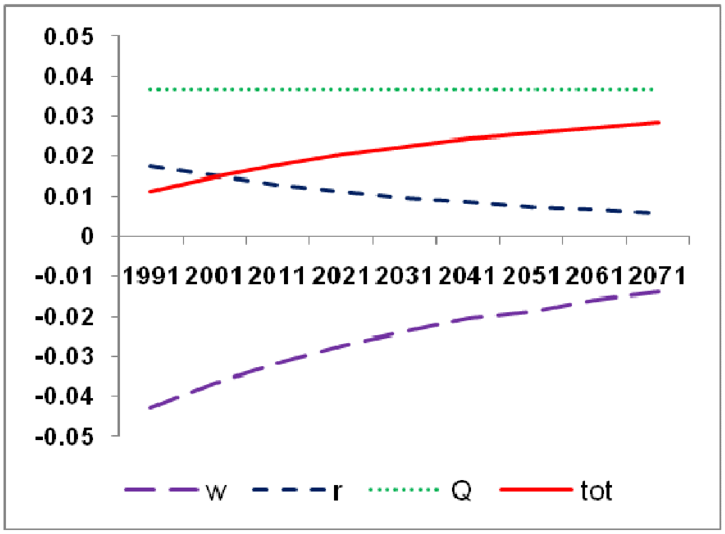


Fig 4.11 Transition Dynamics Information Technology I

Consider the growth in output of the manufacturing sector. The steady state rate of growth is (x+n) which in our baseline model is 4.65 percent. To evaluate the contribution of factors of production in the growth process consider the following growth accounting of the manufacturing sector. Defining elasticity of the supply function with respect to each argument (ε^m_j where $j=k,p_s$), the growth of this sector is an aggregation of the contribution from each factor of production.

$$\varepsilon^m{}_k(p_s,k) = \frac{\partial Y_m(p_s,k)}{\partial k}\left(\frac{k}{Y_m(p_s,k)}\right);$$

$$\varepsilon^m{}_{p_s}(p_s,k) = \frac{\partial Y_m(p_s,k)}{\partial p_s}\frac{p_s}{Y_m(p_s,k)}$$

$$Y_{m\,p_s}(p_s,k) = \varepsilon^m{}_{ps}(p_s,k)\left(\frac{\partial_t p_s}{p_s}\right);\ Y_{mk}(p_s.k) = \varepsilon^m{}_k(p_s,k)\left(\frac{\partial_t k}{k}\right)$$

$$Y_{mL}(p_s,k) = (1-\varepsilon^m{}_k(p_s,k))(x+n);$$

$$\frac{\dot{Y}_m}{Y_m} = \overbrace{Y_{m\,p_s}(p_s,k)}^{0} + \overbrace{Y_{mk}(p_s,k)}^{0} + Y_{mL}(ps,k) \tag{4.19}$$

In steady state the first two terms are zero and $\frac{\dot{Y}_m}{Y_m}$ = (x+n).

Year	tot	k	p	l
1991	0.057894	0.27258	-0.08314	-0.13155
2001	0.049049	0.242379	-0.06599	-0.12734
2011	0.043731	0.227924	-0.05553	-0.12866
2021	0.040137	0.221871	-0.04845	-0.13328
2031	0.037522	0.221204	-0.04334	-0.14034
2041	0.035524	0.224503	-0.03948	-0.1495
2051	0.033946	0.231057	-0.03648	-0.16063
2061	0.03267	0.240511	-0.03408	-0.17376
2071	0.031622	0.252717	-0.03212	-0.18897

Table 4.11 Transition Dynamics Manufacturing I

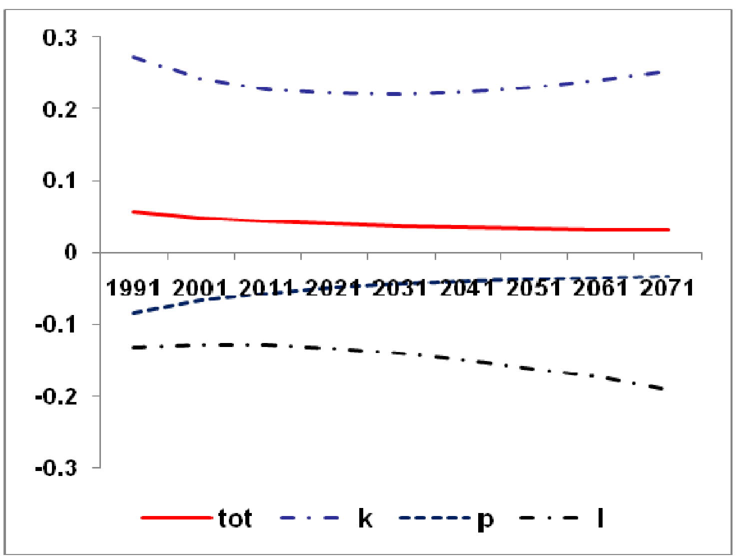


Fig. 4.12 Transition Dynamics Manufacturing I

Please note that the contribution of capital is non-monotonic, the contribution of p_s increases towards steady state. In the long run the growth tends towards the steady state value set by our parameters (x+n) which is again 4.65 percent. The growth of the services sector in transition can be analyzed in a similar way. Consider the contribution of each factor in the growth of services. Elasticities define the sensitivity of output to each factor. By aggregating each factor contribution and observing the long term trend, the steady state growth can be evaluated.

$$\varepsilon^{Y_s}{}_{k}(p_s,k)=\frac{\partial Y_s(p_s,k)}{\partial k}\frac{k}{Y_s(p_s,k)}$$

$$\frac{\dot{Y}_s}{Y_s}=\overbrace{\varepsilon^{Y_s}{}_{k}(p_s,k)\frac{\partial_t k}{k}}^{0}+\overbrace{\varepsilon^{Y_s}{}_{ps}(p_s,k)\frac{\partial_t p_s}{p_s}}^{0}+(1-\varepsilon^{Y_s}{}_{k}(p_s,k))(x+n)$$

Table 4.12 and Fig 4.13 highlight the individual contribution of factors and the transition path of this sector.

Year	tot	p	k	l
1991	0.068868	0.276022	-0.63537	0.428214
2001	0.063852	0.185139	-0.48695	0.365663
2011	0.059782	0.12971	-0.3865	0.316574
2021	0.05644	0.094135	-0.31603	0.278338
2031	0.053664	0.070321	-0.26505	0.248397
2041	0.051337	0.053805	-0.22719	0.224722
2051	0.04937	0.042	-0.19843	0.205794
2061	0.047698	0.03335	-0.17615	0.190497
2071	0.046266	0.026864	-0.15861	0.178008

Table 4.12 Transition Dynamics Services I

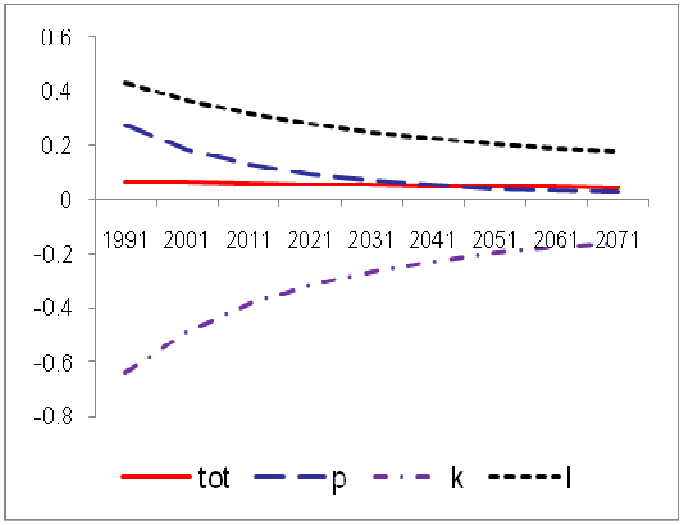


Fig. 4.13 Transition Dynamics Services I

Growth accounting can also be observed from the supply side where total growth in GDP is divided into individual sectors where each sector is weighed by its share in the economy. $Cony_{jt}$ represents the contribution of sector j to GDP growth at time t. GDP growth is the sum of all the sectors. By studying the evolution of this over time the sector driving the growth of GDP can be revealed.

$$
\begin{aligned}
cony_{at} &= \frac{Y_{at}}{GDP_t}\left(\frac{\partial_t Y_{at}}{Y_{at}}\right) \\
cony_{ITt} &= \frac{Y_{ITt}}{GDP_t}\left(\frac{\partial_t Y_{ITt}}{Y_{ITt}}\right) \\
cony_{mt} &= \frac{Y_{mt}}{GDP_t}\left(\frac{\partial_t Y_{mt}}{Y_{mt}}\right) \\
cony_{st} &= \frac{Y_{st}}{GDP_t}\left(\frac{\partial_t Y_{st}}{Y_{st}}\right) \\
\frac{\partial_t GDP_t}{GDP_t} &= cony_{at} + cony_{ITt} + cony_{mt} + cony_{st}
\end{aligned}
\tag{4.20}
$$

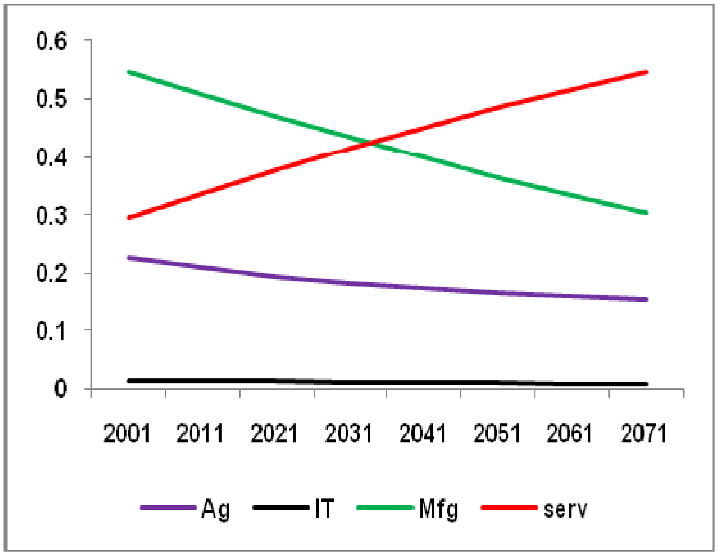


Fig. 4.14 Growth Accounting Supply Side I

From the above graph it can be ascertained that the model captures the sharp rise in the growth of services as the dominant sector contributing towards growth. Fig 4.14 shows a declining contribution from manufacturing and agriculture and a steady level of contribution from growth in information technology.

Introducing Parametric Changes: The Jorgenson Effect

Information technology relies on semiconductors technology and price declines in the latter are transmitted to falling IT prices as suggested by the data on computer, memory and logic chips. Price decline does suggest that computers and communication equipment should become more ubiquitous in the economy however in our baseline specification we do not capture the impact of this relative price decline as we assume prices of all traded goods p_a, p_m and p_{it} are equal and normalized to one. We alter the baseline model by allowing the relative price of IT goods to fall.

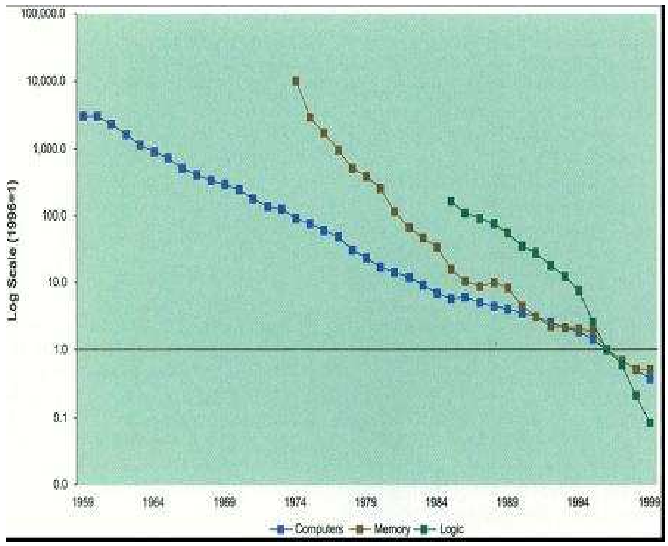


Fig. 4.15 Prices of Computers, Memory and Logic chips,

Source: Jorgenson (2000)

By changing the relative price of information technology in comparison to manufacturing and agriculture, the other two tradable commodities in our economy, we simulate the impact of the relatively faster pace of technical change in the intermediate good sector and allow for greater substitution towards information technology. We also simulates the greater absorption of information technology by means of altering our technology parameter values (Table 4.13) thereby mimicking the changes that accompanied changes in the US economy following large scale absorption of IT in both manufacturing and services (Jorgenson 1999,2000,2001).

Technology Parameters	Baseline	Parametric Experiment
Agriculture		
$\beta_1=L_1/Y_1$	0.4112	0.4112
$\beta_2=L_2/Y_2$	0.2101	0.2101
$\beta_3=(1-\beta_1-\beta_2)$	0.3787	0.3787
Information Technology		
$\alpha_1= L_2/Y_2$	0.5358	0.4554
$\alpha_2= K_2/Y_2$	0.34	0.3757
$\alpha_3=(1-\alpha_1-\alpha_2)$	0.0902	0.1688
Manufacturing		
$\delta_1=L_3/Y_3$	0.3872	0.3446
$\delta_2=K_3/Y_3$	0.6026	0.6478
$\delta_3=(1-\delta_1-\delta_2)$	0.0102	0.0076
Services		
$\zeta_1=L_4/Y_4$	0.4963	0.4417
$\zeta_2=K_4/Y_4$	0.4965	0.5561
$\zeta_3=(1-\zeta_1-\zeta_2)$	0.0071	0.0021

Table 4.13 Comparing Labor and Capital shares

By increasing the capital share and decreasing the labor share we simulate the impact of greater IT penetration through the various sectors of the economy.

Further in chapter we discuss the evolution of aggregate productivity index via production function estimation (refer to Table 2.4 and Fig 2.1). In the process we find that the aggregate productivity index changes on by 20 percent over the period 2002- 2008. Taking an average value of 10 percent as the change in total factor productivity for this sector we allow for a productivity shock in our model. Refer to appendix for chapter 4 for a careful derivation of the scale parameter in the production function and for specific features of each of these 'new economies'.

The combination of the relative price decline of IT goods, the increase in capital coefficients in various sectors of the economy and the aggregate productivity shock to this sector constitutes our parametric experiment. The aim is to observe if the above three changes allow our simulations a better match to the data i.e. via these changes are we able improve the ability of the model to capture structural features of the economy. We call these parametric changes the "Jorgenson Effect" in the honor of Dale Jorgenson.

Another feature unrelated to information technology is the sharp acceleration in the GDP growth rate from 2003-08. In order to account for this structural break in the time series data we allow the harrod rate of growth to increase from 1.25 percent to 2.25 percent. This constitutes the fourth parametric change from our baseline framework. Unlike the earlier three parametric experiments increasing the harrod rate of growth does not affect transition dynamics, only the long run rate of growth to which all sectors of the economy converge. The remaining parameters are taken directly from the literature and remain unchanged from the baseline model.

Discount Rate	**Elasticity of Substitution**	**Depreciation Rate**	**Harrod Rate of Growth**	**Rate of Growth of Population growth**	**Initial Capital Stock**
ρ	θ	δ_d	x	n	K(0)
0.035	1	0.01	0.0225	0.024	2×10^{13}

Table 4.14 Parameter Values for the Jorgenson Effect

Features of the Baseline Economy

Consider specific features of the economy generated by the parametric experiment. Studying the variation in factor shares we observe wages to remain stable at forty percent of total output. Table 4.15 shows that agriculture profit and IT profit decline as a share in output while capital as a share of output rises monotonically from 48 to 60 percent of total output. Consider also the sector shares in GDP and their variation. Table 4.12 and fig 4.16 show the breakdown of GDP into manufacturing, services, IT and agriculture.

YEAR	Wages/GDP	Agr. Profit/GDP	k/GDP	IT Profit/GDP
1991	0.388223	0.1491	0.45449	0.008127
2001	0.3828	0.1136	0.4979	0.005579
2011	0.380426	0.09147	0.523975	0.004125
2021	0.379487	0.076763	0.540522	0.003229
2031	0.379359	0.066522	0.551477	0.002641
2041	0.379671	0.053623	0.558967	0.002238
2051	0.380209	0.049418	0.564218	0.00195
2061	0.381524	0.046181	0.567978	0.001738
2071	0.382185	0.043618	0.5707	0.001579

Table 4.15 Factor Shares in Output

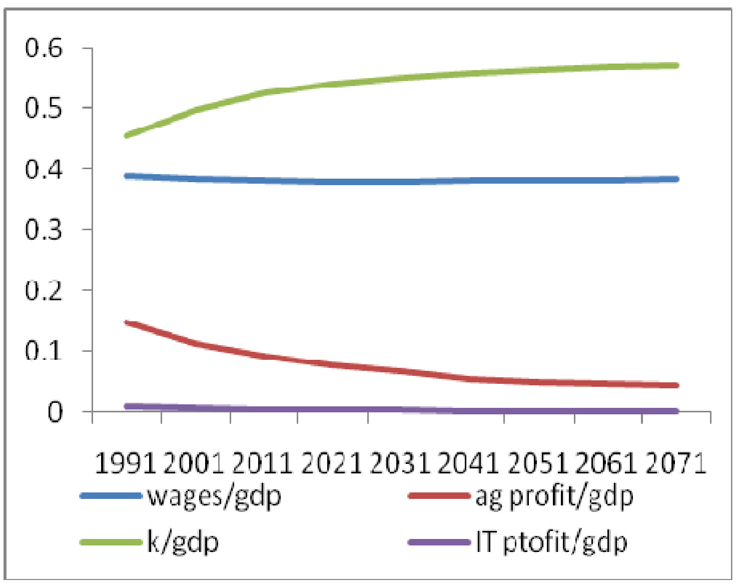


Fig. 4.16 Baseline Model: Factor Shares in Total Output

In comparison to the baseline economy we observe a sharp fall in agriculture and a rise in services as a share of output. Similar to the baseline economy agriculture and information technology constitute a decreasing share of output. Manufacturing output shows a non monotonic variation (Table 4.12) rising as a share of GDP and then showing a decline. As the stock of labor is fixed while capital grows the capital intensive sector experiences a Rybczynski-like effect and tends to grow faster than the labor intensive sector. This affects the relative share of different sectors in the GDP.

The sector variation in GDP in our economy can be explained by the relatively faster rise in labor productivity in the more capital intensive manufacturing sector relative to the labor intensive agriculture sector. This results in labor being pulled out of agriculture into manufacturing and services which are more capital intensive (refer to SAM, Table 4.4) leading to a rise in the growth of manufacturing and services relative to agriculture. The home good sector competes by raising the price of the home good.

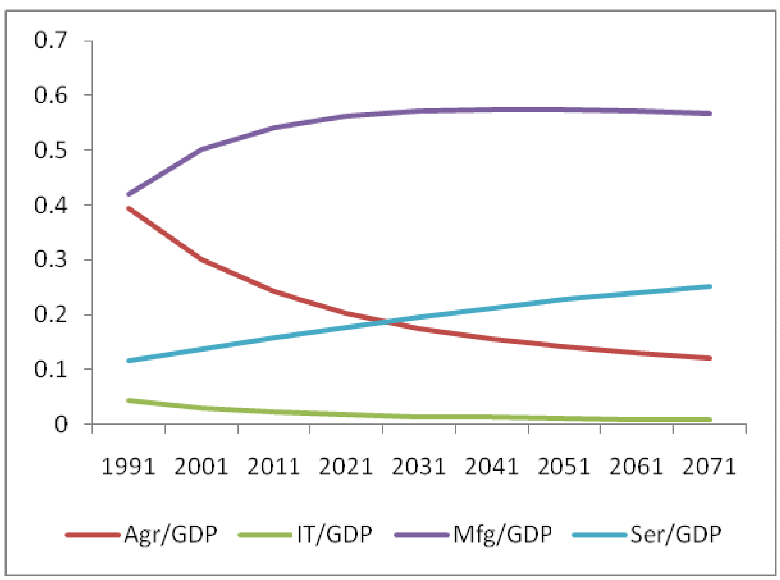


Fig. 4.17 Baseline Model: Sector Shares in Total Output

Year	Agr/GDP	IT/GDP	Mfg./ GDP	Services/ GDP
1991	0.3938	0.0449	0.4208	0.1157
2001	0.3000	0.0308	0.501	0.1375
2011	0.2415	0.0228	0.5422	0.1585
2021	0.2027	0.01787	0.5629	0.1782
2031	0.1756	0.0146	0.5722	0.1964
2041	0.1561	0.0124	0.5749	0.2129
2051	0.1416	0.0108	0.5739	0.2278
2061	0.1305	0.0096	0.5709	0.2410
2071	0.1219	0.0087	0.5668	0.253

Table 4.16 Baseline Model: Sector Shares in Output

Validation of the Information Technology Economy

Using the above parameter values and the change in the relative price of information technology we obtain the model output and compare it to the baseline economy. For this section we assume that the TFP shock is 10 percent. To evaluate changes arising from different levels of shocks refer to the appendix for chapter 4. In the validation exercise with our baseline economy we observe that the total time period can be divided into two parts 1991-2001 and 2001-2009. In the first period the baseline economy fits the WDI time series data for all three final goods. However in the second period we observe that the baseline economy undershoots thereby under estimating the growth in GDP and in the individual sectors of the economy especially for the period 2003-2008.

Fig 4.10 to fig 4.21 show the WDI time series data, the baseline economy output and the Jorgenson effect in relative comparison. The aim of comparing the baseline case to the parametric experiment lies in observing if our experiment can better account for the actual data for the period 2001-2009 i.e. does the greater penetration of IT as an intermediate good help in accounting for the period during which our baseline economy undershoots the actual data ?

Fig. 4.10 to fig 4.21 show that in the case of manufacturing and services the parametric experiment allows a better fit to the WDI data than the baseline economy for the period from 2003-2009. However even the parametric experiment does not account for the actual data as it still undershoots. This implies that the forces driving growth in the Indian economy during this period are outside the scope of the model. Information technology does not explain the sharp rise in the growth rate during the period 2001-2009.

