MODELING AND POLICY ANALYSIS FOR THE U.S. SCIENCE SECTOR[†]

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Abstract

This paper analyzes the production process of scientific outputs and its further implications on the overall U.S. economy using variants of a disaggregated Marshallian Macroeconomic Model (MMM). In this study, the U.S. science sector is modeled using a one-sector MMM that fits the data and provides reliable forecasts. To this regard, we have added to Jeffrey's inputs the traditional economic production inputs such as capital and labor to obtain a production function for scientific production units. Subsequently, we embed science as an additional input and an additional sector of our 17-sector MMM of the overall U.S. economy. In this study, we assume that firms are Bayesian learners while forming expectations about the product price. Throughout a set of policy simulations, this research provides measured information on how selected science policies may affect other sectors of the U.S. economy. Both variants of our MMM have been estimated using advanced econometric techniques such as the transfer functions estimation system.

Keywords: *Disaggregated Marshallian Macroeconomic Model; Transfer Functions; and Bayesian Learners.*

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I. INTRODUCTION

If we understand that scientific progress in general and technological innovation in particular constitute pillars for long and sustainable economic development, then more consideration should be given to modeling and policy simulations designed to promote and advance the science sector. Scientific research and development is at the core of increased productivity and increased competitive advantage for emerging world market economies. Knowledge-driven production framework has generated incommensurable technological advances that have translated into increased wealth, job creation, substantial improvement in living standard, etc.

Although it is more pronounced in developed countries and emerging markets, scientific progress constitutes a key resource to world economies. Advances in science have generated growing demand for skilled labor-force. It is therefore highly relevant to identify and carefully study how scientific knowledge is diffused and how it affects economic performance overall.

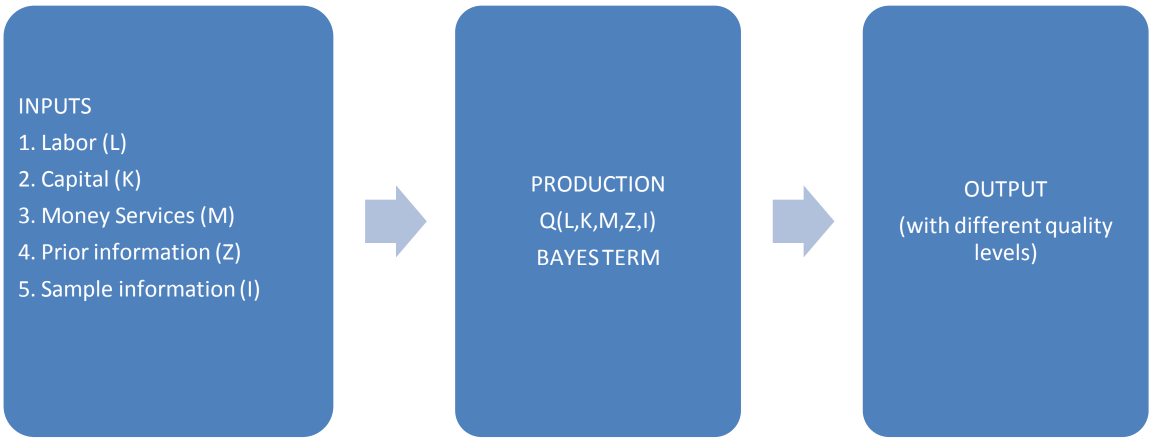
In the promotion and commercialization of scientific outputs, patents have played a continuous role. In this study, we first attempt to measure scientific output proxied by the number of approved patents. Considering the use of information in promoting economic production, we have included sample and prior information in our theoretical framework although lack of available data led us to the use of proxies in our empirical evaluation.

As it has been discussed at length in the media and in the academic community, the United States is still recovering from one of its most devastating economic crisis. The country's economy is pretty much in tatter and most recovery indicators remain turbulent. Importantly, let's note that several efforts have been undertaken to foster the country's economy. Among others, the US Government undertook fiscal stimulus packages of nearly $800 billion that include a substantial amount allocated to scientific and research development. Throughout our modeling exercise, this study attempts to advise policy makers on the use and the impact that scientific stimulus has on the rest of the country's economy. Using a model that fits the data reasonable well and provide reliable predictions, we have performed a set of policy simulations that we believe will be of great use to scientists as well as policy makers.

Having completed our introduction, an overview of the rest of the paper is as follows. The second section is devoted to a thorough description of our modeling framework. Section III includes fits and forecasts of all the variants of our MMM. In this section, we start with a one-sector MMM of the U.S. Science sector without prior and sample information and without variables on exogenous government spending. Further on, we introduce three additional inputs related to research spending on (1) Basic Research, (2) Applied Research, and (3) Development. We then present results of our 16-sector MMM and expand them into a 17-sector MMM with the inclusion of Science which becomes at the same time an additional sector and an additional input for other sectors of the US economy. Besides, we implement a set of policy shocks aimed at assessing the impact of raised research spending on the outcome of the U.S. Science sector and the other sectors of the U.S. economy in Section IV.

II. MODELING FRAMEWORK

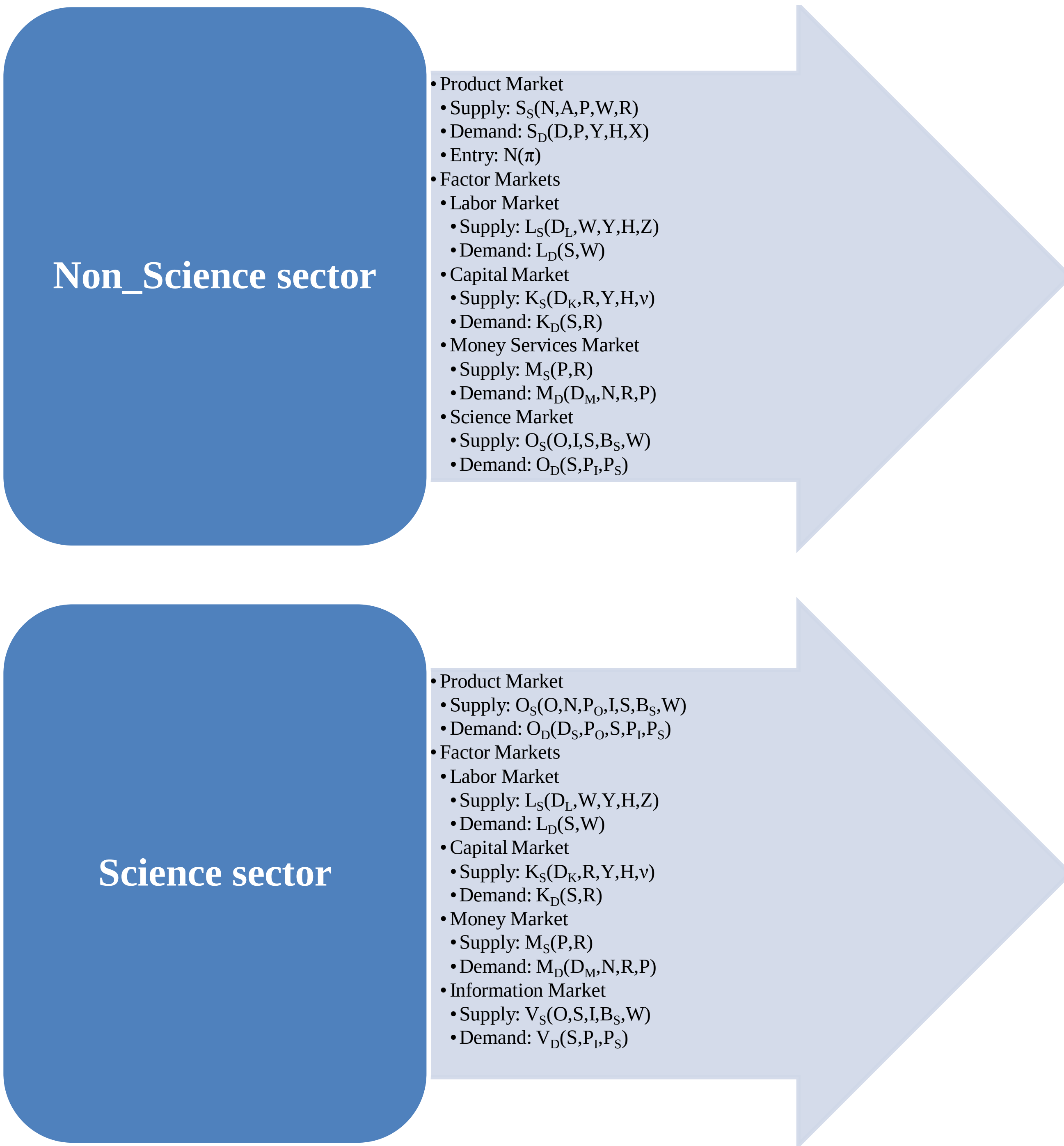
Diagram 1: Production Process in the Science Sector