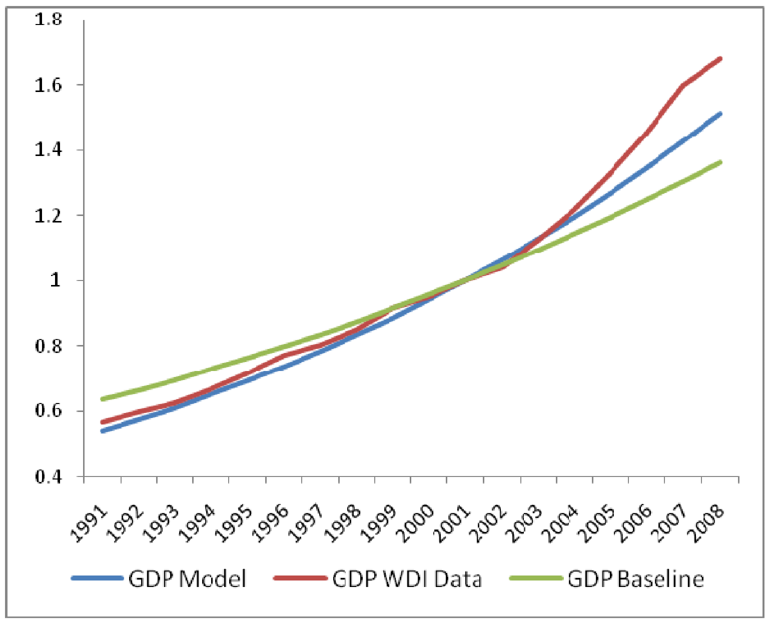


Fig. 4.17 Comparing GDP 1991-2008

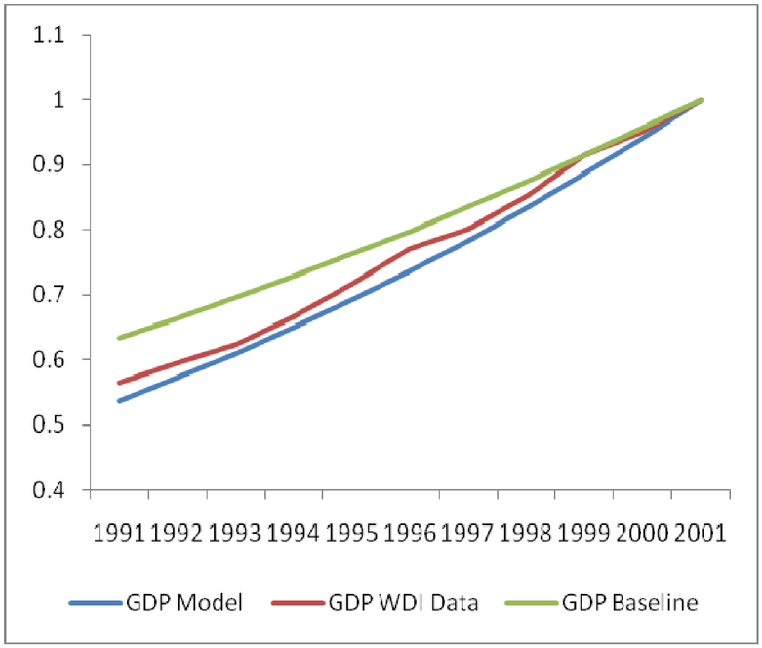


Fig. 4.18 Comparing GDP (1991-2001)

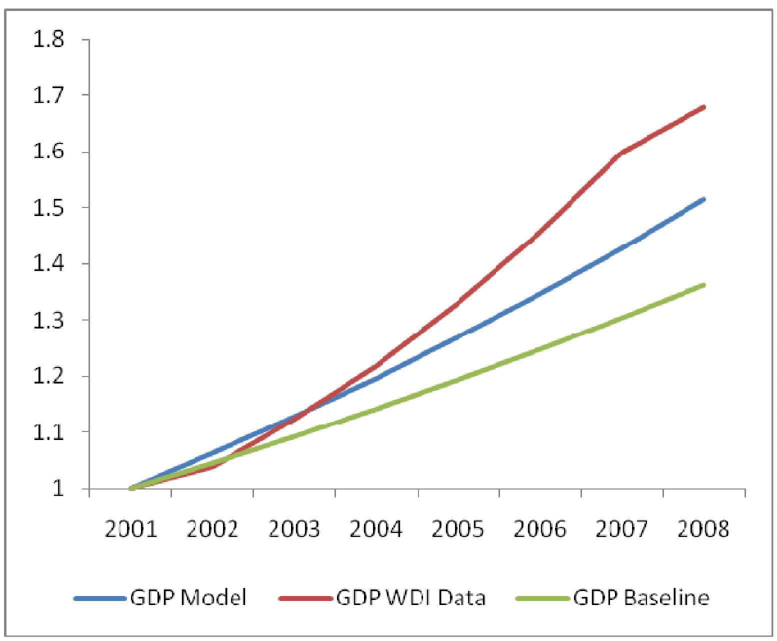


Fig. 4.19 Comparing GDP 2001-08

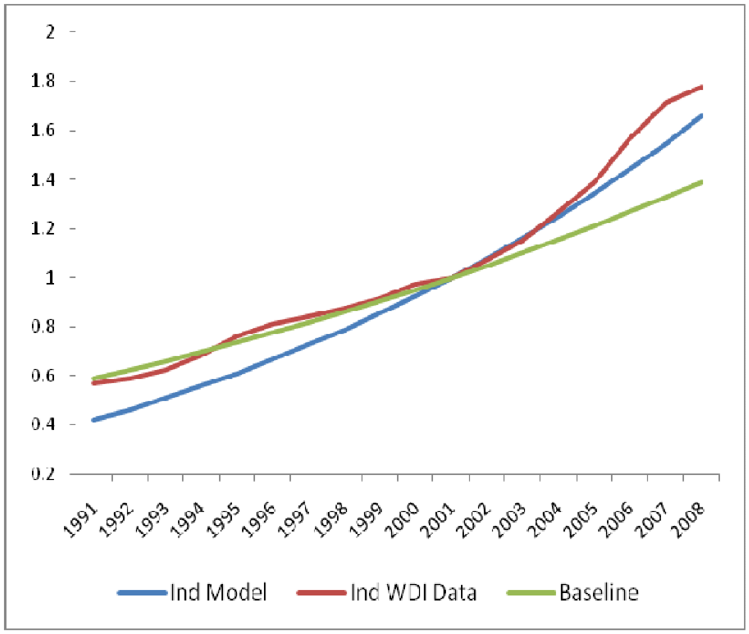


Fig. 4.20 Manufacturing (1991-2008)

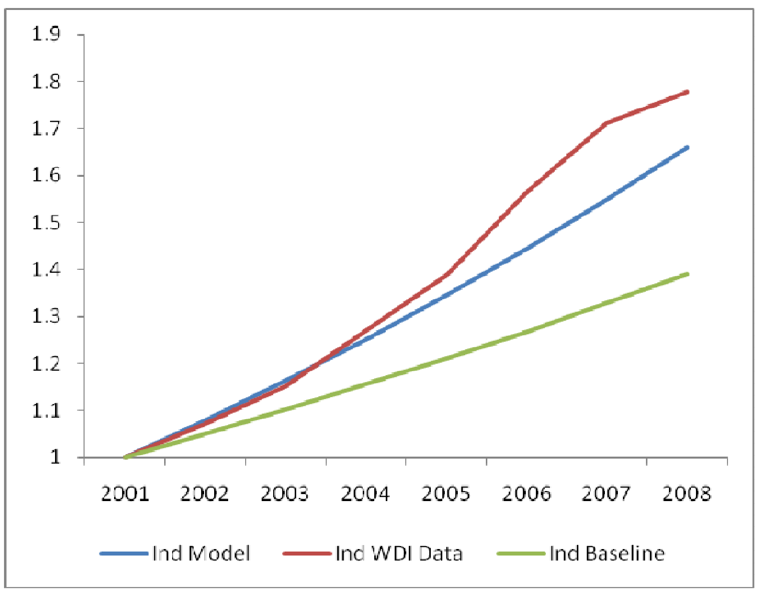


Fig. 4.21 Manufacturing (2001-2008)

We see in the above that our parametric experiment allows us to approximate to the data more closely than the baseline though it also undershoots. This might be the case as the model does not consider differential impact of trade liberalization across sectors and also does not capture key parametric changes. The graph for service sector shows similar results.

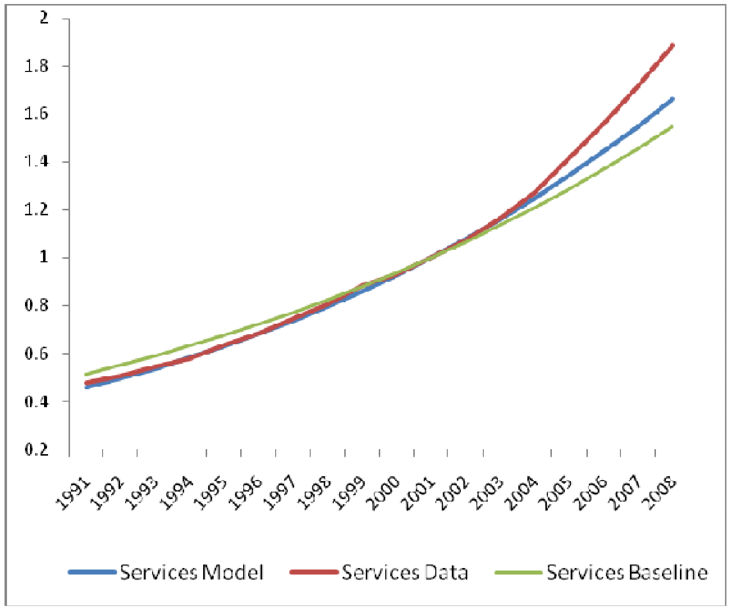


Fig. 4.22 Service Sector (1991-2008)

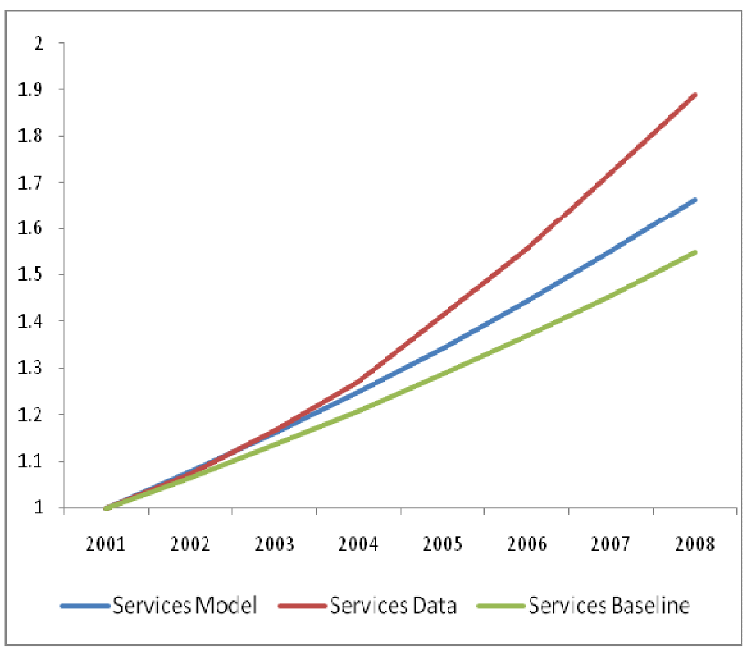


Fig. 4.23 Service Sector (2001-2008)

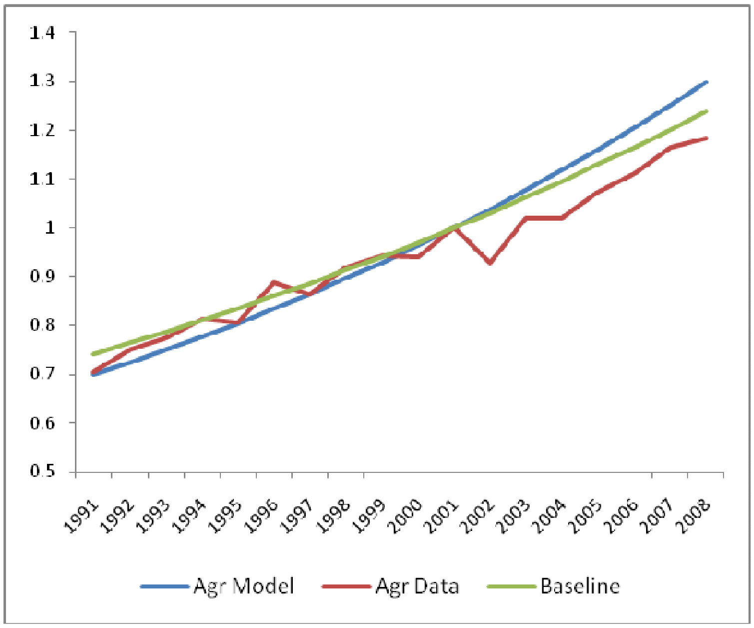


Fig. 4.24 Agriculture Sector (1991-2008)

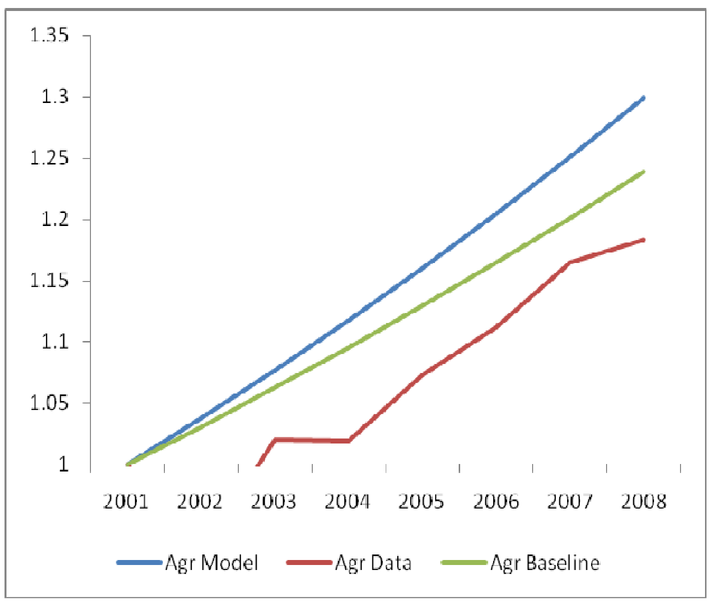


Fig. 4.25 Agriculture Sector (2001-2008)

Transition Dynamics: The Information Technology Economy

To study the growth of individual sectors on their transition path to steady state consider he contribution of individual factors in the total growth of each sector of the economy. In the agriculture sector as table 4.13 suggests wages rise to steady state, capital deepening effect reduces the rate of return to capital leading to a decrease towards constant steady state value (refer to Eqt. 4.17). The return to the fixed factor land is the land augmenting technical progress (x+n) which is higher than in the baseline economy. In steady state the output tends towards 4.65 percent which is the higher steady state level.

Year	Y_{tot}	Y_w	Y_r	Y_H
1991	0.0339	-0.0173	0.0047	0.0465
2001	0.0362	-0.0141	0.0038	0.0465
2011	0.0381	-0.0116	0.0031	0.0465
2021	0.0396	-0.0095	0.0026	0.0465
2031	0.0407	-0.0079	0.0021	0.0465
2041	0.0417	-0.0066	0.0018	0.0465
2051	0.0425	-0.0055	0.0015	0.0465
2061	0.0431	-0.0046	0.0013	0.0465
2071	0.0437	-0.0039	0.0011	0.0465

Table 4.17 Transition Dynamics Agriculture II

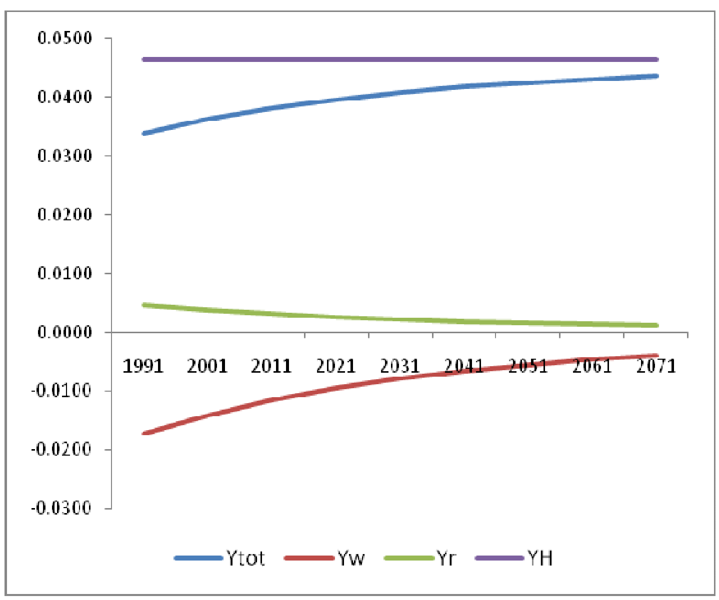


Fig. 4.29 Transition Dynamics Agriculture II

Consider the growth of the information technology sector along the transition path (refer to eqt.4.18). The supply function consists of labor, capital and a fixed factor Q. As in the baseline economy we observe wages to rise towards a constant steady state value while the rate of return to capital decreases towards constant steady state value from above. Return to the fixed factor is the steady state level (x+n) or 4.65 percent. This level is higher than in our baseline economy as the Harrod rate was increased from 1.25 to 2.25 percent to take account of the higher rate of growth of the Indian economy during this period.

Year	Y_w	Y_r	Y_H	Y_p	$Y_{(tot)}$
1991	-0.0429	0.018858	0.0465	0	0.022388
2001	-0.0350227	0.01537	0.0465	0	0.026847
2011	-0.0286907	0.012591	0.0465	0	0.0304
2021	-0.02366532	0.01038	0.0465	0	0.033215
2031	-0.0196132	0.008607	0.0465	0	0.035494
2041	-0.0163444	0.007173	0.0465	0	0.037328
2051	-0.0136773	0.006002	0.0465	0	0.038825
2061	-0.0114853	0.00504	0.0465	0	0.040055
2071	-0.00967207	0.004245	0.0465	0	0.041073

Table 4.18 Transition Dynamics Information Technology II

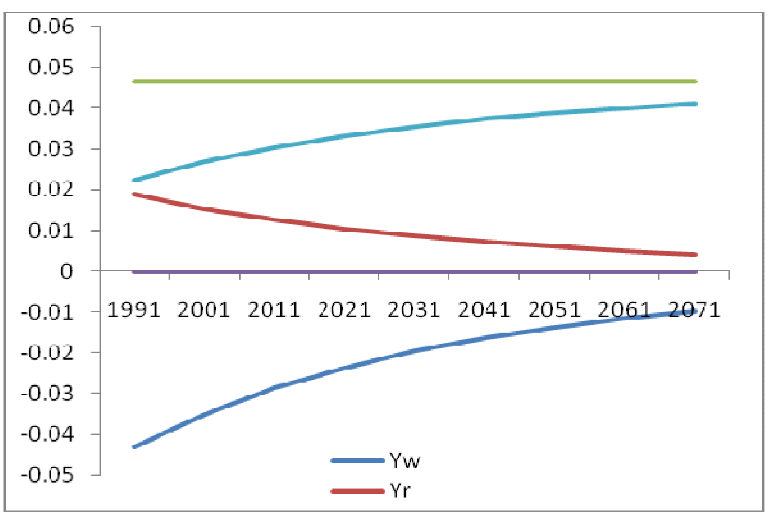


Fig. 4.30 Transition Dynamics Information Technology II

Consider the growth in output of the manufacturing sector (refer to Eqt. 4.19). The steady state rate of growth is (x+n) which in our baseline model is 4.65 percent higher than in the baseline economy. To evaluate the contribution of factors of production in the growth process consider the following growth accounting of the manufacturing sector. The factors are the endogenous price of the home good, capital and labor. Capital tends to its steady state value of ‘x’ or 2.25 percent from above. The home good price rises towards steady state value from below and labor tends to its steady state value from below.

Year	Y_{Tot}	Y_p	Y_K	Y_L
1991	0.0923	-0.1370	0.3978	-0.1686
2001	0.0728	-0.0914	0.3140	-0.1499
2011	0.0637	-0.0681	0.2751	-0.1433
2021	0.0586	-0.0534	0.2531	-0.1411
2031	0.0553	-0.0432	0.2395	-0.1409
2041	0.0531	-0.0356	0.2304	-0.1417
2051	0.0516	-0.0296	0.2242	-0.1429
2061	0.0504	-0.0249	0.2198	-0.1444
2071	0.0496	-0.0210	0.2166	-0.1460

Table.4.19 Transition Dynamics Manufacturing II

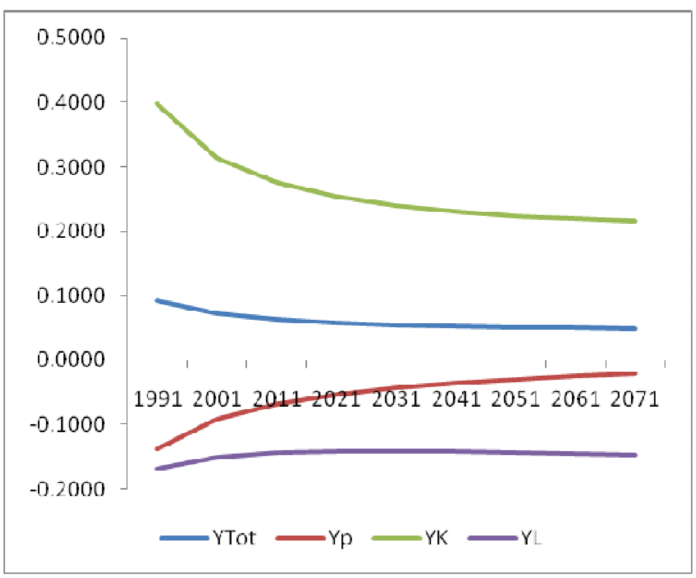


Fig. 4.31 Transition Dynamics Manufacturing

In the long run the growth tends towards the steady state value set by our parameters (x+n) which is higher than in the baseline economy at 4.65 percent. The growth of the services sector in transition can be analyzed in a similar way. Consider the contribution of each factor in the growth of services. Elasticities define the sensitivity of output to each factor. By aggregating each factor contribution and observing the long term trend, the steady state growth can be evaluated. Table 4.20 and Fig 4.32 highlight the individual contribution of factors in production of services and the transition path of this sector.

Year	Y_{TOT}	Y_p	Y_K	Y_L
1991	0.08341	0.733547	-1.51657	0.866429
2001	0.076173	0.474755	-1.18807	0.78948
2011	0.070504	0.324359	-0.9688	0.714948
2021	0.066109	0.231201	-0.81738	0.652287
2031	0.062647	0.17034	-0.70929	0.6016
2041	0.059882	0.128827	-0.62992	0.560972
2051	0.057648	0.099495	-0.57021	0.52365
2061	0.054329	0.078155	-0.52439	0.502061

Table 4.20 Transition Dynamics Services II

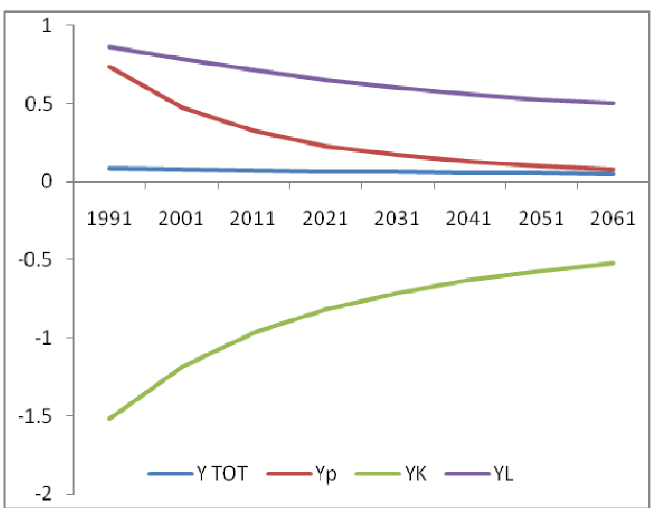


Fig. 4.32 Transition Dynamics Services I

Repeating the growth accounting exercise from the supply side by aggregating the contribution of each sector to the total growth of the GDP (refer to Eqt. 4.21) we observe trends similar to the baseline case. Like the case of the baseline economy, parametric experiment also shows services to be the dominant sector in its contribution to overall GDP growth while manufacturing and agriculture show a declining contribution. The contribution of information technology is constant.

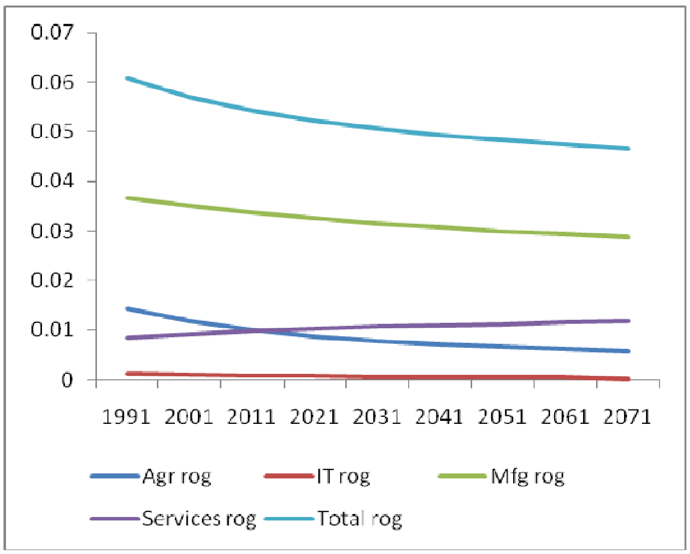


Fig. 4.33 Supply Side Growth Accounting II

Conclusion

The Indian economy has undergone sharp structural changes over the past decade. Accompanying these structural changes is the rise of information technology as the fastest growing sector of the Indian economy. We construct a four sector growth model with three final goods and one intermediate good. The three final goods are agriculture, manufacturing and services and the intermediate good is information technology or IT. IT is an intermediate good in manufacturing and services.

Our construct is a small open economy model with three tradable sectors i.e. agriculture, manufacturing and information technology and one non tradable sector i.e. home goods sector which like agriculture produces a pure consumption good. Using a social accounting matrix (SAM) derived from the GTAP database for the year 2001 as input into the model we compare the output of our baseline economy both in the aggregate (GDP) and in terms of individual sectors with WDI data. We observe that our economy reproduces the data accurately for the period 1991 to 2001 or going backwards in time, however it undershoots when predicting the data going forwards i.e. 2001 to 2009.

In order to simulate data from 2001 to 2009 we change certain technology parameters and allow the relative price of IT to fall, a change I refer to as the 'Jorgenson effect'. The parametric changes involve conservatively changing the capital intensity of all four sectors in our model (refer to table 4.13). It also involves inducing an increase in the scale parameter (A2) in the production function of the information technology sector (refer to appendix 4a for derivation). The latter change attempts to simulate the aggregate productivity change we observe from our firm level data.

The ‘Jorgenson effect’ aims to simulate changes that accompany greater absorption of information technology in the macro-economy as observed from the extensive data work on the US economy from 1959 to 1999 by Jorgenson. The aim is to see if these parametric changes can reproduce the actual data from the WDI on the Indian economy for the period 2001 to 2009 for which the baseline model undershoots. In order to understand the change that we instigate in our baseline economy, consider the following ratio:

$$\Re = \frac{\eta_1 p_a + \eta_3 p_m + \eta_2 p_{it}}{p_s}$$

Where $\Re$ represent the ratio of tradable versus non-tradable commodities or the real exchange rate. η_j stands for sector specific weights. In the baseline economy the $\sum\eta_j=1$ and the prices of all the tradables sums to one thus the real exchange rate is given by $1/p_s$. The transition dynamics (refer to the comparative static section for detailed discussion) shows that the price of the home good p_s rises towards its steady state value p_s^{ss}. This implies a real exchange rate appreciation thereby leading to a terms of trade effect which works against tradables and towards non tradables leading to an expansion of the services sector. This effect is very apparent in the baseline economy as the sector shares in GDP show the service sector expanding. The tradable sector that shrinks drastically is agriculture.

When we allow the price of information technology goods to fall the real exchange still appreciates but the effect is relatively muted. This can be seen as the price of information technology is lower hence its impact on the real exchange rate. The terms of trade effect against tradables is not as adverse as in our baseline economy. This can be seen in the expansion of services that occurs following our parametric changes i.e. Jorgenson effect which in relative comparison is muted in comparison to our baseline economy.

A validation exercise is carried out with our 'new' economy and we observe that the model still cannot predict the forward time series data for both the aggregate GDP and for the two sectors manufacturing and services i.e. for the time period 2001 to 2009. The parametric experiment still undershoots and cannot account for the acceleration in growth rate of the economy post 2001.

However the model both baseline and our parametric variation captures certain key features of the Indian economy. Data on the Indian economy suggests that services have emerged not just as the largest share of GDP but also the fastest growing sector of the Indian economy. Agriculture constitutes a declining share of GDP and constitutes the slowest growing sector of the Indian economy. The model both baseline and the parametric experiment captures both these effects. However given the difference in how the data is organized in the WDI and the GTAP the levels are not replicated.

We observe the share of services increasing and the share of agriculture falling but manufacturing still remains the dominant sector both in the output of the baseline and the parametric experiment. This is again replicated when we look at the growth accounting. The services sector shows an increasing contribution to GDP growth. Again manufacturing has the highest level of contribution albeit a decreasing contribution but services emerges as the sector with increasing levels of contribution to the growth of output. These two observations are replicated as the external TFP shock is varied from five, ten, fifteen and finally twenty percent (refer to Appendix 4b, 4c for results).

The role of information technology as an intermediate good is not able to explain the sharp rise in the GDP growth rate for the period 2001-2009. The parametric experiment is a better fit for the WDI time series data but still undershoots the actual growth trajectory. Hence though IT can explain some features of the data there are forces in the Indian economy that are not captured in our theoretical formulation which deserve attention and should be the focus of future research.

BIBLIOGRAPHY

1) Arora A., Klepper S. and Gambardella A. (2005) "Organizational Capabilities and the Rise of Software Industry in Emerging Economies: Lessons from the History of some US Industries.

2) Arora A., Gambardella A. "Bridging the Gap" in 'From Underdogs to Tigers: Software Industry in Brazil, China, India, Ireland and Israel.' (ed) Arora A., Gambardella A.

3) Arora, A. and Athreye, Suma (2002) "The Software Industry and India's Economic Development" *Information Economics and Policy,* 14(2), 253-273

4) Arora, A., Arunachalam, V. S. Asundi, J. Fernandes, R. (2001) "The Indian Software Services Industry" *Research Policy,* 30(8), 1267-1287.

5) Athreye, S. "The Indian Software Industry" in 'From Underdogs to Tigers: The Rise and Growth of the Software Industry in Brazil, China, India and Israel. ed. by Arora, Gambardella

6) Barro, Sala-I-Martin (1995) "Economic Growth" McGraw-Hill, Inc.

7) Bernard, Jensen, Kortum and Eaton (2003) "Plants and Productivity in International trade" AER 94(3) 2004.

8) Bhagwati (1993), "India In Transition: Freeing the Economy" Clarendon Press

9) Bhagwati, Panagariya and Srinivasan (1998) "Lectures in International Trade" MIT Press.

10) Brunner, H. P. (1995) "Closing the Technology Gap" Sage Publicatio

11) Chanda, Rupa (2002) "Globalization of Services: India's Opportunities

and Constraints” ICRIER, OUP Publication.

12) Eaton, Kortum, Kramarz “An Anatomy of International trade: Evidence from French Firms” (2005 Work in progress)

13) Heeks, Richard (1996) “India’s Software Industry: State Policy”

14) Jones, Charles (2008) “Intermediate Goods, Weak Links, and Superstars: A Theory of Development”

15) Jorgenson “Information Technology and World Growth Resurgence” German Economic Review 2007, pg. 125-145

16) Jorgenson and Stiroh “Information Technology and Growth” AER 1999

17) Jorgenson “Information Technology and the G7 Economies” World Economies, Vol.4, Oct-Dec 2004

18) Jorgenson “Accounting for Growth in the Information Age” Working papers 2000

19) Kenney, Martin “The Growth and Development of the Internet in the United States.” In the “Internet Economy”

20) Lateef, A. (1997) “Linking up with the Global Economy: A Case of the Bangalore Software Industry, New Industrial Organization Program, discussion paper/96/1997 ILO, Geneva.

21) Levinsohn and Petrin (1999), “When Industries become more Productive” (Mimeo, University of Michigan).

22) Markusen, Melvin, Kaempfer, Maskus (1995), “International Trade: Theory and Evidence” McGraw-Hill, Inc.

23) McLaren, John (2004) "Trade and Market Thickness: Effects on Organizations"

24) NASSCOM: Indian Information Technology Software and Service Directory 1992, 1994-95 to 2004.

25) Olley and Pakes (1996), "The Dynamics of Productivity in the Telecommunications." Econometrica1996.

26) Pavcnik, Nina (2005) "Trade Liberalization, Exit, and Productivity Improvement: Evidence from Chilean plants".

27) Roe, Terry (2010) "Multi-sector Growth Models: Theory and Applications"

28) Rothboeck S, Gayathri V, Vijaybhaskar M (2001)"Labor in the New Economy: Case of the Indian Software India in *The Indian Journal of Labor Economics*, Vol. 44, No. 1, 2001.

29) Ruttan, Vernon (2001), "Technology, Growth and Development: An Induced Innovation Perspective" OUP.

30) Saracoglu, Sirin (2007), "The Informal sector and tax on employment: A dynamic general equilibrium investigation" Journal of Economic Dynamics and Control.

31) Srinivasan, Bhagwati, Panagariya (2004) "Muddles Over Outsourcing" JEP

32) Stigler, George J, (1951) "The Division of Labor Is Limited by the End of the Market", Journal of Political Economy, No. 3, 185-194.

33) Subramanian, C.R. (1992) "India and the Computer: A Study of Planned Development, New Delhi, OUP.

34) World Trade Report 2005, Chapter 2 "Economics of Outsourcing"

35) World Investment Report 2004. “FDI in Services”

36) Zaheer, S. Rajan R. “Creativity under Constraint: Technological Imprinting and Migration of Indian Business to the New Economy” in the Internet Economy.

<u>Appendix Chapter 2</u>: <u>Growth and Productivity of Firms:</u> <u>Size and Growth Effects:</u>

Tables (NASSCOM DATASET, Deflated values of sales and total employment (1995 -2003)

Size (Revenue in rupees) Mean Growth of Revenues n=112 1995-96								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
No. of firms	**91**		**11**		**7**		**3**	
Age (year)	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**
0-5	6.25	27.09	0.181	1.331	-0.26	0.807	Nil	Nil
6-10	2.08	4.381	1.338	1.370	Nil	Nil	0.379	Nil
11-15	1.27	1.476	0.456	0.732	2.113	0.994	0.992	Nil
15 >	1.556	4.770	0.585	0.928	0.859	1.197	0.914	Nil
Total	**4.71**	**17.77**	**0.779**	**1.108**	0.904	**1.319**	**0.761**	**0.333**

Table 2.7, Source: NASSCOM Dataset

Size (Revenue in Rupees) Mean Growth of Revenues N=212 1996-97								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
N	**180**		**9**		**15**		**8**	
Age (yrs)	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**
0-5	1.793	5.586	1.066	1.398	0.367	0.323	Nil	Nil
6-10	4.543	21.692	0.097	0.092	0.177	0.374	Nil	Nil
11-15	0.562	1.350	0.1784	Nil	-0.050	0.646	nil	nil
15 >	0.242	1.048	nil	Nil	0.194	0.287	0.529	0.112
Total	**2.040**	**12.256**	**0.592**	**1.098**	**0.169**	**0.426**	**0.468**	**0.191**

Table 2.8, Source: NASSCOM Database

Size (Revenue in Rupees) Mean Growth of Revenues N=282 1997-98								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
N	**279**		**27**		**12**		**17**	
Age (year)	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std. Dev.**
0-5	5.657	41.122	0.347	0.205	0.215	0.228	0.72	0.522
6-10	0.545	1.225	0.419	0.512	0.093	0.178	0.33	0.266
11-15	0.878	4.186	0.062	0.150	0.208	Nil	0.73	Nil
15 >	0.925	2.61	0.163	0.143	0.051	Nil	0.26	0.217
Total	**4.499**	**30.9**	**0.322**	**0.395**	**0.144**	**0.182**	**0.39**	**0.336**

Table 2.9, Source: NASSCOM Database

Size (Revenue in Rupees) Mean Growth of Revenues N=335 1998-99								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
N	**219**		**22**		**16**		**25**	
Age (years)	**Avg.**	**Std. Dev.**	**Avg.**	**Std. Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**
0-5	10.791	61.25	0.155	0.380	0.315	0.997	6.897	14.455
6-10	0.925	2.569	-0.074	0.318	0.359	0.664	0.390	1.117
11-15	0.589	1.149	0.295	0.226	-0.177	Nil	0.489	0.204
15 >	5.219	12.38	0.353	0.391	0.098	0.406	0.628	0.778
Total	**6.419**	**44.79**	**0.144**	**0.35**	**0.266**	**0.671**	**1.580**	**5.483**

Table 2.10, Source: NASSCOM Dataset

Size (Revenue in Rupees) Mean Growth of Revenues N=357 1999-2000								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
N	**275**		**33**		**16**		**33**	
Age (years)	**Avg.**	**Std. Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std. Dev.**	**Avg.**	**Std Dev.**
0-5	5.239	20.858	0.194	0.480	0.098	0.648	0.200	0.515
6-10	1.793	6.047	0.225	0.735	1.767	1.592	0.642	0.537
11-15	0.699	1.839	0.296	0.581	0.478	0.309	0.352	0.556
15 >	0.627	1.283	0.600	0.918	0.305	0.267	0.494	0.464
Total	**4.660**	**16.458**	**0.255**	**0.585**	**0.660**	**1.088**	**0.486**	**0.514**

Table 2.11, Source: NASSCOM Dataset

Size (Revenue in rupees) Mean Growth of Revenues N=336 2000-01								
	0-250mn		**250-500mn**		**500-1000mn**		**1000mn >**	
Number of Firms	**237**		**35**		**21**		**43**	
Age (years)	**Avg.**	**Std. Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std. Dev.**	**Avg.**	**Std. Dev.**
0-5	14.80	120.3	0.1010	0.353	0.31	0.21	-0.26	0.44
6-10	0.631	4.340	-0.025	0.429	-0.15	0.33	0.13	0.45
11-15	1.017	4.944	0.214	0.628	-0.16	0.20	0.73	2.07
15 >	0.732	2.733	0.372	0.288	-0.33	0.11	0.08	0.28
Total	**7.847**	**86.65**	**0.078**	**0.446**	**-0.06**	**0.32**	**0.23**	**1.13**

Table 2.12, Source: NASSCOM Database

Size (Number of Workers) Mean Growth in Employment 1996-97								
	0-250		**250-500**		**500-1000**		**1000>**	
Age (years)	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**
0-5	0.602	0.946	0.247	0.720	0.364	0.418	0.575	0.481
6-10	0.652	2.707	0.443	0.626	0.530	0.377	-0.099	0.081
11-15	0.355	0.746	0.062	0.561	0.154	0.084	0.261	0.422
15>	-0.0004	0.453	-0.143	0.376	0.061	0.667	0.175	0.231
Total	**0.558**	**1.189**	**0.208**	**0.628**	**0.302**	**0.499**	**0.178**	**0.268**

Table 2.13, Source: NASSCOM Datase

Size (Number of Workers) Mean Growth in Employment 1998-99								
	0-250		**250-500**		**500-1000**		**1000>**	
N=287	**n =201**		**n=40**		**n=19**		**n=27**	
Age (years)	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**	**Avg.**	**Std Dev.**
0-5	0.678	1.608	0.346	0.631	Nil	Nil	0.221	0.249
6-10	0.522	1.146	0.349	0.386	0.1426	0.462	0.008	0.289
11-15	0.344	0.559	0.255	0.525	-0.01	0.183	0.254	0.503
15>	1.409	4.071	0.076	0.478	0.268	0.267	0.122	0.378
Total	**0.636**	**1.726**	**0.301**	**0.487**	**0.128**	**0.365**	**0.132**	**0.357**

Table 2.14, Source: NASSCOM Database

Size (Number of Workers) Mean Growth in Employment 2000-01								
	0-250		250-500		500-1000		1000>	
N=369	n =245		n=55		n=28		n=41	
Age (years)	Avg.	Std Dev.	Avg.	Std Dev.	Avg.	Std Dev.	Avg.	Std Dev.
0-5	0.091	0.428	-0.159	0.486	0.035	0.318	0.061	0.213
6-10	-0.108	0.585	-0.447	0.211	0.076	1.166	0.032	0.144
11-15	-0.306	0.527	-0.008	0.427	-0.136	0.276	0.081	0.218
15>	0.125	0.292	0.090	0.350	-0.265	0.376	0.004	0.326
Total	**0.017**	**0.484**	**-0.232**	**0.364**	**-0.013**	**0.800**	**0.035**	**0.235**

Table 2.15, Source: NASSCOM Dataset

Appendix Chapter 4a.

FIRM'S COST MINIMIZATION PROBLEM

In solving the firm's problem with a Cobb Douglas production function we determine the unit cost function and the conditional factor demands. In the process we determine scale parameters a1,a2,a3. To induce TFP shock in our model we use increments on these parameters. The following exercise is carried out for the manufacturing and services sectors or j=3,4 where IT is used an an input.

$$MinC(w, r_k, p_{it}) = wL + r_k K + p_{it} Y_{it}$$
$$s.t. Y \leq AK^{\alpha 1}(L)^{\alpha 2}(Y_{it})^{\alpha 3}; \sum_i \alpha i = 1$$

Constructing the Lagrange for the above problem we have

$$\Psi(w, r_k, p_{it}) = wL + r^k K + p_{it} Y_{it} + \lambda[Y - AK^{\alpha 1}(L)^{\alpha 2}(Y_{it})^{\alpha 3}]$$

From the above f.o.c. we obtain the following:

$$\frac{w}{r^k} = \frac{\alpha_2}{\alpha_1}\frac{K}{L}$$
$$\frac{r^k}{p_{it}} = \frac{\alpha_1}{\alpha_3}\frac{y_{it}}{K}$$
$$\frac{w}{p_{it}} = \frac{\alpha_2}{\alpha_3}\frac{y_{it}}{L}$$

Substituting the above conditions we obtain the following:

$$L = \frac{r^k}{w}\frac{\alpha_2}{\alpha_1}K, y_{it} = \frac{r^k}{p_{it}}\frac{\alpha_4}{\alpha_1}K$$
$$Y = AK^{\alpha 1}(\frac{r^k}{w}\frac{\alpha_2}{\alpha_1}K)^{\alpha_2}(\frac{r^k}{p_{it}}\frac{\alpha_4}{\alpha_1}K)^{\alpha 3}$$

$$K^* = (\frac{Y}{A})\frac{\alpha_1^{(\alpha 2+\alpha 3)}}{r^{k(\alpha 2+\alpha 3)}}\frac{w^{\alpha 2}p_{it}^{\alpha 3}}{\alpha_1^{\alpha 1}\alpha_2^{\alpha 2}\alpha_3^{\alpha 3}}$$

Similar substitutions yield the following for equilibrium levels of inputs

$$L^* = (\frac{Y}{A})\frac{\alpha_2^{(\alpha 1+\alpha 3)}}{w^{(\alpha 1+\alpha 3)}}\frac{r^{k\,\alpha 1} p_{it}^{\ \alpha 3}}{\alpha_1^{\ \alpha 1}\alpha_3^{\ \alpha 3}}$$

$$K^* = (\frac{Y}{A})\frac{\alpha_1^{(\alpha 2+\alpha 3)}}{r^{k(\alpha 2+\alpha 3)}}\frac{w^{\alpha 2} p_{it}^{\ \alpha 3}}{\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3}}$$

$$y_{it}^{\ *} = (\frac{Y}{A})\frac{\alpha_3^{(\alpha 1+\alpha 2)}}{p_{it}^{\ (\alpha 1+\alpha 2)}}\frac{r^{k\,\alpha 1} w^{\alpha 2}}{\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}}$$

Substituting into the total cost function we obtain the following:

$$C^*(w, r^k, p_{it}, Y) = wL^* + r^k K^* + p_{it} Y^*{}_{it}$$

$$= (\frac{Y}{A})\frac{r^{k\,\alpha 1} w^{\alpha 2} p_{it}^{\ \alpha 3}}{\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3}}$$

$$c(w, r^k, p_{it}) = \frac{C^*(w, r^k, p_{it})}{Y} = \frac{r^{k\,\alpha 1} w^{\alpha 2} p_{it}^{\ \alpha 3}}{A\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3}}$$

From Shephards Lemma I derive the conditional factor demands :

$$l^*(w, r^k, p_{it}) = \frac{\partial C(w, r^k, p_{it})}{\partial w} = \frac{\alpha_2 r^{k\,\alpha 1} w^{\alpha 2-1} p_{it}^{\ \alpha 3}}{A\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3}}$$