The modeling of a U.S. Science sector includes a product market with different quality levels of research outputs and markets for the production factors. The factors of production are (1) Labor, (2) Capital, (3) Money services, (4) Prior Information, and (4) Sample Information. For each of these inputs there is a market with supply, demand and equilibrium dynamics. Prior information and sample information are used through Bayes terms to produce respectively information in posterior distribution of parameters and information in marginal density of observations. Prior information can be measured through the amount of consultancy work the sector makes use of while sample information will be the amount of data and other information available to the lab. Furthermore, we price the output information and the input information to get the profit that is maximized. Also, the labor market could be used to gauge the potential job creation process that occurs as a result of federal investments.

The science sector affects other sectors of the economy through their factor markets. Output of the science sector i.e. innovation, constitutes a key input for other sectors. In the traditional macroeconomic models, scientific outputs such as innovation appear through the technological factor productivity.

Diagram 2: Product and Factor Markets for the Science and Non-Science sectors



Note: In the diagram, the letters represent different variables expressed in real terms such as *S* (product real sales), *N* (number of firms operating in the sector), *A* (technological factor productivity), *P* (product price), W (real wage), R (interest rate), L (labor), K (capital), Y (real income), H (number of households), X (other demand shifters), D_K (number of capital suppliers), π (individual firms profit), D_L(number of labor suppliers), D_M (number of demanders of money services), O (output of the science sector), I (prior information), S (sample information), B_S (budgeted amount for Research and Development), P_S(price of sample information), P_I (price of prior information), V (output of the information market).

Supply, Demand and Entry Equations

We assume a Cobb-Douglas specification of the production function and firms are profit optimizers in the science sector.

The optimization process yields the following output function for an individual firm.

$$Q_t = A_t^{\frac{1}{1-\alpha-\beta-\gamma-\sigma}} \alpha^{\frac{\alpha}{1-\alpha-\beta-\gamma-\sigma}} \beta^{\frac{\beta}{1-\alpha-\beta-\gamma-\sigma}} \sigma^{\frac{\sigma}{1-\alpha-\beta-\gamma-\sigma}} \gamma^{\frac{-\alpha-\beta-\sigma}{1-\alpha-\beta-\gamma-\sigma}} r_t^{\frac{-\beta}{1-\alpha-\beta-\gamma-\sigma}} w_t^{\frac{-\alpha}{1-\alpha-\beta-\gamma-\sigma}} P_{Zt}^{\frac{-\gamma}{1-\alpha-\beta-\gamma-\sigma}} P_{It}^{\frac{-\sigma}{1-\alpha-\beta-\gamma-\sigma}} (\alpha+\beta+\gamma+\sigma)^{\frac{\alpha+\beta+\gamma+\sigma}{1-\alpha-\beta-\gamma-\sigma}} \quad (1)$$

Multiplying output by the price we obtain the sales supply function for an individual firm and the sector's sales supply function is obtained by multiplying individual sales by the total number of firms within the sector (N).

Supply Function

$$S_{St} = N_t.P_t.A_t^{\frac{1}{1-\alpha-\beta-\gamma-\sigma}} \alpha^{\frac{\alpha}{1-\alpha-\beta-\gamma-\sigma}} \beta^{\frac{\beta}{1-\alpha-\beta-\gamma-\sigma}} \sigma^{\frac{\sigma}{1-\alpha-\beta-\gamma-\sigma}} \gamma^{\frac{-\alpha-\beta-\sigma}{1-\alpha-\beta-\gamma-\sigma}} r_t^{\frac{-\beta}{1-\alpha-\beta-\gamma-\sigma}} w_t^{\frac{-\alpha}{1-\alpha-\beta-\gamma-\sigma}} P_{Zt}^{\frac{-\gamma}{1-\alpha-\beta-\gamma-\sigma}} P_{It}^{\frac{-\sigma}{1-\alpha-\beta-\gamma-\sigma}} (\alpha+\beta+\gamma+\sigma)^{\frac{\alpha+\beta+\gamma+\sigma}{1-\alpha-\beta-\gamma-\sigma}} \quad (2)$$

Demand Function

Similarly, on multiplying both sides of the consumers' demand function for output, we have the following "product sales demand function":

$$S_{Dt} = DP_t^{1-\theta} Y_t^{\theta_S} H_t^{\theta_H} \prod_{j=1}^{n} X_{jt}^{\theta_j} \tag{3}$$

In (3), Y is personal disposable income, H, the number of demanders of scientific products, X, the demand shifters (with n, the number of demand shifters), and D, a constant. In a one sector economy with taxes, if $\theta = \theta_S$ there is no money illusion.

Entry-Exit Function

Firms enter the industry when economic profits are positive and leave the industry when economic profits are negative and give rise to associated shifts in the industry supply function that we represent in the following equation:

$$\frac{\dot{N}_t}{N_t} = C_E \pi_t \tag{4}$$

In (4), the market profit within a given sector at time t is equal to π_t. Given profit maximization and the Cobb-Douglas specification, a firm's profit π is equal to a proportion ℓ of its sales S_S, that is, $\pi_t = \ell S_{St}$, we can transform (4) as follows

$$\frac{\dot{N}_t}{N_t} = C_E \ell S_{St} \tag{5}$$

As shown in diagram 2, besides supply, demand and entry-exit equations, each input is modeled in a competitive market (see Zellner and Ngoie, 2010 for a complete MMM).

Predictive probability density function for expected prices

In our model, we assume that firms or labs are Bayesian learners, they produce based on prices derived from a predictive probability density function that is developed as follows.

$$p\left(P_{T+1}^{e} \middle| D_T\right) = \int_{\theta} f(P_{T+1}^{e} | \theta, D_T)\pi(\theta | D_T)d\theta \tag{6}$$

Where:

- $f(P_{T+1}^{e} | \theta, D_T)$ represents the pdf;
- $\pi(\theta | D_T)$ is the posterior pdf of θ;
- D_T is the past sample and prior information as of time *T*;
- θ being the parameter vector included in a parameter space.

Further, we obtain the reduced form dynamic equilibrium function by equating (2) and (3) while replacing *N* in (2) by (5). Optimal input costs are obtained from our factor markets optimization (see Zellner and Ngoie, 2010). From the reduced form dynamic equilibrium equations we now derive our transfer equations.

Transfer functions

We have derived mathematically our transfer functions from the dynamic linear structural equation models referred above. Referring to Quenouille (1957) we can represent a linear multiple time series process as follows (see Zellner and Palm, 2004).

$$\underset{mx1}{H(L)\, z_t} = \underset{mxm}{F(L)}\, \underset{mx1}{\varepsilon_t} \ , \tag{7}$$

where (1) $z_t^{'} = (z_{1t}, z_{2t}, ..., z_{mt})$ is a vector of random variables, and (2) $\varepsilon_t^{'} = (\varepsilon_{1t}, \varepsilon_{2t}, ..., \varepsilon_{mt})$ is the random error vector. $H(L)$ and $F(L)$ are the full rank matrices with polynomial lag operators as elements. Then we allow $z_t^{'} = (y_t^{'}, x_t^{'})$ with y_t as vector of the endogenous variables and x_t the vector of the exogenous variables. Then (7) becomes

$$\begin{bmatrix} H_{11}(L) & H_{12}(L) \\ H_{21}(L) & H_{22}(L) \end{bmatrix} \begin{bmatrix} y_t \\ x_t \end{bmatrix} = \begin{bmatrix} F_{11}(L) & F_{12}(L) \\ F_{21}(L) & F_{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

Assuming x_t as exogenous, the system can be written as follows.