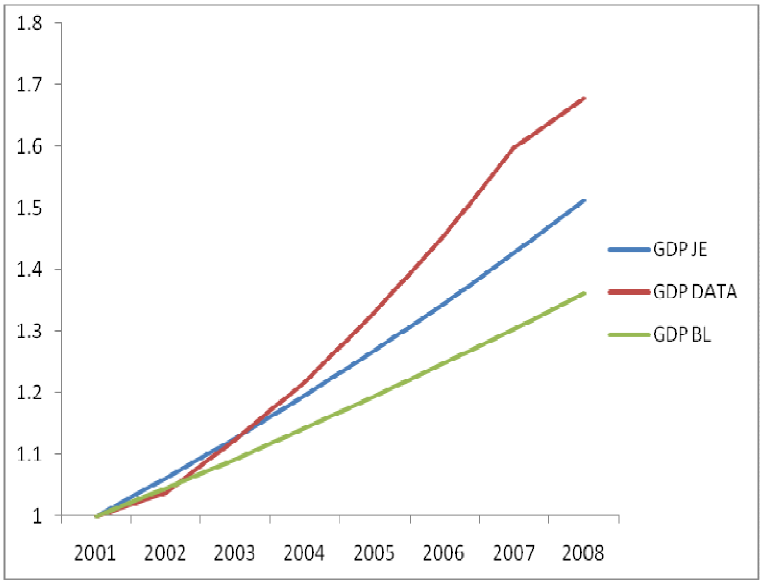
$$a\mathbf{1} = A\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3};$$

$$k^*(w, r^k, p_{it}) = \frac{\partial C(w, r^k, p_{it})}{\partial r^k} = \frac{\alpha_1 r^{k\,\alpha 1-1} w^{\alpha 2} p_{it}^{\ \alpha 3}}{A\alpha_1^{\ \alpha 1}\alpha_2^{\ \alpha 2}\alpha_3^{\ \alpha 3}} = \frac{\alpha_1 r^{k\,\alpha 1-1} w^{\alpha 2} p_{it}^{\ \alpha 3}}{a\mathbf{1}}$$

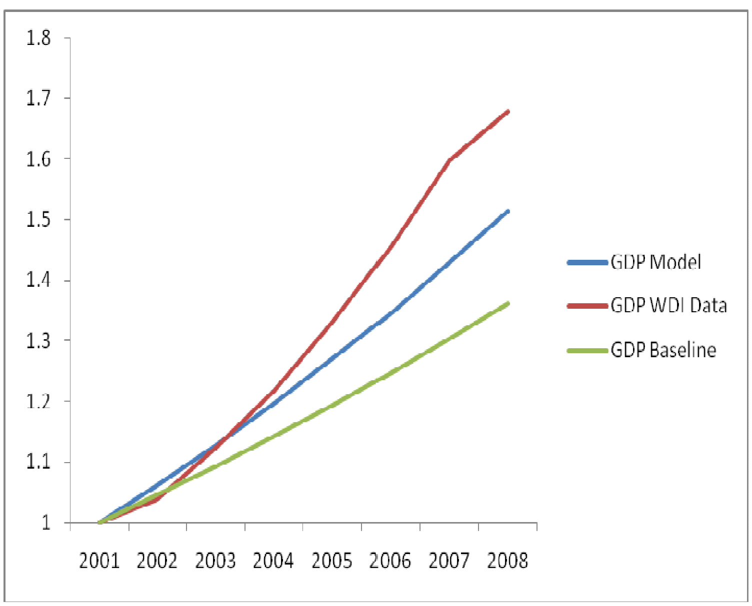
$$y^*{}_{it}(w, r^k, p_{it}) = \frac{\partial C(w, r^k, p_{it})}{\partial\ p_{it}} = \frac{\alpha_3 r^{k\,\alpha 1} w^{\alpha 2} p_{it}^{\ \alpha 3-1}}{a\mathbf{1}}$$

<u>Appendix Chapter 4b</u>: Validation of GDP

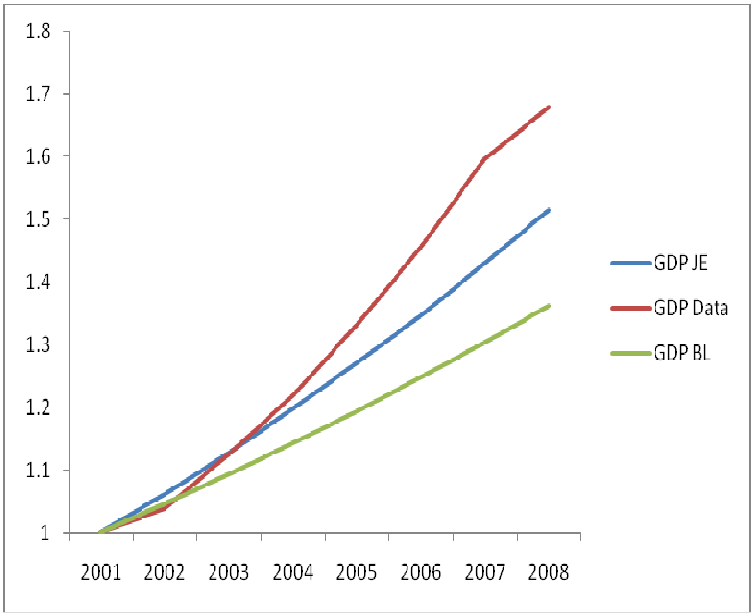
1) TFP Shock : 1.05* A2



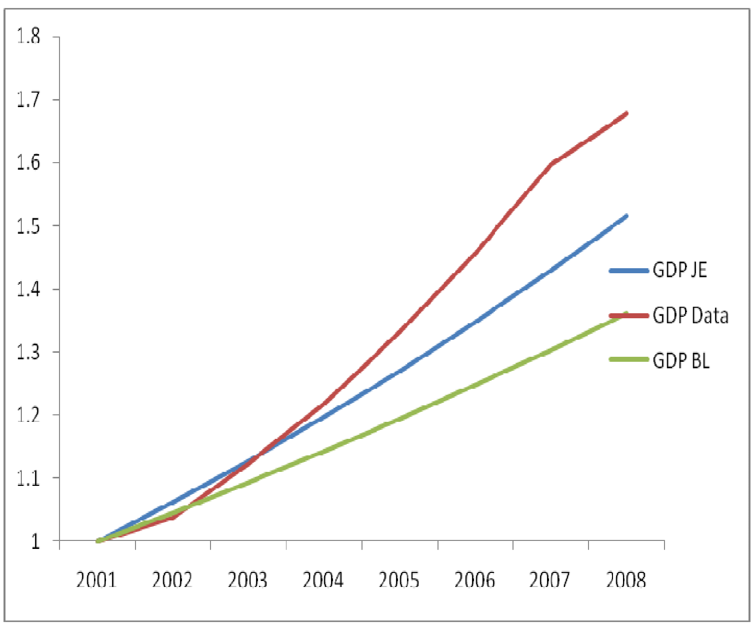
2) TFP Shock : 1.1*A2



3) TFP Shock: 1.15*A2

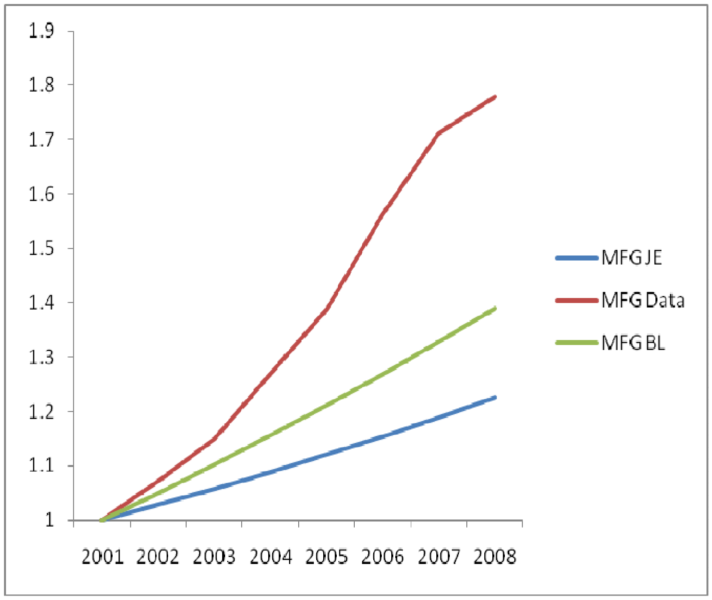


4) TFP Shock: 1.20*A2

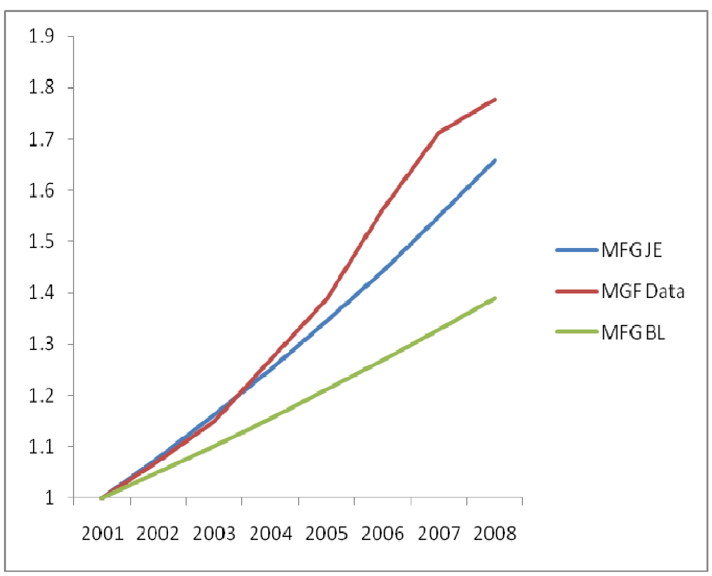


Validation of Manufacturing Sector

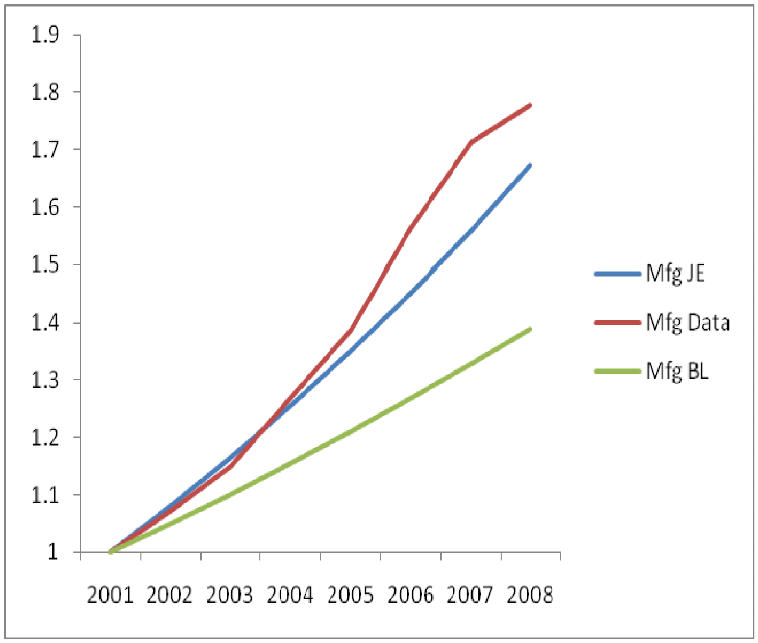
1) TFP Shock 1.05*A2



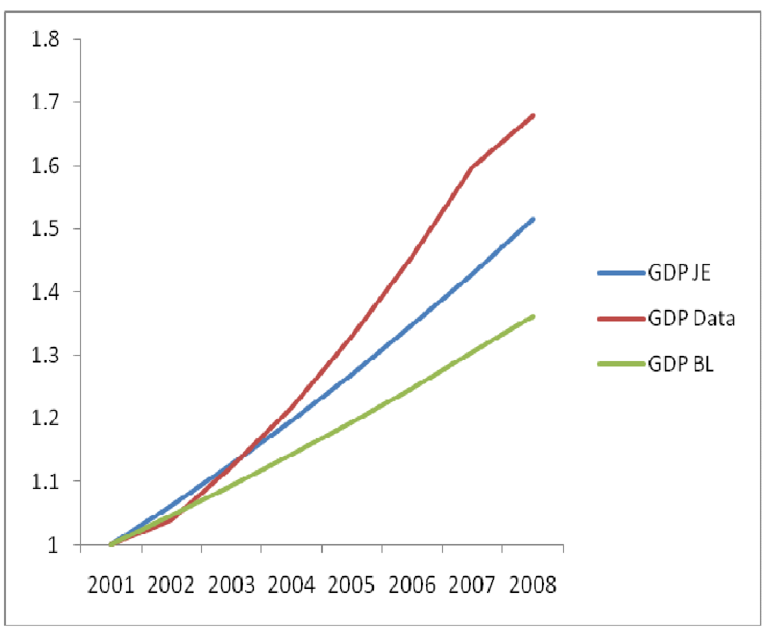
2) TFP Shock 1.1*A2



3) TFP Shock 1.15*A2

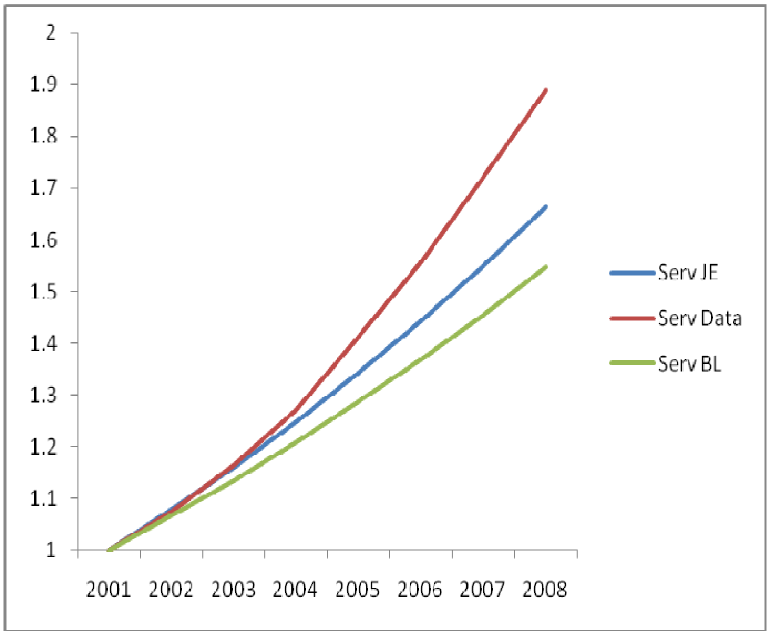


4) TFP Shock 1.20*A2

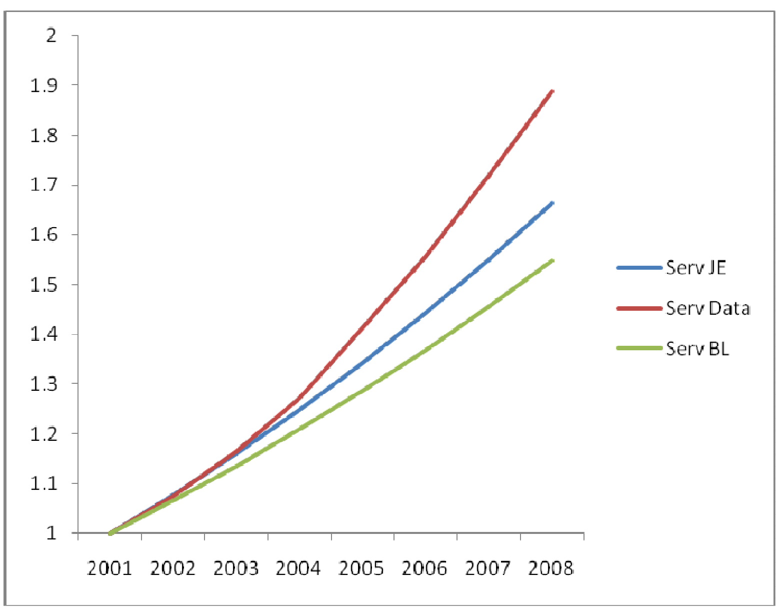


Validation of Services

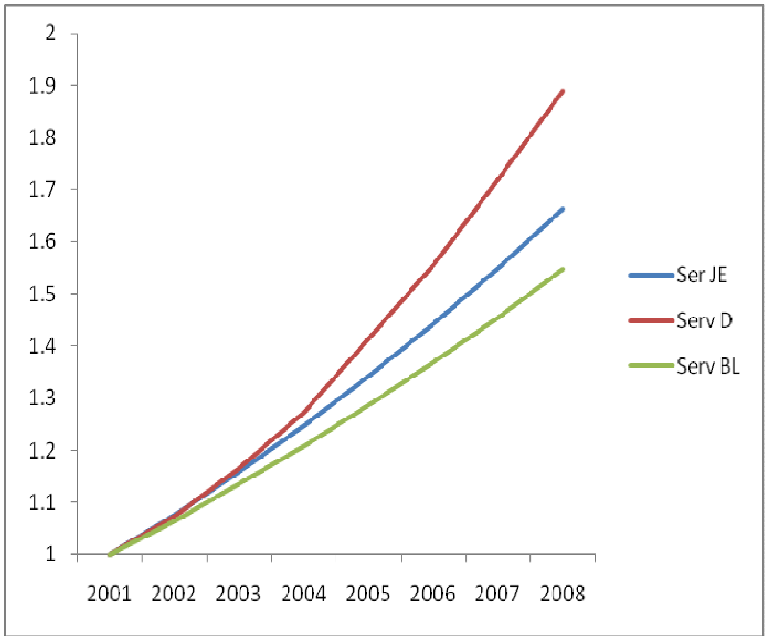
1) TFP Shock 1.05*A2



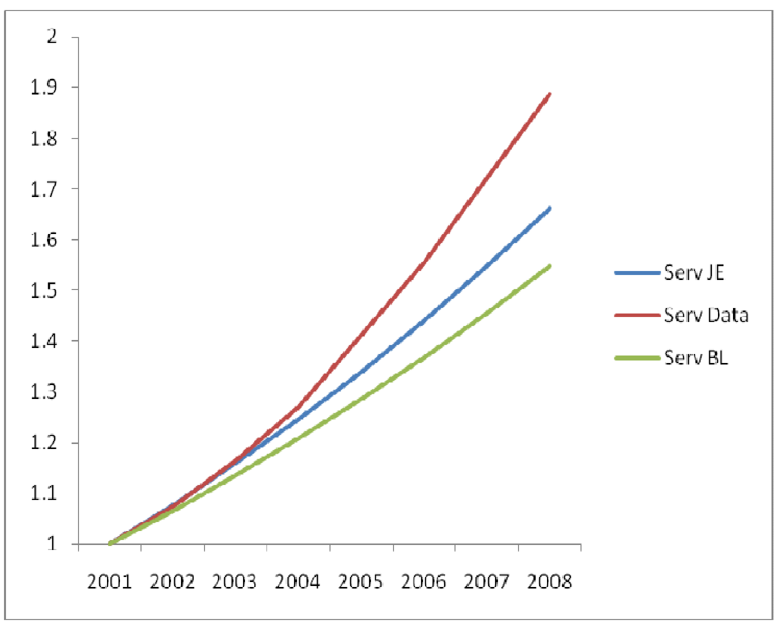
2) TFP Shock 1.1*A2



3) TFP Shock 1.15*A2



4) TFP Shock 1.2*A2



Sector Shares of GDP

Year	Agr/GDP	IT/GDP	Mfg/GDP	Ser/GDP
1991	0.417166	0.055568	0.381911	0.091811
2001	0.320567	0.038671	0.47975	0.107802
2011	0.25952	0.02888	0.534917	0.123101
2021	0.218886	0.022772	0.566911	0.137395
2031	0.190331	0.018735	0.585582	0.150529
2041	0.169602	0.015943	0.596301	0.162444
2051	0.154123	0.01394	0.602161	0.173144
2061	0.142296	0.012461	0.605023	0.182674
2071	0.133092	0.011343	0.606039	0.191107
2081	0.125819	0.01048	0.605937	0.198528
2091	0.12	0.009803	0.605181	0.205029

Table A4.1 Sectoral Shares of Output (TFP Shock 1.05*A2)

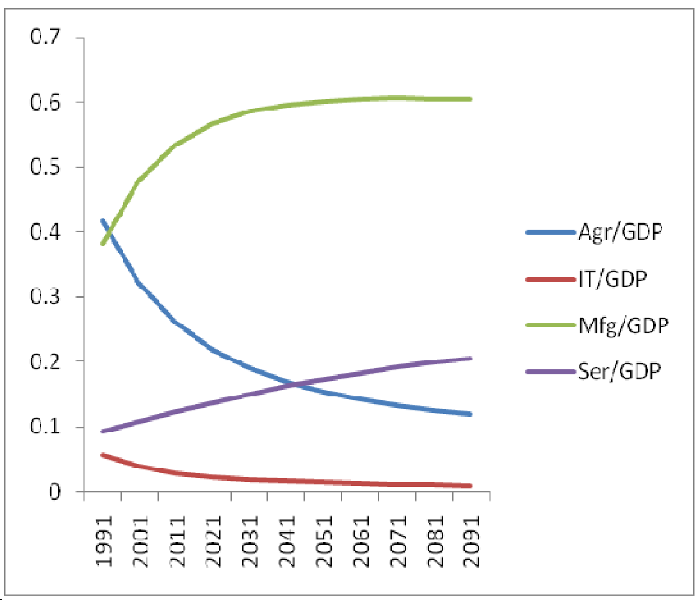


Fig A4.1 Sectoral Shares of Output (TFP Shock 1.05*A2)

Growth Accounting

Year	Agr	IT	Mfg	Serv
1991	0.0144	0.0013	0.0375	0.0075
2001	0.0118	0.0011	0.0361	0.0081
2011	0.0100	0.0009	0.0348	0.0085
2021	0.0087	0.0008	0.0337	0.0090
2031	0.0078	0.0007	0.0328	0.0093
2041	0.0071	0.0006	0.0320	0.0096
2051	0.0066	0.0005	0.0313	0.0099
2061	0.0062	0.0005	0.0308	0.0101
2071	0.0058	0.0005	0.0303	0.0103

Table A4.2 Growth Accounting TFP Shock 1.05*A2

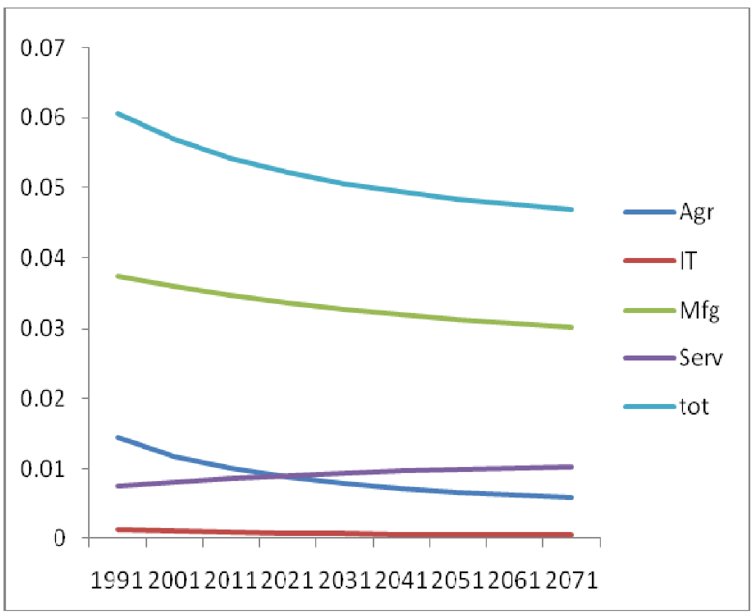


Fig A4.2 Growth Accounting TFP Shock 1.05*A2

Sector Shares of GDP

Year	Agr	IT	Mfg	Serv
1991	0.4169	0.0731	0.3850	0.0693
2001	0.3201	0.0509	0.4926	0.0812
2011	0.2589	0.0380	0.5552	0.0927
2021	0.2180	0.0299	0.5932	0.1033
2031	0.1893	0.0246	0.6169	0.1132
2041	0.1685	0.0209	0.6318	0.1221
2051	0.1530	0.0182	0.6414	0.1300
2061	0.1411	0.0163	0.6474	0.1372
2071	0.1319	0.0148	0.6512	0.1435
2081	0.1245	0.0137	0.6535	0.1490

Table A4.3 Sector shares with TFP Shock 1.1*A2

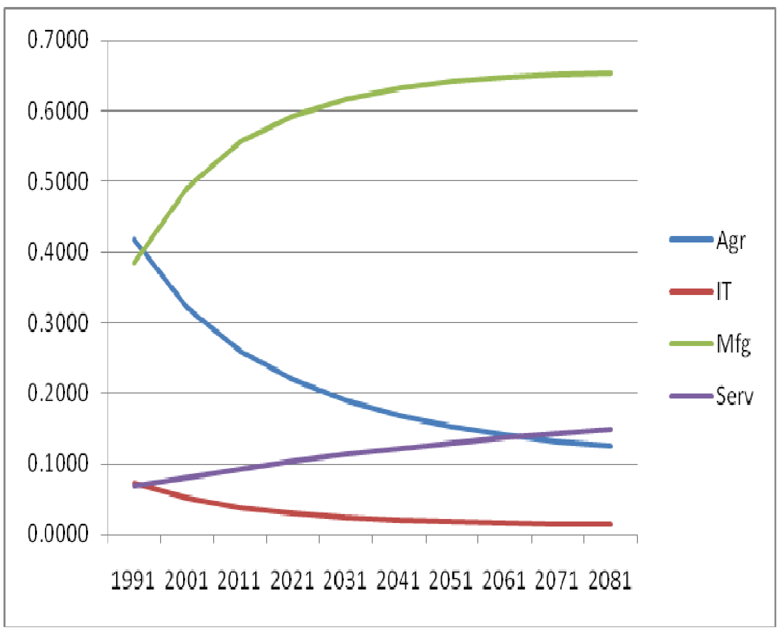


Table A4.3 Sector shares in GDP TFP 1.1*A2

Growth Accounting

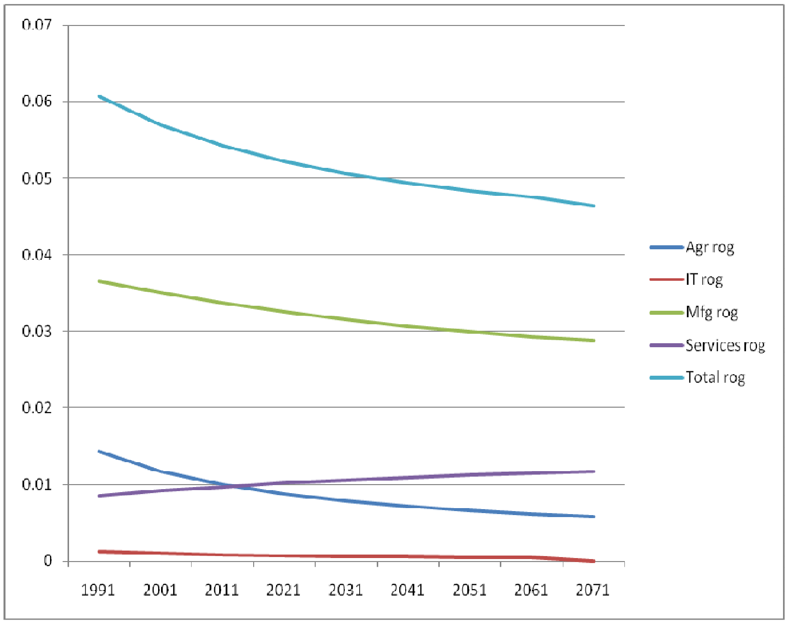


Fig. A4.4 Growth Accounting TFP shock 1.1*A2

Year	Agr.	IT	Mfg	Services
1991	0.0144	0.0012	0.0366	0.0085
2001	0.0118	0.0010	0.0350	0.0092
2011	0.0100	0.0008	0.0337	0.0097
2021	0.0087	0.0007	0.0325	0.0102
2031	0.0078	0.0006	0.0315	0.0106
2041	0.0071	0.0006	0.0307	0.0110
2051	0.0066	0.0005	0.0300	0.0113
2061	0.0062	0.0005	0.0293	0.0115
2071	0.0059	0.0000	0.0288	0.0118

Table A4.4 Growth Accounting TFP shock 1.1*A2

Sector Shares of GDP

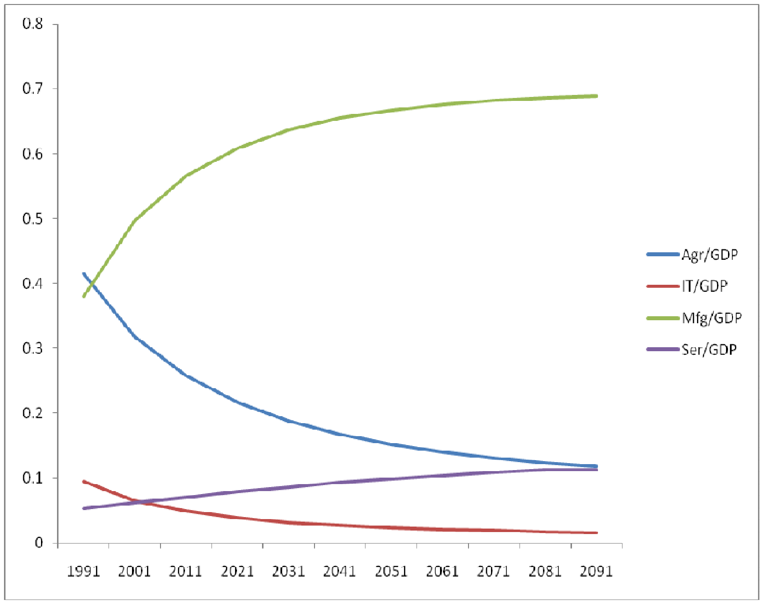


Fig.A4.5 Sectoral Shares in Output TFP Shock 1.15*A2

Year	Agr/GDP	IT/GDP	Mfg/GDP	Ser/GDP
1991	0.4146	0.0943	0.3805	0.0533
2001	0.3186	0.0658	0.4967	0.0623
2011	0.2578	0.0491	0.5656	0.0709
2021	0.2170	0.0387	0.6086	0.0790
2031	0.1884	0.0318	0.6363	0.0865
2041	0.1676	0.0270	0.6547	0.0932
2051	0.1520	0.0236	0.6672	0.0993
2061	0.1402	0.0211	0.6757	0.1047
2071	0.1309	0.0192	0.6816	0.1094

Table A4.5 Sectoral shares in GDP TFP Shock 1.15*A2

Growth Accounting

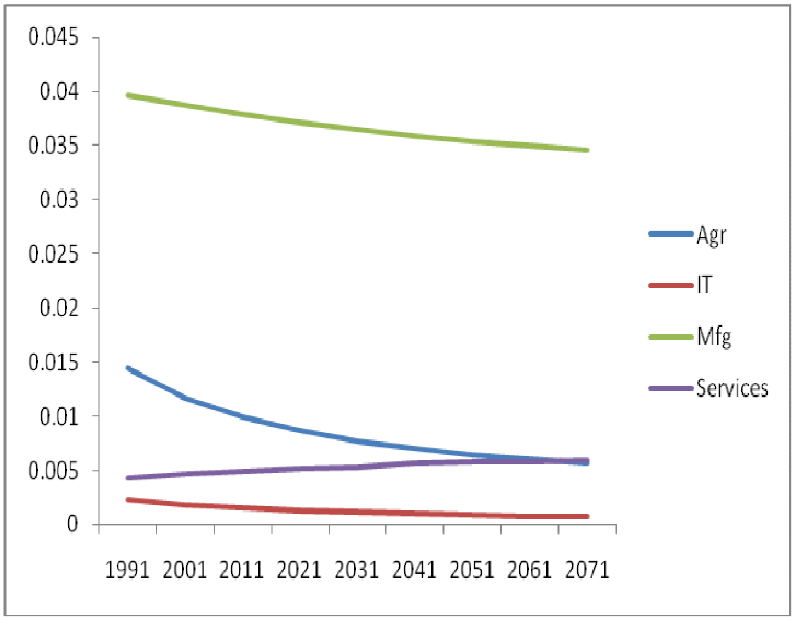


Fig. A4.6 Growth accounting TFP=1.15*A2

Year	Agr	IT	Mfg	Services
1991	0.0144	0.0023	0.0396	0.0043
2001	0.0117	0.0018	0.0388	0.0047
2011	0.0099	0.0015	0.0379	0.0049
2021	0.0087	0.0013	0.0372	0.0052
2031	0.0077	0.0011	0.0365	0.0054
2041	0.0070	0.0010	0.0359	0.0057
2051	0.0065	0.0009	0.0354	0.0058
2061	0.0061	0.0008	0.0350	0.0058
2071	0.0057	0.0008	0.0346	0.0059

Table A4.6 Growth Accounting TFP=1.15*A2

Sector Shares of GDP

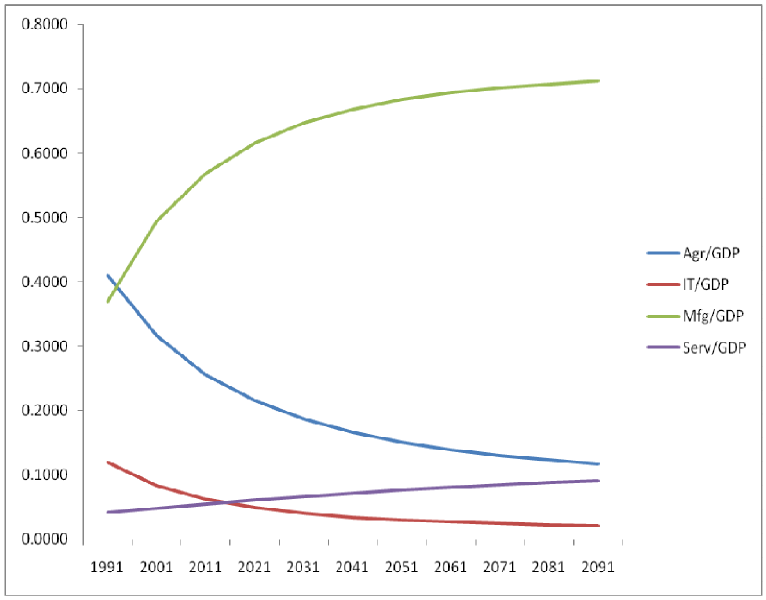


Fig. A4.7 Sectoral Shares with TFP Shock=1.2*A2

Year	Agr/GDP	IT/GDP	Mfg/GDP	Serv/GDP
1991	0.4106	0.1195	0.3697	0.0416
2001	0.3162	0.0837	0.4937	0.0485
2011	0.2562	0.0627	0.5684	0.0551
2021	0.2158	0.0495	0.6158	0.0613
2031	0.1874	0.0407	0.6471	0.0670
2041	0.1667	0.0346	0.6684	0.0722
2051	0.1513	0.0302	0.6833	0.0769
2061	0.1394	0.0270	0.6939	0.0810
2071	0.1302	0.0245	0.7016	0.0847
2081	0.1229	0.0226	0.7072	0.0879
2091	0.1171	0.0211	0.7115	0.0907

Table A4.7 Sectoral Shares with TFP Shock=1.2*A2

<u>**Growth Accounting**</u>

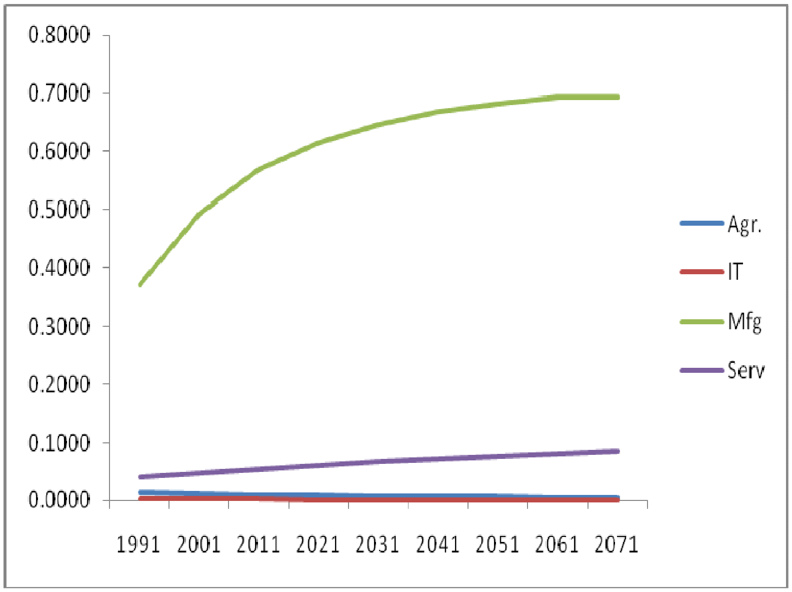


Fig. A4.8 Growth Accounting TFP Shock=1.2*A2

Year	Agr.	IT	Mfg.	Serv.
1991	0.0144	0.0029	0.3697	0.0416
2001	0.0117	0.0024	0.4937	0.0485
2011	0.0099	0.0020	0.5684	0.0551
2021	0.0086	0.0017	0.6158	0.0613
2031	0.0077	0.0015	0.6471	0.0670
2041	0.0070	0.0013	0.6684	0.0722
2051	0.0065	0.0012	0.6833	0.0769
2061	0.0060	0.0011	0.6939	0.0810
2071	0.0057	0.0010	0.6939	0.0847

Table A4.8 Growth Accounting TFP =1.2*A2

Appendix Chapter 4c: Computer Code (Mathematica)

```
(*TT is the length of time over which the model has to be solved,
j=1=Agr.,2=IT.,3=Mfg, 4=Services
mn=number used to normalize data,
T=land normalized to unity,
Q=Stock of knowledge, fixed factor in IT
LL=no of workers given by data,
p1=boarder price of sector 2, price of sector 1 numeraire,
aπ= total land rent,
KK=Stock of capital from Growth Accounting,
k0 is initial capital stock typically set equal to KK,
C (j)=consumption in t (0), (i.e. value of consumption),
L (j)=labor in t (0)(i.e. value of labor services),
K (j)=capital in t (0) (i.e. value of capital services),
Y (j)=output in t (0) (i.e. value of output),
ρ,x,n,δd=rate of time discount, Harrod rate of exogenous technical change, rate of growth
of the workforce, depreciation, respectively,
rk=r+δd*)
TT=100;
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
{T=1,p3=1,θ=1,ρ=0.035, x=0.0225, n=0.024,δd=0.01, TM=100, mn=1000 (* With mn =
1000 means that variables are in billions of $ *)};
{C1=102248.2032/mn,C2=0,C3=63710.46143/mn,C4=237584.9701/mn,sav=42372.5469
1/mn}//N
{102.248,0.,64.7105,237.584,42.3725}
{LL=400362025,L1=48739.05225/mn,L2=5406.222/mn,L3=31851.55322/
mn,L4=117918.1992/mn,aπ=44887.64844/mn,Q=1254.178/mn}//N
{4.00362×10^8,48.7391,5.40622,31.8516,117.918,44.8876,1.25318}
{K1=24897.16992/mn,K2=3430.6/mn,K3=49568.73047/mn,K4=117962.8281/mn(*
KK=(4.92×(10^13)*0.05)/mn*) }//N(*Payment on capital services*)
{24.8972,4.4306,49.5687,117.963}
{IT1=0/mn,IT2=0/mn,IT3=836.0471962/mn,IT4=1702.942804/mn,IT=IT3+IT4}//N
{0.,0.,0.836047,1.70294,2.53899}
GDP=L1+L2+L3+L4+K1+K2+K3+K4+aπ+Q
445.915
MatrixForm[{{i11=0,i12=0,i13=0,i14=0},
{i21=0,i22=0,i23=0,i24=0},{i31=0,i32=0,i33=0,i34=0},{i41=0,i42=0,i43=0,i44=0}}]//N
(\[NoBreak]{
 {0., 0., 0., 0.},
 {0., 0., 0., 0.},
{0., 0., 0., 0.},
{0., 0., 0., 0.}
 }\[NoBreak])
{Y1=L1+K1+aπ+i11+i21+i31+i41,Y2=L2+K2+IT2+i12+i22+i32+i42+Q,Y3=L3+K3+I
T3+i13+i23+i33+i43,Y4=L4+K4+IT4+i14+i24+i34+i44}//N
{118.524,10.09,82.2563,237.584}
MatrixForm[{{ai11=i11/Y1,ai12=i12/Y2,ai13=i13/Y3,ai14=i14/Y4},{ai21=i21/Y1,ai22=
i22/Y2,ai23=i23/Y3,ai24=i24/Y4},{ai31=i31/Y1,ai32=i32/Y2,
ai33=i33/Y3,ai34=i34/Y4},{ai41=i41/Y1,ai42=i42/Y2,ai43=i43/Y3,ai44=i44/Y4}}]//N
(\[NoBreak]{
{0., 0., 0., 0.},
```

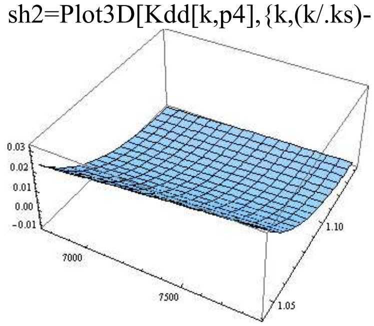
```
{0., 0., 0., 0.},
{0., 0., 0., 0.},
 {0., 0., 0., 0.}
 }\[NoBreak])
{Y3-(ai13 Y3+ai23 Y3+ai33 Y3+ai43 Y3)-L3-K3-IT3,(Y3-i13-i23-i33-i43)-L3-K3-IT3}//N
{0.,0.}
{Y1-(ai11 Y1 +ai21 Y1+ai31 Y1+ai41 Y1),(Y1-i11-i21-i31-i41), L1+K1+aπ}
//N(*check*)
{118.524,118.524,118.524}
{K=(K1+K2+K3+K4),L=L1+L2+L3+L4,IT=IT1+IT2+IT3+IT4}
{195.859,204.915,2.53899}
{R=(K/(KK*.7)),ρ+x+δd}
{0.124571,0.0675}
ρ+θ x+δd
0.0675
R=.07725(* .077 SUPPOSE ASSUMPTION *)
0.07725
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
R=0.0872(* THIS IS ABOUT AS LARGE AS YOU CAN MAKE R *)
0.0872
KK=K/R;
k0=KK
2246.09
{CC=C1+C3+C4,λ2=0,λ1=C1/CC,λ3=C3/CC ,λ4=1-λ1-λ2-λ3}(* C2 λ2=C2/CC cut these because there is no C2 in consumption *)
{404.543,0,0.253376,0.157878,0.588746}
{β1=L1/(Y1-i11-i21-i31-i41),β2=K1/(Y1-i11-i21-i31-i41),β3=(1-β1-β2)}
{0.411217,0.21006,0.378722}
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
{α1=L2/(Y2-i12-i22-i32-i42),α2=K2*1.1/(Y2-i12-i22-i32-i42),α3=(1-α1-α2)}
{0.5358,0.374,0.0902}
{α1=L2*0.85/(Y2-i12-i22-i32-i42),α2=K2*1.105/(Y2-i12-i22-i32-i42),α3=(1-α1-α2)}
{0.45543,0.3757,0.16887}
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
{δ1=L3/(Y3-i13-i23-i33-i43),δ2=K3/(Y3-i13-i23-i33-i43),δ3=(1-δ1-δ2)}
{0.387223,0.602613,0.0101639}
{δ1=L3*.89/(Y3-i13-i23-i33-i43),δ2=K3*1.075/(Y3-i13-i23-i33-i43),δ3=(1-δ1-δ2)}
{0.344629,0.647809,0.0075625}
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
{ζ1=L4/(Y4-i14-i24-i34-i44),ζ2=K4/(Y4-i14-i24-i34-i44),ζ3=(1-ζ1-ζ2)}//N
{0.496322,0.49651,0.00716775}
{ζ1=L4*.89/(Y4-i14-i24-i34-i44),ζ2=K4*1.12/(Y4-i14-i24-i34-i44),ζ3=(1-ζ1-ζ2)}//N
{0.441727,0.556091,0.00218199}
{A1=Y1/((L1/L)^β1 (K1/R)^β2 T^β3),A2=Y2/((L2/L)^α1 (K2/R)^α2 ((1)^α3)),A3=(Y3)/((L3/L)^δ1 (K3/R)^δ2 (IT3)^δ3),A4=Y4/((L4/L)^ζ1 (K4/R)^ζ2 (IT4)^ζ3)}
{65.0992,14.2652,2.56522,5.48449}
Q
1.25318
((L2/L)^α1 (K2/R)^α2)A2-Y2
0.
(* roe *)
{a1=A1 (β1^β1)(β2^β2)(β3^β3),a2=A2 (α1^α1)(α2^α2)(α3^α3),a3=A3 (δ1^δ1)(δ2^δ2)(δ3^δ3)*.95,a4=A4 (ζ1^ζ1)(ζ2^ζ2)(ζ3^ζ3)}
{22.5334,4.75308,1.22805,2.72184}
```