$H_{21}(L) = 0$, $F_{12}(L) = 0$ and $F_{21}(L) = 0$ y_t,

$$H_{11}(L) y_t + H_{12}(L) x_t = F_{11}(L) \varepsilon_{1t} \tag{8}$$

$$H_{22}(L) x_t = F_{22}(L) \varepsilon_{2t} \tag{9}$$

From the system above, we derive the transfer functions by multiplying both sides of (9) by H_{11}^{-1} to obtain

$$y_t = -H_{11}^{-1} H_{12}(L) x_t + H_{11}^{-1} F_{11} \varepsilon_{1t} \tag{10}$$

From $H_{11}^{-1} = \dfrac{H_{11}^{adj}}{|H_{11}|}$, (10) can be expressed as

$$|H_{11}| y_t = -H_{11}^{adj} H_{12}(L) x_t + H_{11}^{adj} F_{11}(L) \varepsilon_{1t}$$

Transfer functions for the endogenous variables in our MMM-DA are obtained from (10) with

$$H_{11} = \begin{bmatrix} 1 & -\lambda(L) & -1 \\ 1 & -\gamma(L) & 0 \\ 0 & 0 & 1 \end{bmatrix}, \text{ and } H_{11}^{-1} = \frac{1}{|H_{11}|} \begin{bmatrix} -\gamma(L) & \lambda(L) & -\gamma(L) \\ -1 & 1 & -1 \\ 0 & 0 & \lambda(L) - \gamma(L) \end{bmatrix}$$

Therefore: $H_{11}^{adj} = \begin{bmatrix} -\gamma(L) & \lambda(L) & -\gamma(L) \\ -1 & 1 & -1 \\ 0 & 0 & \lambda(L) - \gamma(L) \end{bmatrix}$

where $\lambda(L)$ and $\gamma(L)$ are polynomial lag operators.

III. RESULTS

As a starting point in this results' section, we explore the fit as well as forecasting performance of our one-sector MMM of the U.S. Science sector without prior and sample information and without variables on exogenous government spending. Further on, we introduce three additional input costs related to research spending on (1) Basic Research, (2) Applied Research, and (3) Development and describe the fit and forecasting performance of our expanded model. Due to lack of appropriate data series, we have been unable to include well defined variables representing sample and prior information. Work is underway to this regard and in further studies we shall include those series and assess the impact of the fit and model's forecast performance. The use of well defined research inputs and costs is a good way to palliate to this data weakness and we have been pleased by the results.

III.1. ONE-SECTOR MMM OF THE US SCIENCE SECTOR WITH OUTPUT MEASURED USING THE NUMBER OF PATENTS (without the two additional inputs: Prior and Sample Information)

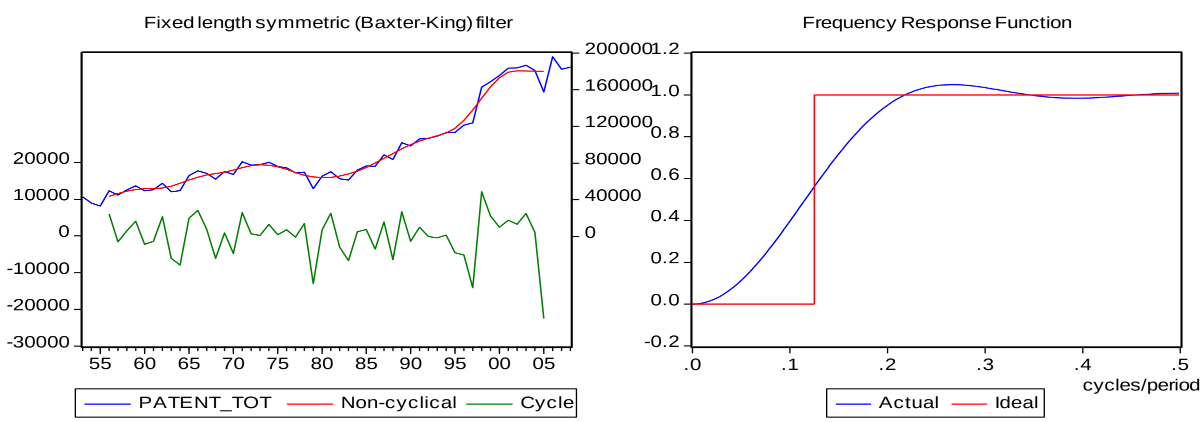
a) Fitted transfer equations

The transfer function fitted for our one-sector MMM of the U.S. science sector is as follows.