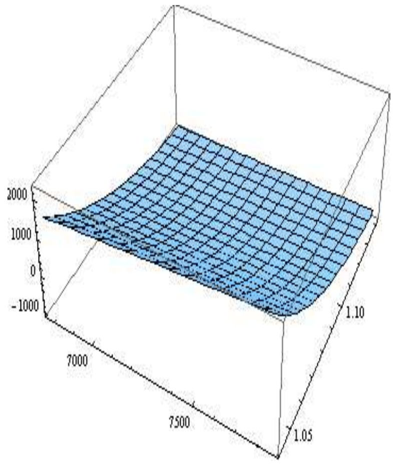
pf[p1_,w_,rk_]=(a1)$^{1/\beta3}$ (p1)$^{1/\beta3}$ (w)$^{-\beta1/\beta3}$ (rk)$^{-\beta2/\beta3}$ T;
ysa[p1_,w_,rk_]=(1/β3) (a1)$^{((1/\beta3))}$ (p1)$^{(1/\beta3)-1}$ (w)$^{-\beta1/\beta3}$ (rk)$^{-\beta2/\beta3}$ T;
lsa[p1_,w_,rk_]=-∂_{w} **pf[p1, w, rk]**;
ksa[p1_,w_,rk_]=-∂_{rk} **pf[p1, w, rk]**;
{p3=1.07,p1=1.07,p2=1.07}(* ## *)
{1.07,1.07,1.07}
{p3=1.07,p1=1.07,p2=1.01}(* ## *)
{1.07,1.07,1.01}
{ysa[1,L,R]-Y1,lsa[1,L,R]-L1/L}
{1.56319×10^{-13},6.10623×10^{-16}}
P3[pp4_]=p3-p3 ai13-p2 ai23-pp4 ai33
pa[pp4_]=p1-p1 ai21-p1 ai11-pp4 ai31
P4[pp4_]=pp4-pp4 ai34-p3 ai14-p1 ai24
1.07
1.07
pp4
p22[pp4_]=p2-p2 ai22-p3 ai32-pp4 ai42
1.01
p22[pp4_]=p2-p2 ai22-p3 ai32-pp4 ai42
1.01
{pf[1,L,R]-aπ}//N
{4.26326×10^{-14}}
(*2 Eqts necessary for obtaining the steady state*)
(*2.1 From zero profit conditions rental rates as a function of home good price p4*)
Clear[p2]
Cm[w_,rk_,p2_]=1/a3 w$^{\delta1}$ rk$^{\delta2}$ p2$^{\delta3}$
Cs[w_,rk_,p2_]=1/a4 w$^{\zeta1}$ rk$^{\zeta2}$ p2$^{\zeta3}$
0.814297 p2$^{0.0075625}$ rk$^{0.647809}$ w$^{0.344629}$
0.367398 p2$^{0.00218199}$ rk$^{0.556091}$ w$^{0.441727}$
{Cm[L,R,1],Cs[L,R,1]}(* marginal cost should equal output price from zero profit conditions *)
{1.04795,0.99109}
sy=Solve[Cm[w,rk,p2]==p3,rk]
Solve::ifun: Inverse functions are being used by \[NoBreak]Solve\[NoBreak], so some solutions may not be found; use Reduce for complete solution information. □
{{rk→1.52433 (1/(p2^0.0075625 w^0.344629))$^{1.543665056133560}$}}
rr[p2_,w_]=(rk/.sy)[[1]];
sw=Solve[Cs[w,rr[p2,w],p2]-p4==0,w]
Solve::ifun: Inverse functions are being used by \[NoBreak]Solve\[NoBreak], so some solutions may not be found; use Reduce for complete solution information. □
{{w→191.819 (p2^0.0043098 p4)$^{6.85442460549955}$}}
ww[p2_,p4_]=(w/.sw)[[1]]
191.819 (p2^0.0043098 p4)$^{6.85442460549955}$
204.91502667` (p2^0.0012065974051975294` p4)$^{5.640857939538017600250808760840`15.040843072621447}$
rk[p2_,p4_]=rr[p2,ww[p2,p4]]
204.915 (p2^0.0012066 p4)$^{5.64085793953802}$
0.0930254 (1/(p2^0.0075625 ((p2^0.0043098 p4)^6.85442460549955)^0.344629))$^{1.543665056133560}$
{ww[1,1]-L,rk[1,1]-R}
{-12.0959,0.00582541}
p2=1

```
1
pπ[p4_]=pf[p1,ww[p2,p4],rk[p2,p4]];
ys1[p4_]=ysa[p1,ww[p2,p4],rk[p2,p4]];
lag[p4_]=lsa[p1,ww[p2,p4],rk[p2,p4]];
kag[p4_]=ksa[p1,ww[p2,p4],rk[p2,p4]];
{pπ[1]-aπ, lag[1]-(L1/L),ys1[1]-(Y1),kag[1]-(K1/R)}//N(* ck *)
{1.39148,0.0229486,4.67413,-9.58309}
Y11neT[p4_]=(1-ai22)ys1[p4];
{Y11neT[1],Y1-i11}
{122.198,118.524}
{p3=1,p1=1,p2=1}
{1,1,1}
{p3=1.07,p1=1.07,p2=1.07}
(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## *)
{1.07,1.07,1.07}
{p3=1.07,p1=1.07,p2=1.07}(* ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ## ##
## ## ## ## ## ## ## ## *)
{1.07,1.07,1.07}
p2f[pp2_,w_,rk_]=(a2)^(1/α3) (pp2)^(1/α3) (w)^(-α1/α3) (rk)^(-α2/α3);
ysIT[pp2_,w_,rk_]=□pp2 p2f[pp2, w, rk];
ysIT[w_,rk_]=ysIT[p2,w,rk];
lsIT[w_,rk_]=-□w p2f[p2, w, rk];
ksIT[w_,rk_]=-□rk p2f[p2, w, rk];
{p2f[1,L,R]-Q,ysIT[L,R]-Y2,lsIT[L,R]-(L2/L),ksIT[L,R]-(K2/R)}
P2f[p4_]=p2f[p2,ww[p2,p4],rk[p2,p4]];
YsIT[p4_]=ysIT[ww[p2,p4],rk[p2,p4]];
LsIT[p4_]=lsIT[ww[p2,p4],rk[p2,p4]];
KsIT[p4_]=ksIT[ww[p2,p4],rk[p2,p4]];
{P2f[1]-Q,YsIT[1]-Y2,LsIT[1]-(L2/L),KsIT[1]-(K2/R)}
{0.119484,1.25043,0.000588901,12.9386}
{0.836863,1.47694,0.00281462,10.7362}
Euler[p4_]=rk[p2,p4]-(ρ+θ x+δd)-0.0675+0.0928532/(p4^6.85442460549955)^0.531991
ps=FindRoot[Euler[p4]□0,{p4,1}]{p4→1.09139}
p4ss=(p4/.ps);
Clear[p2]
a3L[w_,rk_,p2_]=□w Cm[w, rk, p2];
a3K[w_,rk_,p2_]=□rk Cm[w, rk, p2];
a3I[w_,rk_,p2_]=□p2 Cm[w, rk, p2];
a4L[w_,rk_,p2_]=□w Cs[w, rk, p2];
a4K[w_,rk_,p2_]=□rk Cs[w, rk, p2];
a4I[w_,rk_,p2_]=□p2 Cs[w, rk, p2];
Cs[w,rk,p2]
0.367398 p2^0.00218199 rk^0.556091 w^0.441727
p2=1;
A3L[p4_]=a3L[ww[p2,p4],rk[p2,p4],p2];
A3K[p4_]=a3K[ww[p2,p4],rk[p2,p4],p2];
A3I[p4_]=a3I[ww[p2,p4],rk[p2,p4],p2];
A4L[p4_]=a4L[ww[p2,p4],rk[p2,p4],p2];
A4K[p4_]=a4K[ww[p2,p4],rk[p2,p4],p2];
A4I[p4_]=a4I[ww[p2,p4],rk[p2,p4],p2];
```

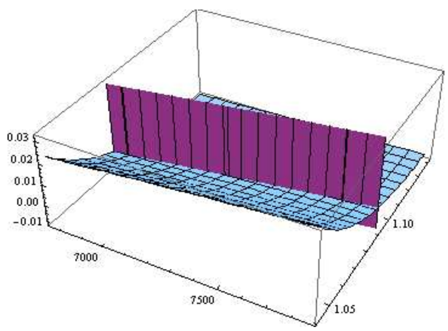
```
A3I[p4]
0.00809187 p4^6.85442460549955  5.55112□10^17
{A3L[1] Y3-L3/L,A3K[1] Y3-(K3/R),A4L[1] Y4-L4/L,A4K[1] Y4-(K4/R),A3I[1] Y3-IT3,A4I[1] Y4-IT4,lag[1]-(L1/L),kag[1]-(K1/R),LsIT[1]-(L2/L),KsIT[1]-(K2/R)}
{0.00192919,44.4637,-0.031156,67.4548,-0.17044,-1.18454,0.0229486,-9.58309,0.00281462,10.7362}
La[p4_,y3_,y4_]=A3L[p4]y3+A4L[p4]y4+lag[p4] +LsIT[p4]-1;(*Labor mkt clearing*)
Ka[k_,p4_,y3_,y4_]=A3K[p4]y3+A4K[p4]y4+kag[p4]+KsIT[p4]-k;
(*Capital market clearing*)
{La[1,Y3,Y4],Ka[K/R,1,Y3,Y4]}(* NOTE: could also use KK instead of K/R see above *)

{-0.00346362,114.072}
sy=Solve[{La[p4,y3,y4]□0,Ka[k,p4,y3,y4]□0},{y3,y4}];

y3[k_,p4_]=(y3/.sy)[[1]];
y4[k_,p4_]=(y4/.sy)[[1]];
y3[KK,1]
32.6567
Y3
82.2563
{y3[KK,1]-Y3, y4[KK,1]-Y4,YsIT[1]-Y2,A3I[1]y3[KK,1]-IT3,A4I[1]y4[KK,1]-IT4}
{-49.5996,42.9097,1.47694,-0.571793,-1.09091}
gdp2[k_,p4_]=ww[p2,p4]+k rk[p2,p4]+pπ[p4] +P2f[p4];(* gdp at factor prices *)
Yinet[k_,p4_]=(YsIT[p4]-A3I[p4]y3[k,p4]-A4I[p4]y4[k,p4]);
(* net production of IT *)

gdpout[k_,p4_]=ys1[p4]+Yinet[k,p4]+y3[k,p4]+p4 y4[k,p4];(* gdp at output prices *)
{Yinet[KK,1],Y2,-IT3-IT4}
{10.6907,10.09,-2.53899}
A3I[1]y3[KK,1]+A4I[1]y4[KK,1]-IT3-IT4-1.6627
{gdp2[KK,1],GDP,gdpout[KK,1]}
{449.132,445.915,446.039}
(* II Solution to the Steady state *)
(* Expd eqtn using the home good market clearing *)
λ4
0.588746
exp[k_,p4_]=p4/λ4 y4[k,p4];
c1[k_,p4_]=(λ1 exp[k,p4])/p1;
c3[k_,p4_]=(λ3 exp[k,p4])/p3;
c4[k_,p4_]=(λ4 exp[k,p4])/p4;
cpi[p4_]=p1^λ1 (p3^λ3)(p4^λ4);
{exp[KK,1],CC}
{476.426,404.543}
{y4[KK,1]-C4}
{42.9097}
{pπ[p4ss],pπ[1],P2f[p4ss],P2f[1]}
{28.8094,46.2791,0.84369,2.09004}
(rk[p2,p4ss])-θ x-ρ-δd(* Check Euler *)
0.000125203
KK
2246.09
(* III Derivation of Differential Equations *)
(* 1. Derive the kdot eqtn *)
```

```
Kdd[k_,p4_]=ww[p2,p4]+k (rk[p2,p4]-x-n-δd)+pπ[p4]+P2f[p4]-exp[k,p4];
ks=FindRoot[{Kdd[k,p4]□0,rk[p2,p4]-(ρ+θ x+δd)□0},{k,3521},{p4,p3}]
{k→7769.37,p4→1.09194}
{Kdd[k,p4],rk[p2,p4]-(ρ+θ x+δd)}/.ks
{-1.59162×10^-12,-1.38778×10^-17}
p4ss
1.09139
(*Check findroot plus selected ss values*)
{Kdd[k,p4],rk[p2,p4]-(ρ+θ x+δd)}/.ks
{-1.59162×10^-12,-1.38778×10^-17}
KK
2246.09
(* roe *)
{kss=k/.ks,y3[k/.ks,p4/.ps],y4[k/.ks,p4/.ps]}
{7769.37,480.607,287.373}
edot[k_,p4_,kdot_,p4dot_]=(□k exp⌊k, p4⌊)kdot+(□p4 exp⌊k, p4⌊)p4dot;
(* Now use the Euler to sub for edot=e(rk-ρ-x-δd) where we replace e with
exp□>exp[k,pp3](rk-ρ-x-δd)*)
pdot=Solve[exp[k,p4](1/θ)(rk[p2,p4]-ρ-θ x-δd+λ4 (p4dot/p4)(θ-1))-
edot[k,p4,Kdd[k,p4],p4dot]□0,p4dot];
Pd4[k_,p4_]=(p4dot/.pdot)[[1]];
Pd4[kss,p4ss]
0.000168914
(*2.2 Now assemble the p3 dot equation *)
(* Pd3[k_,p3_]=((rk[p3]-ρ-x-δd)p3*y3[k,p3]-
p3*dyk[k,p3]*Kdd[k,p3])/(y3[k,p3]+p3*dyp[k,p3])*)
st=FindRoot[{Pd4[k,p4]□0,Kdd[k,p4]□0},{k,k/.ks},{p4,p4/.ps},MaxIterations→1000,
AccuracyGoal→10]
{k→7769.37,p4→1.09194}
p4/.ps
1.09139
{Pd4[k,p4],Kdd[k,p4]}/.st
{-1.3991×10^-17,-1.25056×10^-12}
{Pd4[k/.ks,p4/.ps],Kdd[k/.ks,p4/.ps]}
{0.000168914,15.1141}
sh1=Plot3D[Pd4[k,p4],{k,(k/.ks)-1000,(k/.ks)+100},{p4,(p4/.ps)-0.05,(p4/.ps)+0.05}]
sh2=Plot3D[Kdd[k,p4],{k,(k/.ks)-1000,(k/.ks)+100},{p4,(p4/.ps)-0.05,(p4/.ps)+0.05}]
```



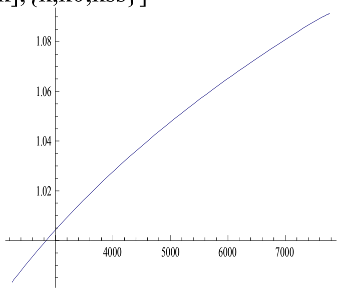


Show[sh1,sh2]

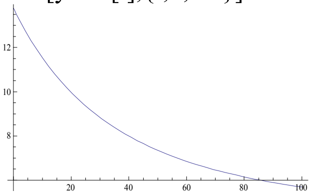


pss=p4/.ps
1.09139
kss
7769.37
a_{11}=D[Kdd[k,p4],k]/.{(k→kss),p4→(pss)};
a_{12}=D[Kdd[k,p4],p4]/.{(k→kss),p4→(pss)};
a_{21}=D[Pd4[k,p4],k]/.{(k→kss),p4→(pss)};
a_{22}=D[Pd4[k,p4],p4]/.{(k→kss),p4→(pss)};m={{a_{11},a_{12}},{a_{21},a_{22}}}
{{0.364503,-27385.4},{4.02356×10^{-6},-0.306842}}
MatrixForm[m]
(\[NoBreak]{
{0.364503, -27385.4},
{4.02356×10^{-6}, -0.306842}
}\[NoBreak])
(*Compute Eigenvalues and Eigenvectors of Jacobian*)
{ε1,ε2}=Eigenvalues[m]
{0.0787196,-0.0210589}
{{v11,v12},{v21,v22}}=Eigenvectors[m]
{{1.,0.0000104356},{1.,0.0000140791}}
If[ε1<0,slope=v12/v11,slope=v22/v21]
0.0000140791
{k0,kss,pss,slope}
{2246.09,7769.37,1.09139,0.0000140791}
s2=NDSolve[{p'[k]□If[k□kss,slope,(Pd4[k,p[k]]/Kdd[k,p[k]])],p[kss]□(pss)},p,{k,k0*.8, kss}]
{{p→InterpolatingFunction[{{1796.87,7769.37}},<>]}}
pp[k_]=(p[k]/.s2)[[1]]
InterpolatingFunction[{{1796.87,7769.37}},<>][k]

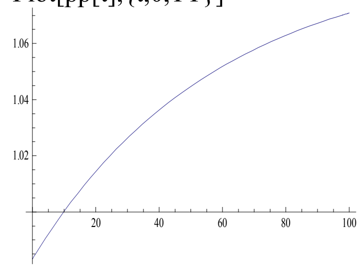
```
Plot[pp[k],{k,k0,kss}]
```



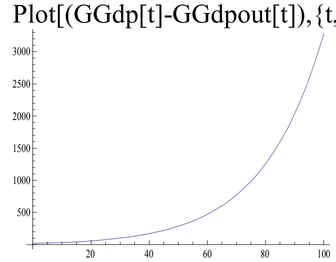

```
(* Plot [(p (k)/.s2),{k,KK,kss},PlotLabel→"The Policy Function"]*)
(*5. Integrate forward kdot using policy finction*)
s3=NDSolve[{k'[t]□Kdd[k[t],(p[k[t]]/.s2[[1,1]])],k[0]□k0},k,{t,-10,TT}]
InterpolatingFunction::dmval: Input value \[NoBreak]{1791.64}\[NoBreak] lies outside
the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1791.64}\[NoBreak] lies outside
the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1740.6}\[NoBreak] lies outside
the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will
be suppressed during this calculation. □
{{k→InterpolatingFunction[{{-10.,100.}},<>]}}
(* Compute rest of endogenous variables *)
kk[t_]=(k[t]/.s3)[[1]];
pp[t_]=(p[k[t]]/.s3/.s2)[[1,1]];
cpit[t_]=cpi[pp[t]];
w1[t_]=ww[p2,pp[t]];
rr[t_]=rk[p2,pp[t]];
pπt[t_]=pπ[pp[t]];
l12[t_]=lag[pp[t]]; (* Share of labor in agriculture *)
p2ft[t_]=P2f[pp[t]];
kdot[t_]=Kdd[kk[t],pp[t]];
Kk[t_]=kk[t]-kag[pp[t]];
(*Share of capital outside ag*)
P3va[t_]=P3[pp[t]];(*value added prices*)
Pva[t_]=pa[pp[t]];
P4va[t_]=P4[pp[t]];
(* Total and Net supply*)
y3t[t_]=y3[kk[t],pp[t]];
(* y3nett[t_]=y3net[kk[t],pp[t]];*)
ysITt[t_]=YsIT[pp[t]];
y1t[t_]=ys1[pp[t]];
(*y1nett[t_]=y1net[kk[t],pp[t]];*)
(*y1nett[t_]=y1[kk[t],pp[t]](*Final cons. +composite k*)*)
y4t[t_]=y4[kk[t],pp[t]];
(* y4nett[t_]=y4net[kk[t],pp[t]];*)
It3t[t_]=A3I[pp[t]]y3t[t];(* Demand for it in sector 3 *)
It4t[t_]=A4I[pp[t]]y4t[t];(* Demand for it in sector 4 *)
Plot[ysITt[t],{t,0,TT}]
```



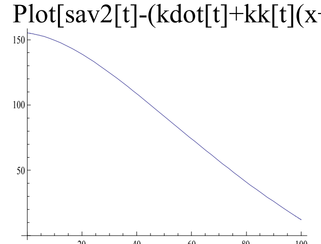
```
Plot[pp[t],{t,0,TT}]
```



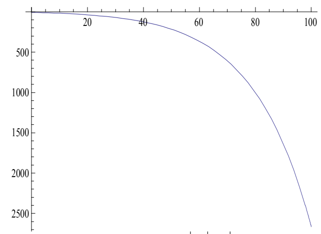

```
{gdp2[KK,1],GDP,gdpout[KK,1]}
449.132,445.915,446.039}
GGdp[t_]=gdp2[kk[t],pp[t]] Exp[(x+n)t];
GGdpout[t_]=gdpout[kk[t],pp[t]] Exp[(x+n)t];
ee[t_]=exp[kk[t],pp[t]];
c3[t_]=λ3 ee[t];
c1[t_]=((λ1 ee[t])/p1);
c4[t_]=(ee[t]λ4)/pp[t];
ct[t_]=ee[t]/((p1^λ1)(pp[t]^λ4));
sv[t_]=GGdp[t]-ee[t]Exp[(x+n)t];
ex3t[t_]=(y3t[t]-c3[t]-kdot[t]-kk[t](x+n+δd))Exp[(x+n)t];
(*excess demand mft*)
ex3bt[t_]=(y3t[t]-c3[t])Exp[(x+n)t]-sv[t];(* alternative to ex3t[t] *)
exc1t[t_]=p1 (y1t[t]-c1[t])Exp[(x+n)t];(* Agriculture excess demand *)
exc2t[t_]=p2 (ysITt[t]-It3t[t]-It4t[t])Exp[(x+n)t];(* IT excess demand *)
sav2[t_]=gdp2[kk[t],pp[t]]-ee[t];
Plot[(GGdp[t]-GGdpout[t]),{t,0,TT}]
```



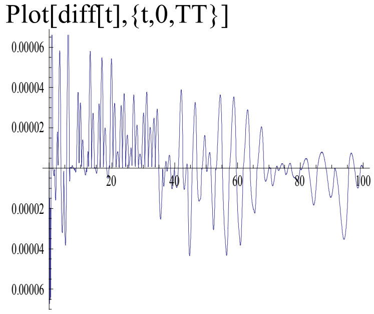

```
zz[t_]=ww[p2,pp[t]]+kk[t](rk[p2,pp[t]])+pπ[pp[t]]+P2f[pp[t]];
Set::write: Tag \[NoBreak]Integer\[NoBreak] in \[NoBreak]0[t_]\[NoBreak] is Protected.
□
zz2[t_]=gdp2[kk[t],pp[t]];
{zz2[10],zz[10],gdp2[kk[10],pp[10]]}
{505.174,0[10],505.174}
zz3[t_]=-(kdot[t]+kk[t](x+n+δd))+zz2[t];
{zz3[10],ee[10]}
{285.633,136.054}
Plot[sav2[t]-(kdot[t]+kk[t](x+n+δd)),{t,0,TT}]
```



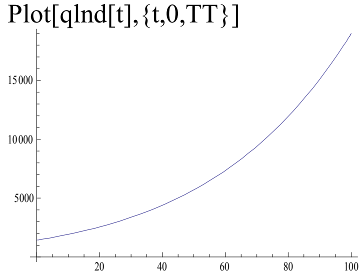

```
TB[t_]=exc1t[t]+ex3bt[t]+exc2t[t];
TB2[t_]=(y3t[t]-c3[t]-kdot[t]-kk[t](x+n+δd))+p1 (y1t[t]-c1[t])+p2 (ysITt[t]-It3t[t]-
It4t[t]);
Plot[TB[t],{t,0,TT}]
```