$$[\lambda(L)-\gamma(L)]s_t = -\gamma(L)[\varphi_0 - \varphi_1 S_{t-1} - \sigma_1 w_t - \sigma_2 r_t - \sigma_3 m2_{t-1} - \sigma_4 ctax_t - \mu_{1t} - \mu_{2t}]$$
$$+\lambda(L)[\Delta_1 y_t + \Delta_2 open_t + \Delta_3 h_t + \mu_{3t}] \quad (11)$$

Besides, we made use of the Baxter-King filter to better appraise the salient characteristics of cycles, trends and frequency responses in the total number of patents approved over the years in the U.S.

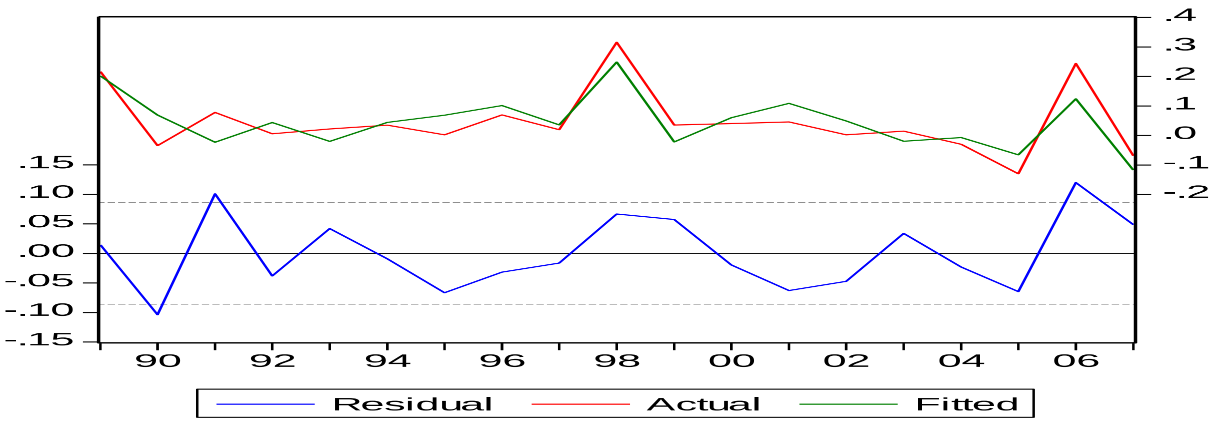
Fig.1 - Trend, Cycle and Frequency Response Function for Total Number of Patents Delivered in the US Economy from 1953 to 2008



Although the concept 'cycle' is a misnomer insofar as no sole periodic behavior is observable in a given economy, filtering process are of great use in identifying some of the non-unique periodicities that exist. Fig. 1 depicts the cyclicality of the number of patents and portrays to some large extent regularities of long standing (Zarnowitz, 1992). Indeed, we observe large variations of fluctuations in amplitude, scope and frequency, yet they are persistent and some commonalities can be extracted. Also, we have obtained satisfactory results for the frequency response function which seems to stabilize over the periods. More measures of productivity related to the science sector are reported using figures in the Appendix.

Fig. 2 - Actual, Fit and Residuals of the one-sector MMM of the U.S. science sector, 1988 to 2008