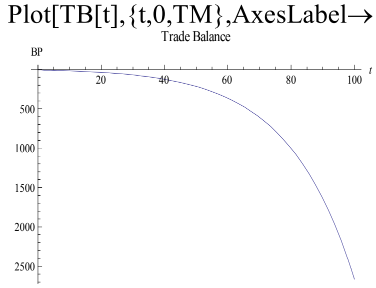
```
diff[t_]=□t kk[t]-kdot[t];
Plot[diff[t],{t,0,TT}]
```



```
y4t[10]-c4[10]
0.
wkr[t_]=LL Exp[n t]; (*number of workers*)
{slr[t_]=w1[t]
Exp[(x+n)t]/GGdp[t],skr[t_]=(rr[t]kk[t])Exp[(x+n)t]/GGdp[t],s11[t_]=(pπt[t]
Exp[(x+n)t])/GGdp[t],smIT[t_]=p2ft[t]Exp[(x+n)t]/GGdp[t]};

slr[TT]+skr[TT]+s11[TT]+smIT[TT](*check*)
1.
(* Land market analysis *)
(*2. Land values using the no-arbitrage conditions*)
qT=pπt[TT]/(rr[TT]-n-x-δd)
1999.03
sq=NDSolve[{q'[t]□q[t] (rr[t]-x-n-δd)-pπt[t], q[TT]==qT},q,{t,0,TT}]
{{q→InterpolatingFunction[{{0.,100.}},<>]}}
qlnd[t_]=((q[t]/.sq)[[1]])Exp[x t]
©0.0225 t InterpolatingFunction[{{0.,100.}},<>][t]
Plot[qlnd[t],{t,0,TT}]
```

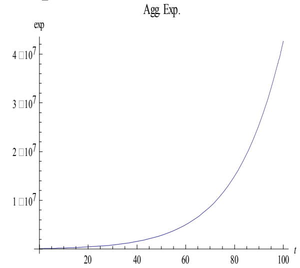


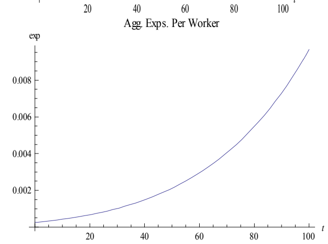
```
Plot[TB[t],{t,0,TM},AxesLabel→{t,BP},PlotLabel→"Trade Balance"]
```




```
Plot[mn ee[t] Exp[(x+n)t],{t,0,TM},AxesLabel →{t,exp},PlotLabel→" Agg. Exp."]
```

Plot[(mn ee[t] Exp[(x+n)t])/wkr[t],{t,0,TM},AxesLabel→{t,exp},PlotLabel→"Agg. Exps. Per Worker"]

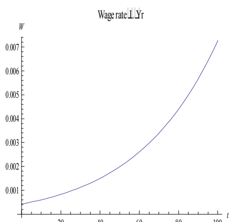


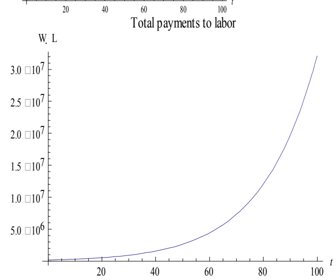


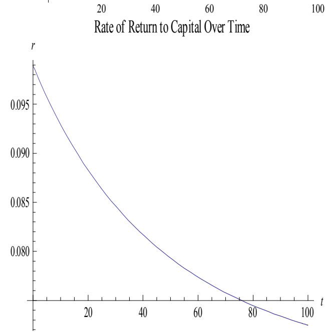
Plot[mn (w1[t] Exp[(x+n)t])/(wkr[t]),{t,0,TM},AxesLabel→{t,W},PlotLabel→" Wage rate/L/Yr"]

Plot[mn w1[t] Exp[(x+n)t],{t,0,TM},AxesLabel→{t,"W*L"},PlotLabel→" Total payments to labor"]

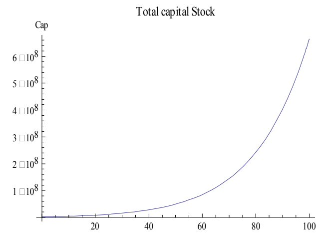
Plot[rr[t], {t,0,TM},AxesLabel→{t,r},PlotLabel→" Rate of Return to Capital Over Time"]



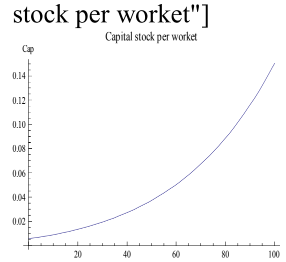




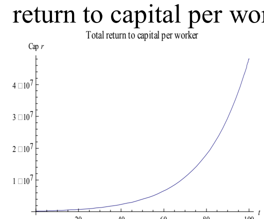
Plot[mn kk[t] Exp[(x+n)t],{t,0,TM},AxesLabel→{t,Cap}, PlotLabel→"Total capital Stock"]



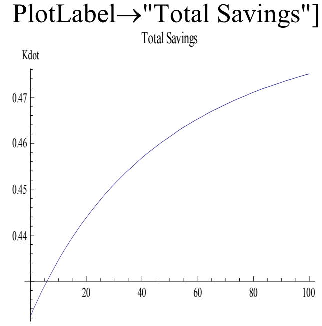
Plot[(mn kk[t] Exp[(x+n)t])/wkr[t],{t,0,TM},AxesLabel→{t,Cap}, PlotLabel→"Capital stock per worket"]



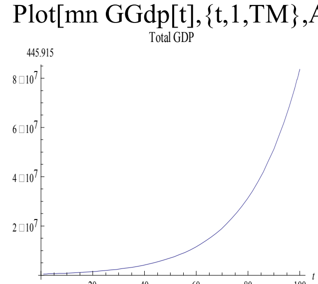
Plot[(rr[t] mn kk[t]Exp[(x+n)t]),{t,0,TM},AxesLabel→{t,r*Cap},PlotLabel→"Total return to capital per worker"]



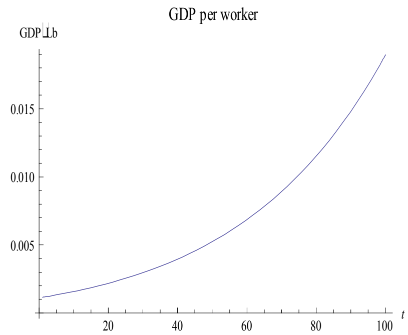
Plot[(kdot[t]+kk[t](x+n+δd))/gdp2[kk[t],pp[t]],{t,0,TM},AxesLabel→{t,Kdot}, PlotLabel→"Total Savings"]



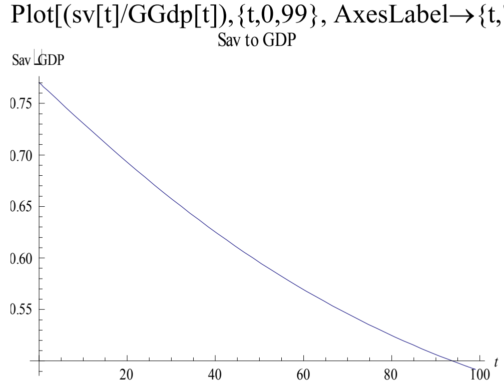
Plot[mn GGdp[t],{t,1,TM},AxesLabel→{t,GDP},PlotLabel→"Total GDP"]



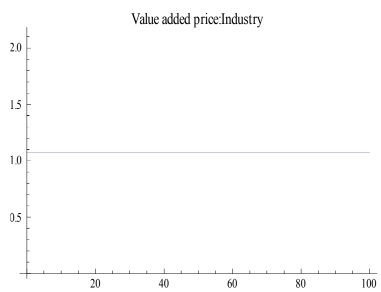
Plot[mn GGdp[t]/wkr[t],{t,1,TM},AxesLabel→{t,"GDP/Lb"}, PlotLabel→"GDP per worker"]

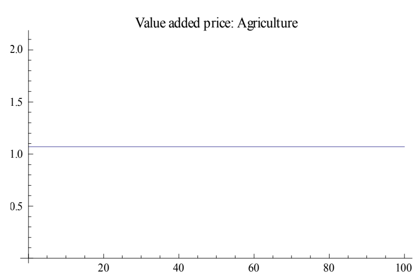


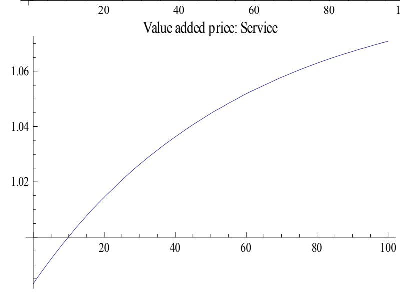
Plot[(sv[t]/GGdp[t]),{t,0,99}, AxesLabel→{t,"Sav/GDP"},PlotLabel→"Sav to GDP"]



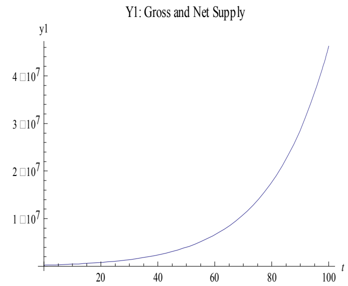
Plot[P3va[t],{t,0,TT},PlotLabel→"Value added price:Industry"]
Plot[Pva[t],{t,0,TT},PlotLabel→"Value added price: Agriculture"]
Plot[P4va[t],{t,0,TT}, PlotLabel→"Value added price: Service"]



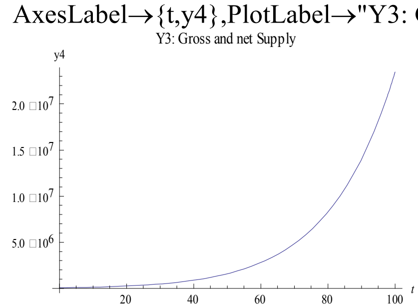




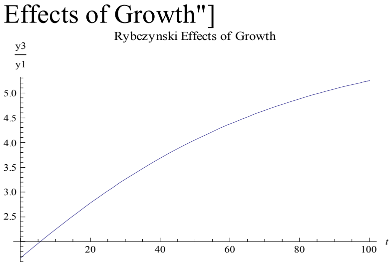
Plot[{mn y3t[t] Exp[(x+n)t],mn y3nett[t] Exp[(n+x)t]},{t,0,TM},AxesLabel→{t,y1}, PlotLabel→"Y1: Gross and Net Supply"]



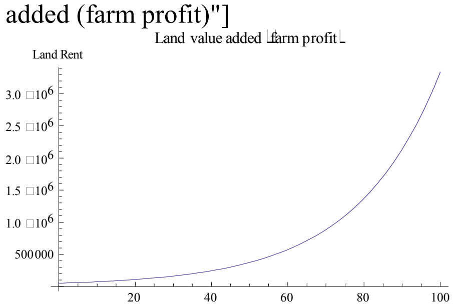
Plot[{mn y4t[t] Exp[(n+x)t], mn y4nett[t] Exp[(n+x)t]},{t,0,TM}, AxesLabel→{t,y4},PlotLabel→"Y3: Gross and net Supply"]



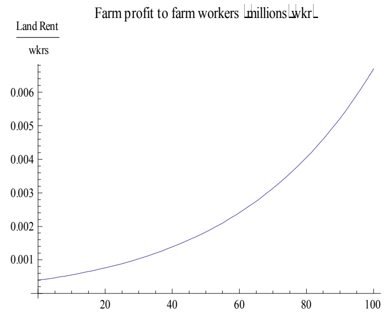
Plot[Evaluate[(y3t[t])/y1t[t]],{t,0,TM},AxesLabel→{t,y3/y1},PlotLabel→"Rybczynski Effects of Growth"]



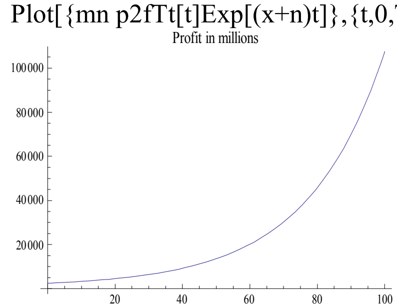
Plot[mn pπt[t]Exp[(x+n)t],{t,0,TM},AxesLabel→{t,Land Rent},PlotLabel→"Land value added (farm profit)"]



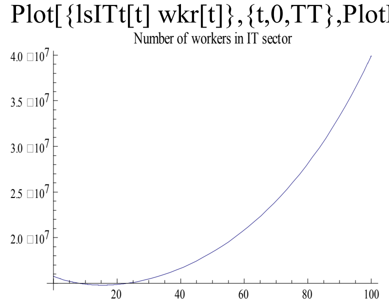
Plot[(mn pπt[t]Exp[(x+n)t])/(l12[t]wkr[t]),{t,0,TM},AxesLabel→{t,Land Rent/wkrs},PlotLabel→"Farm profit to farm workers (millions/wkr)"]



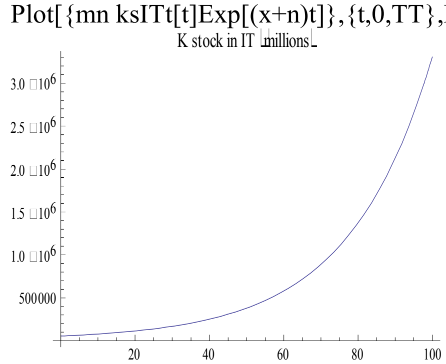
p2fTt[t_]=p2ft[t];(* profit in IT *)
lsITt[t_]=lsIT[w1[t],rr[t]];(* Share of economy-wide labor in IT*)
ksITt[t_]=ksIT[w1[t],rr[t]];(* K per unit of effective labor in IT *)
Plot[{mn p2fTt[t]Exp[(x+n)t]},{t,0,TT},PlotLabel→"Profit in millions"]



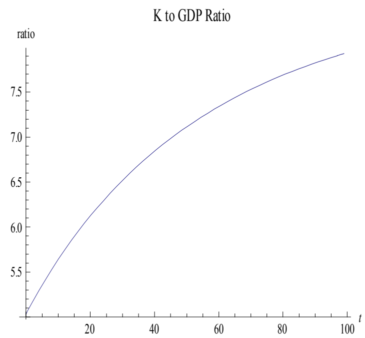
Plot[{lsITt[t] wkr[t]},{t,0,TT},PlotLabel→"Number of workers in IT sector"]



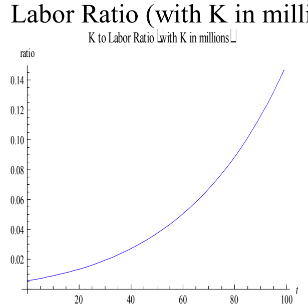
Plot[{mn ksITt[t]Exp[(x+n)t]},{t,0,TT},PlotLabel→"K stock in IT (millions)"]



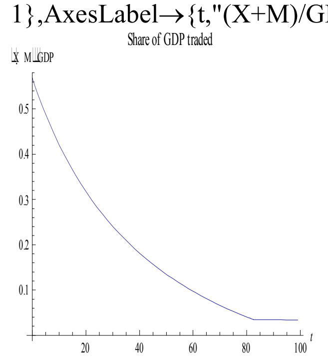
Plot[kk[t]Exp[(x+n)t]/GGdp[t],{t,0,TM-1},AxesLabel→{t,ratio},PlotLabel→"   K to GDP Ratio"]



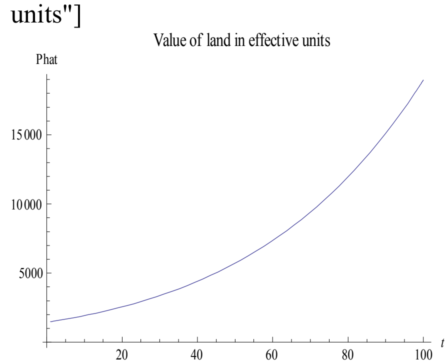
Plot[mn kk[t]Exp[(x+n)t]/wkr[t],{t,0,TM-1},AxesLabel→{t,ratio},PlotLabel→"   K to Labor Ratio (with K in millions) ",PlotStyle->{Hue[0.7]}]



exc1t[t]+ex3bt[t]+exc2t[t];
Plot[(Abs[exc1t[t]]+Abs[ex3bt[t]])/GGdp[t],{t,0,TM-1},AxesLabel→{t,"(X+M)/GDP"},PlotLabel→"   Share of GDP traded"]

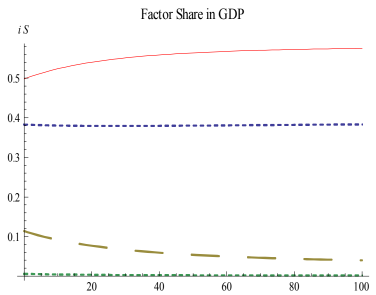


qlnd[1]
1479.46
qT
1999.03
Plot[{qlnd[t]},{t,1,TT},AxesLabel→{t,Phat},PlotLabel→"   Value of land in effective units"]



Plot[{slr[t],skr[t],s11[t],smIT[t]},{t,0,TM},AxesLabel→{t,S (i)},PlotLabel→"Factor Share in GDP",PlotStyle→{Dashing[{0.01}],Hue[2.0],Dashing[{0.08}]}]

Print["Labor Share =small dash;K share=sold; Land Share=large dash"]



Labor Share =small dash;K share=sold; Land Share=large dash
aa[t_]=Exp[(x+n)t]

©0.0465 t
yrcal=2001
2001
TableForm[base=Table[{yrcal+t,mn GGdp[t],(mn y1t[t] aa[t]),(mn ysITt[t]aa[t]),(mn y3t[t] aa[t]),(mn y4t[t]aa[t]),mn ct[t]aa[t]},{t,0,TT,10}],TableHeadings→{Automatic,{Year,"GDP",y1t,"ysITt",y3t,y4t,"ct"}}]
{
{\[Null], Year, GDP, y1t, ysITt, y3t, y4t, ct},
TableForm[base=Table[{yrcal+t,mn GGdp[t],(mn y1t[t] aa[t]),(mn ysITt[t]aa[t]),(mn y3t[t] aa[t]),(mn y4t[t]aa[t])},{t,-10,20,1}],TableHeadings→{Automatic,{Year,"GDP",y1t,"y2t",y3t,y4t}}]

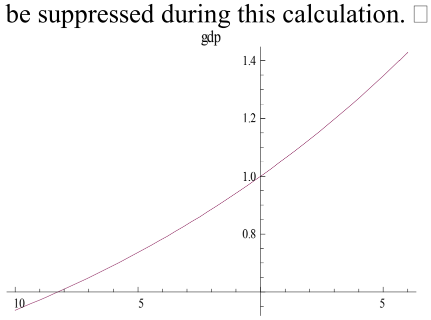
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □
{
TableForm[base=Table[{yrcal+t,mn GGdp[t]/wkr[t],(y1t[t] aa[t]/GGdp[t]),(ysITt[t]aa[t]/GGdp[t]),(y3t[t] aa[t]/ GGdp[t]),(y4t[t]aa[t])/ GGdp[t]},{t,-10,90,10}],TableHeadings→{Automatic,{Year,"GDP/wkr","y1t/GDP","y2t/GDP","y3t/GDP","y4t/GDP"}}]
{
TableForm[base=Table[{yrcal+t,(mn GGdp[t]/wkr[t]) aa[t],((rr[t] kk[t]/GGdp[t]) aa[t]),(mn (w1[t] Exp[(x+n)t])/(wkr[t])),(rr[t] Exp[(x+n)t]),(w1[t] Exp[(x+n)t])/ GGdp[t],(pπt[t]/GGdp[t]) aa[t],((rr[t]kk[t]/GGdp[t]) aa[t]),((p2ft[t]/GGdp[t]) aa[t])},{t,-10,20,1}],TableHeadings→{Automatic,{Year,"GDP per wkr","K/GDP","wage rate","rate of interest: rk", "Share of Wages","Agr profit/GDP","Share of Capital","IT profit/GDP"}}]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □

General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation.
{
{\[Null], Year, GDP per wkr, K/GDP, wage rate, rate of interest: rk, Share of Wages, Agr profit/GDP, Share of Capital, IT profit/GDP},
TableForm[base=Table[{yrcal+t,(mn GGdp[t]/wkr[t]) aa[t],((rr[t] kk[t]/GGdp[t]) aa[t]),(mn (w1[t] Exp[(x+n)t])/(wkr[t])),(rr[t] Exp[(x+n)t]),(w1[t] Exp[(x+n)t])/ GGdp[t],(pπt[t]/GGdp[t]) aa[t],((rr[t]kk[t]/GGdp[t]) aa[t]),((p2ft[t]/GGdp[t]) aa[t])},{t,-10,90,10}],TableHeadings→{Automatic,{Year,"GDP per wkr","K/GDP","wage rate","rate of interest: rk", "Share of Wages","Agr profit/GDP","Share of Capital","IT profit/GDP"}}]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation.
{
{\[Null], Year, GDP per wkr, K/GDP, wage rate, rate of interest: rk, Share of Wages, Agr profit/GDP, Share of Capital, IT profit/GDP},

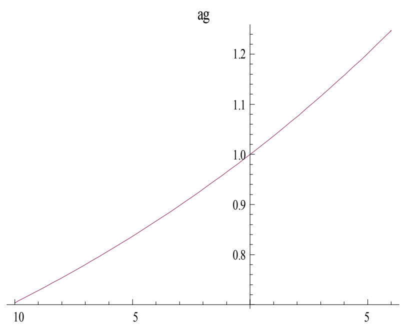
Export["C:\\Documents and Settings\\vigxx003\\My Documents\\cas 2.xls",base]
Export::nodir: Directory \[NoBreak]C:\Documents and Settings\vigxx003\My Documents\\[NoBreak] does not exist.
Export::noopen: Cannot open \[NoBreak]C:\Documents and Settings\vigxx003\My Documents\cas 2.xls\[NoBreak].
$Failed
(* Next statement in the *.xls file, the first number 6 is sheet number and the 5 is the first 5 rows *)

xx= Take[Import["c:\m\grad\joyti\yr09\jv_dec09.XLS", {"Data",6}],5]//TableForm
Import::nffil: File not found during \[NoBreak]Import\[NoBreak].
Take::normal: Nonatomic expression expected at position \[NoBreak]1\[NoBreak] in \[NoBreak]Take[$Failed,5]\[NoBreak].
Take[$Failed,5]
gd=xx[[1,2]]
ag=xx[[1,3]]
mf=xx[[1,4]]
sr=xx[[1,5]
gdpdata[t_]=Interpolation[Table[gd[[i]],{i,1,17}]][t](* Here we assume the τo are data on the share of capital stock each t placed in foreign accounts; This is where a regression model fits in *)
General::stop: Further output of \[NoBreak]Part::partd\[NoBreak] will be suppressed during this calculation.
InterpolatingFunction[{{1,17}},<>][t]
agdata[t_]=Interpolation[Table[ag[[i]],{i,1,17}]][t]
mfdata[t_]=Interpolation[Table[mf[[i]],{i,1,17}]][t]
srdata[t_]=Interpolation[Table[sr[[i]],{i,1,17}]][t]
Part::partw: Part \[NoBreak]4\[NoBreak] of
General::stop: Further output of \[NoBreak]Part::partw\[NoBreak] will be suppressed during this calculation.
InterpolatingFunction[{{1,17}},<>][t]

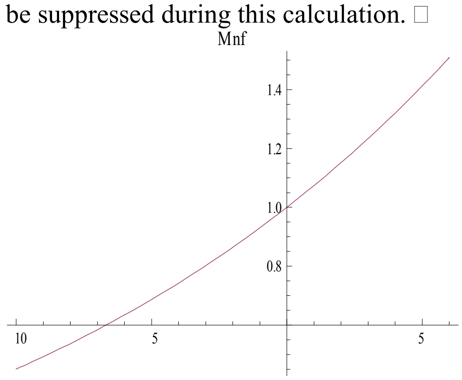
General::stop: Further output of \[NoBreak]Part::partw\[NoBreak] will be suppressed during this calculation. □
InterpolatingFunction[{{1,17}},<>][t]
General::stop: Further output of \[NoBreak]Part::partw\[NoBreak] will be suppressed during this calculation. □
InterpolatingFunction[{{1,17}},<>][t]
mn GGdp[-10]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □
239346.
Plot[{gdpdata[t+11],mn GGdp[t]/(mn GGdp[0])},{t,-10,6},PlotLabel→"gdp"]
General::stop: Further output of \[NoBreak]Part::partd\[NoBreak] will be suppressed during this calculation. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □



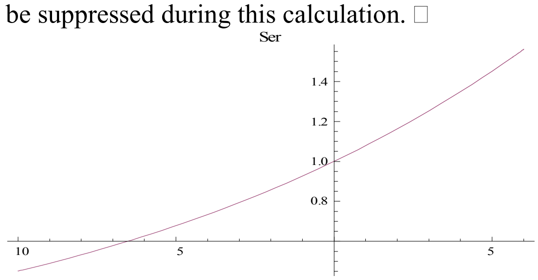
Plot[{agdata[t+11],(mn y1t[t] aa[t])/(mn y1t[0] aa[0])},{t,-10,6},PlotLabel→"ag"]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □



Plot[{mfdata[t+11],(mn y3t[t] aa[t])/(mn y3t[0] aa[0])},{t,-10,6},PlotLabel→"Mnf"]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □

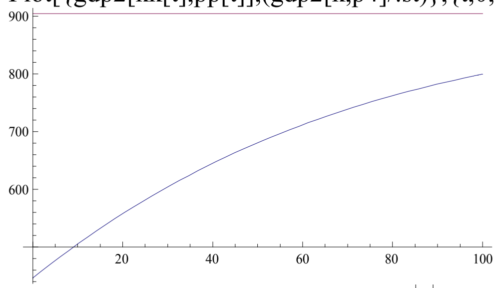


Plot[{srdata[t+11],(mn y4t[t]aa[t])/(mn y4t[0] aa[0])},{t,-10,6},PlotLabel→"Ser"]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □

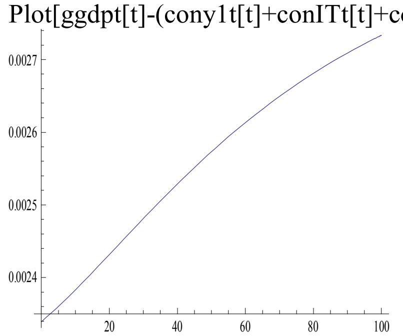


FindRoot[GGdp[t]-2*GGdp[0]□0,{t,30}]
{t→11.8179}
FindRoot[GGdp[t]Exp[-n t]-2*GGdp[0]□0,{t,30}]
{t→20.6442}
FindRoot[(gdp2[kk[t],pp[t]]-gdp2[kk[0],pp[0]])-0.5*((gdp2[k,p4]/.st)-gdp2[kk[0],pp[0]])□0,{t,50}]
{t→48.3737}

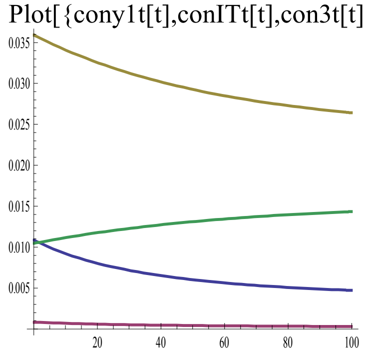
Plot[{gdp2[kk[t],pp[t]],(gdp2[k,p4]/.st)},{t,0,TT}]



cony1t[t_]=(y1t[t] aa[t])/GGdp[t] □t └mn y1t└t┘ aa└t┘┘/(mn y1t[t] aa[t]);
conITt[t_]=(ysITt[t] aa[t])/GGdp[t] □t └mn ysITt└t┘ aa└t┘┘/(mn ysITt[t] aa[t]);
con3t[t_]=(y3t[t] aa[t])/GGdp[t] □t └mn y3t└t┘ aa└t┘┘/(mn y3t[t] aa[t]);
con4t[t_]=(y4t[t] aa[t])/GGdp[t] □t └mn y4t└t┘ aa└t┘┘/(mn y4t[t] aa[t]);
ggdpt[t_]=□t GGdp└t┘/GGdp[t];
Plot[ggdpt[t]-(cony1t[t]+conITt[t]+con3t[t]+con4t[t]),{t,0,TT}]

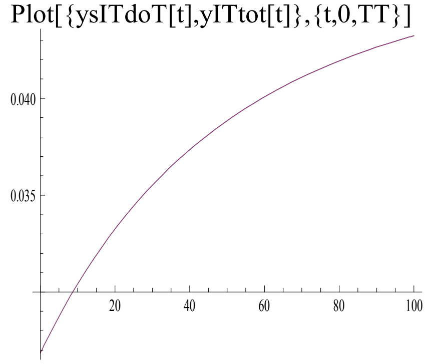


Plot[{cony1t[t],conITt[t],con3t[t],con4t[t]},{t,0,TT},PlotStyle→{Thick}]

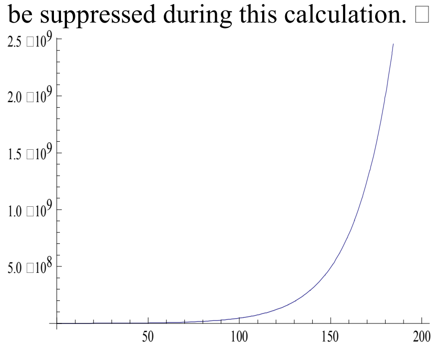


yr=2001
TableForm[baserate = Table[{yr+t,cony1t[t] ,conITt[t],con3t[t],con4t[t],ggdpt[t]},{t,-10,70,10}],TableHeadings→{Automatic,{"yr+t","Agr","IT","mfg","serv","tot"}}]
2001
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □

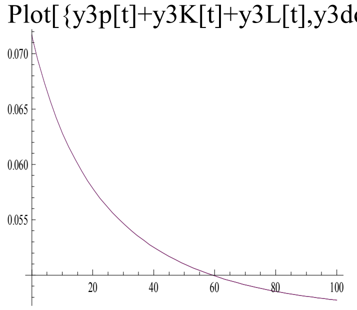
```
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. 
{
 {\[Null], yr+t, Agr, IT, mfg, serv, tot},

(* Growth accounting *)
(* Calculating Elasticities *)
(* y1[pf_,w_,rk_],y3[k_,p4_]],y4[k_,p4]*)

εy3k[k_,p4_]=((∂k y3[k, p4])k)/y3[k,p4];
εy3p[k_,p4_]=((∂p4 y3[k, p4])p4)/y3[k,p4];
εyITw[pp2_,w_,rk_]=((∂w ysIT[pp2, w, rk])w)/ysIT[pp2,w,rk];
εyITr[pp2_,w_,rk_]=((∂rk ysIT[pp2, w, rk])rk)/ysIT[pp2,w,rk];
εyITp[pp2_,w_,rk_]=((∂pp2 ysIT[pp2, w, rk])pp2)/ysIT[pp2,w,rk]
4.92171
εy4k[k_,p4_]=((∂k y4[k, p4])k)/y4[k,p4];
εy4p[k_,p4_]=((∂p4 y4[k, p4])p4)/y4[k,p4];
εys1w[pf_,w_,rk_]=((∂w ysa[pf, w, rk])w)/ysa[pf,w,rk];
εys1r[pf_,w_,rk_]=((∂rk ysa[pf, w, rk])rk)/ysa[pf,w,rk];
εys1pf[pf_,w_,rk_]=((∂pf ysa[pf, w, rk])pf)/ysa[pf,w,rk];
εy1H=1;
{(εys1pf[1,L,R]+εys1w[1,L,R]+εys1r[1,L,R]),εy3k[KK,1],εy3p[KK,1],εy4k[KK,1],εy4p[KK,1]}

{-1.64046,27.948,-354.927,-2.71632,46.6797}
{εyITw[1,L,R],εyITr[1,L,R],εyITp[1,L,R]}
{-2.69693,-2.22479,4.92171}
ysITdoT[t_]=(∂t (ysITt[t] aa[t]))/(ysITt[t]aa[t]);
yITp[t_]=εyITp[1,w1[t],rr[t]]/1 (0);
yITw[t_]=(εyITw[1,w1[t],rr[t]])/w1[t] (∂t w1[t]);
yITr[t_]=εyITr[1,w1[t],rr[t]]× ((∂t rr[t])/rr[t]);
yITH=εy1H (x+n);
yITtot[t_]=yITp[t]+yITw[t]+yITr[t]+yITH; (* Total effect *)
Plot[{ysITdoT[t],yITtot[t]},{t,0,TT}]
```



z[pf_,w_,rk_]=(((□pf ysa[pf, w, rk])pf)/ysa[pf,w,rk])(* Partial equilibrium supply elasticity *)
0
ys1[p4_]=ysa[p1,ww[p2,p4],rk[p2,p4]];
(* Growth effects in level variables *)
KS[t_]=kk[t]Exp[(x+n)t];
(* Manufacturing Y3 effects *)
y3p[t_]=(εy3p[kk[t],pp[t]])/pp[t] (□t pp[t]);
y3K[t_]=(εy3k[kk[t],pp[t]])/KS[t] (□t KS[t]);
y3L[t_]=(1-εy3k[kk[t],pp[t]])(x+n);
y3tot[t_]=y3p[t]+y3K[t]+y3L[t]; (* Total effect *)
{y3p[0],y3K[0],y3L[0]}
{-0.0939066,0.320983,-0.155384}
y3dot[t_]=□t [mn y3t[t] aa[t]]/(mn y3t[t] aa[t]);
Plot[(mn y3t[t] aa[t]),{t,0,200}]
InterpolatingFunction::dmval: Input value \[NoBreak]{101.9}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{106.122}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{110.062}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □

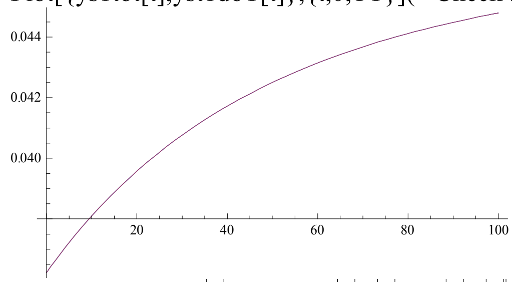


TT
100
Plot[{y3p[t]+y3K[t]+y3L[t],y3dot[t]},{t,0,100}]

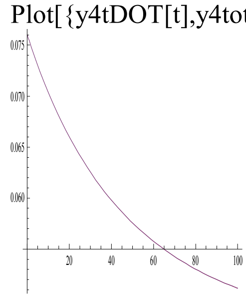


ys1tt[t_]=ys1t[t]Exp[(x+n)t];
yst1doT[t_]=(□t [y1t[t] aa[t]])/(y1t[t]aa[t]);
ys1p[t_]=εys1pf[1,w1[t],rr[t]]/1 (0);
ys1w[t_]=(εys1w[1,w1[t],rr[t]])/w1[t] (□t w1[t]);
ys1r[t_]=εys1r[1,w1[t],rr[t]]× (□t rr[t])/rr[t];

ys1H=εy1H (x+n);
ys1tot[t_]=ys1p[t]+ys1w[t]+ys1r[t]+ys1H; (* Total effect *)
Plot[{ys1tot[t],yst1doT[t]},{t,0,TT}](* Check should be equal *)



y4tDOT[t_]=∂t[mn y4t[t] aa[t]]/(mn y4t[t] aa[t]);
y4p[t_]=(εy4p[kk[t],pp[t]])/pp[t] (∂t pp[t]);
y4K[t_]=(εy4k[kk[t],pp[t]])/KS[t] (∂t KS[t]);
y4L[t_]=(1-εy4k[kk[t],pp[t]])(x+n);
y4tot[t_]=y4p[t]+y4K[t]+y4L[t]; (* Total effect *)
{y4p[0],y4K[0],y4L[0]}
{0.397794,-0.992489,0.670734}
Plot[{y4tDOT[t],y4tot[t]},{t,0,TT}]



yr=2001

TableForm[baserate = Table[{yr+t, y3tot[t],y3p[t],y3K[t],y3L[t],ys1tot[t],ys1p[t],ys1w[t],ys1r[t],ys1H,y4tot[t], y4p[t],y4K[t],y4L[t]},{t,0,70,10}],TableHeadings→{Automatic,{"yr+t","y3tot[t]","y3p[t]","y3K[t]","y3L[t]","ys1tot[t]","ys1p[t]","ys1w[t]","ys1r[t]","ys1H","y4tot[t]","y4p[t]","y4K[t]","y4L[t]"}}]
2001
{\[Null], yr+t, y3tot[t], y3p[t], y3K[t], y3L[t], ys1tot[t], ys1p[t], ys1w[t], ys1r[t], ys1H, y4tot[t], y4p[t], y4K[t], y4L[t]},
TableForm[baserate = Table[{yr+t, y3tot[t],y3p[t],y3K[t],y3L[t]},{t,-10,70,10}],TableHeadings→{Automatic,{"yr+t","y3tot[t]","y3p[t]","y3K[t]","y3L[t]"}}]
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □
{
}
TableForm[baserate = Table[{yr+t,yITp[t],yITw[t],yITr[t],yITH,yITtot[t]},{t,-10,70,10}],TableHeadings→{Automatic,{"yr+t","yITp[t]","yITw[t]","yITr[t]","yITH","yITtot[t]"}}]

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation.
{
 {\[Null], yr+t, yITp[t], yITw[t], yITr[t], yITH, yITtot[t]},

```
TableForm[baserate = Table[{yr+t,y4tot[t], y4p[t],y4K[t],y4L[t]
                        {t,10,70,10}],
TableHeadings→{Automatic,{"yr+t","y4tot[t]","y4p[t]","y4K[t]","y4L[t]"}}]
```

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation.
{

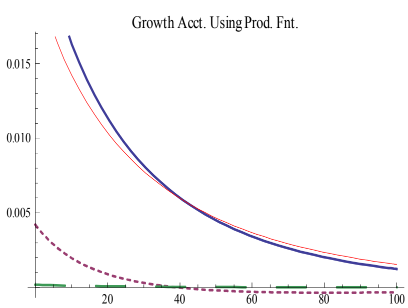
```
TableForm[baserate = Table[{yr+t,ys1tot[t],ys1p[t],ys1w[t],ys1r[t],ys1H
},{t,-
10,70,10}],TableHeadings→{Automatic,{"yr+t","ys1tot[t]","ys1p[t]","ys1w[t]","ys1r[t]",
"ys1H[t]"}}]
```

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used.
General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation.
{

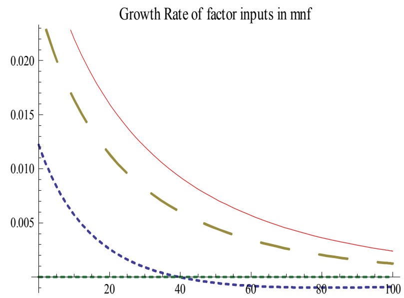
Table::itform: Argument \[NoBreak]yITtot[t]\[NoBreak] at position \[NoBreak]2\[NoBreak] does have the correct form for an iterator.

```
Table[{yr+t,y3tot[t],y3p[t],y3K[t],y3L[t],ys1tot[t],ys1p[t],ys1w[t],ys1r[t],ys1H,y4tot[t],y
4p[t],y4K[t],y4L[t]},yITtot[t],yITp[t],yITw[t],yITr[t],yITH,{t,0,70,10}]
(* A3 ((L3/L)^δ1 (K3/R)^δ2  (IT3)^δ3)
l12[t_]=lag[pp[t]]
La[p4_,y3_,y4_]=A3L[p4]y3+A4L[p4]y4+lag[p4] +LsIT[p4]-1;(*Labor mkt clearing*)
Ka[k_,p4_,y3_,y4_]=A3K[p4]y3+A4K[p4]y4+kag[p4]+KsIT[p4]-k;*)
l33[t_]=A3L[pp[t]]y3t[t];(* labor share in mnf. *)
l44[t_]=A4L[pp[t]]y4t[t];(* labor share in serv *)
lag1[t_]=lag[pp[t]];(* labor share in ag *)
lsit[t_]=LsIT[pp[t]];(* labor share in it *)
k33[t_]=A3K[pp[t]]y3t[t];(* k hat in mnf *)
k44[t_]=A4K[pp[t]]y4t[t];(* k hat in serv *)
kagt[t_]=kag[pp[t]];(* k hat in ag *)
ksItt[t_]=KsIT[pp[t]];(* k hat in it *)
ii3[t_]=A3I[pp[t]]y3t[t];(*it hat demand in mnf *)
ii4[t_]=A4I[pp[t]]y4t[t];(* it hat demand in services *)
```

itab[t_]=ii4[t]+ii3[t]; (* it hat employed in economy *)
itexpt[t_]=ysITt[t]-ii3[t]-ii4[t];(* it hat exported *)
(* ck *)
{l33[10]+l44[10]+lag1[10]+lsit[10],k33[10]+k44[10]+kagt[10]+ksItt[10]-kk[10]}
{1.,0.}
TableForm[base=Table[{yrcal+t,l33[t],l44[t],lag1[t],lsit[t],k33[t]/kk[t],k44[t]/kk[t],kagt[t]/kk[t],ksItt[t]/kk[t],ii3[t]/ysITt[t],ii4[t]/ysITt[t],itexpt[t]/ysITt[t]},{t,0,TT,10}],TableHeadings→{Automatic,{Year,"l33[t]","l44[t]","lag1[t]","lsit[t]","k33[t]","k44[t]","kagt[t]","ksItt[t]","ii3[t]/ysITt[t]","ii4[t]/ysITt[t]","itexpt[t]/ysITt[t]"}}]
{
{\[Null], Year, l33[t], l44[t], lag1[t], lsit[t], k33[t], k44[t], kagt[t], ksItt[t], ii3[t]/ysITt[t], ii4[t]/ysITt[t], itexpt[t]/ysITt[t]},
A3 ((l33[t])$^{\delta1}$ (k33[t])$^{\delta2}$ (ii3[t])$^{\delta3}$)-y3t[t];
{A3*.95 ((l33[0])$^{\delta1}$ (k33[0])$^{\delta2}$ (ii3[0])$^{\delta3}$),y3t[0]}
{224.563,224.563}
{conlab3[l3_,k3_,i3_,t_]=((D[A3*.95 (l3)$^{\delta1}$ (k3)$^{\delta2}$ (i3)$^{\delta3}$,l3])l33[t])/y3t[t] ∂t l33[t]/l33[t],concap3[l3_,k3_,i3_,t_]=((D[A3 *.95 (l3)$^{\delta1}$ (k3)$^{\delta2}$ (i3)$^{\delta3}$,k3])k33[t])/y3t[t] ∂t k33[t]/k33[t],conIt3[l3_,k3_,i3_,t_]=((D[A3 *.95 (l3)$^{\delta1}$ (k3)$^{\delta2}$ (i3)$^{\delta3}$,i3])ii3[t])/y3t[t] ∂t ii3[t]/ii3[t],gwthl3[t_]=∂t l33[t]/l33[t],gwthk33[t_]=∂t k33[t]/k33[t],gwthii33[t_]=∂t ii3[t]/ii3[t]};{conLab3[t_]=conlab3[l33[t],k33[t],ii3[t],t],conCap3[t_]=concap3[l33[t],k33[t],ii3[t],t],conIT3[t_]=conIt3[l33[t],k33[t],ii3[t],t]};
{conLab3[10],conCap3[10],conIT3[10]}
{0.00197994,0.0142651,0.00012379}
gwthy3[t_]=(∂t y3t[t])/y3t[t];
Plot[{gwthy3[t],conLab3[t],conCap3[t],conIT3[t]},{t,0,TT},PlotLabel→"Growth Acct. Using Prod. Fnt.",PlotStyle→{Thick,Dashing[{0.01}],Hue[2.0],Dashing[{0.08}]}]
Print["Thick = total yhatdot/yhat, Labor Cont =small dash;K Cont =sold; It Contr=large dash"]



Thick = total yhatdot/yhat, Labor Cont =small dash;K Cont =sold; It Contr=large dash
Plot[{gwthl3[t],gwthk33[t],gwthii33[t],zz=0},{t,0,TT},PlotLabel→"Growth Rate of factor inputs in mnf",PlotStyle→{Dashing[{0.01}],Hue[2.0],Dashing[{0.08}]}]
Print["Labor =small dash;K =sold; It =large dash"]



Labor =small dash;K =sold; It =large dash

TableForm[
base=Table[{yrcal+t,k33[t]/l33[t],k44[t]/l44[t],kagt[t]/lag1[t],ksItt[t]/lsit[t]
},{t,-10,TT,10}],
TableHeadings→{Automatic,{Year,"mfg","serv","ag1","IT"}}]

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □

InterpolatingFunction::dmval: Input value \[NoBreak]{1621.33}\[NoBreak] lies outside the range of data in the interpolating function. Extrapolation will be used. □

General::stop: Further output of \[NoBreak]InterpolatingFunction::dmval\[NoBreak] will be suppressed during this calculation. □

{
{\[Null], Year, mfg, serv, ag1, IT},