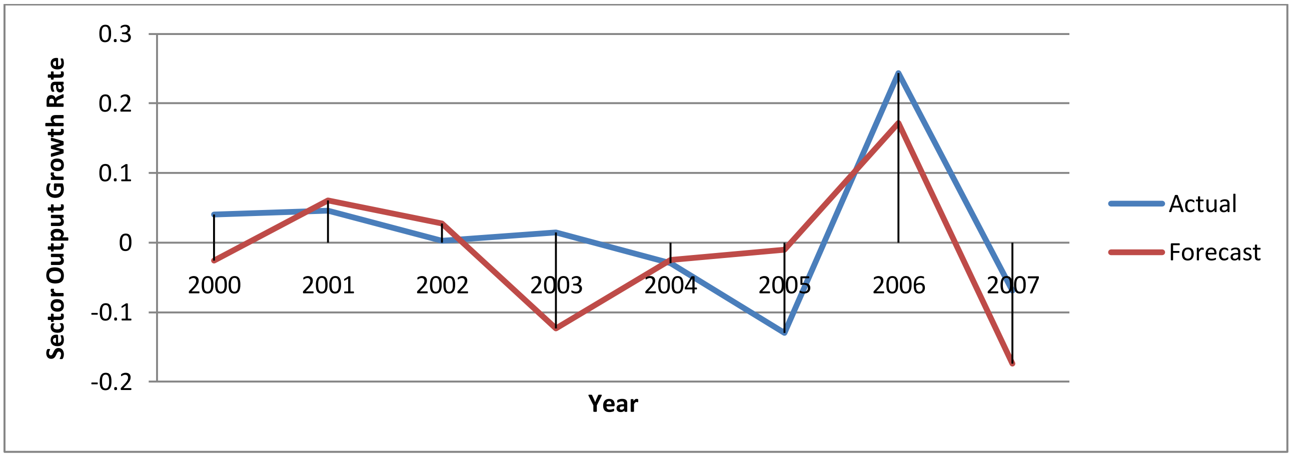
No. of patents (growth rate)



Year

Fig.2 portrays reliable fit although fitness in itself can be misleading in macroeconomic modeling. Things commonly practiced such as overparameterization can lead to remarkable fit even though the model used in itself is totally unreliable. To this regard, we have performed generic statistical testing and produce forecasts. Below, we made report values of Mean Absolute Forecast Errors (MAFE) and Root Mean Square Forecast Errors (RMSFE) in assessment of the accuracy of our forecasts. The choice between existing measures of accuracy in forecasting is driven by the conception of types and amplitude of errors and how they affect the forecast (see Zarnowitz, 1999). For example, the MAE will be used when the size of the difference between predicted and actual values is the only determinant of the loss. However, if we are more concerned by larger errors (positive or negative), the RMSE is recommended. When both matter, the size of the difference as well as the sign of the errors, the loss function will be asymmetric.

Fig. 3 - One-Year Ahead Forecast of the one-sector MMM of the U.S. Science sector, 2000 - 2008



Mean Absolute Forecast Error (MAFE) = 2.31 percentage points

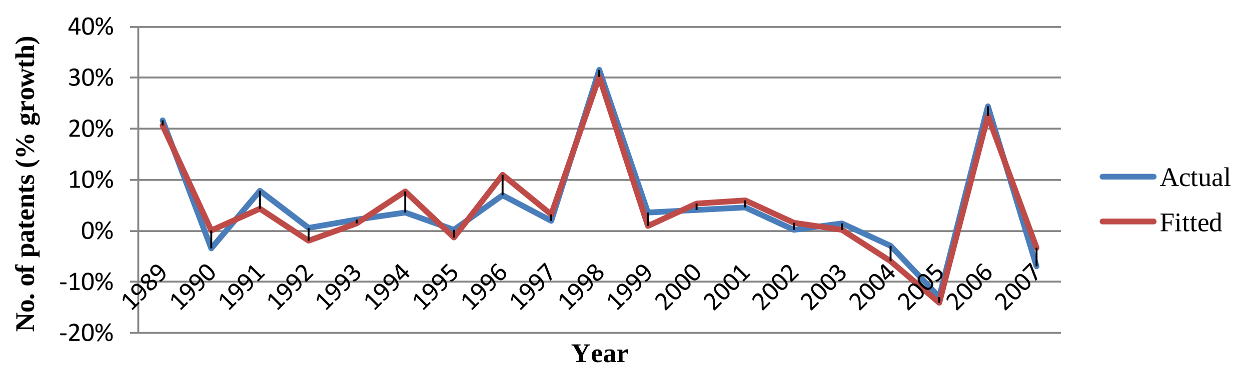
Root Mean Squared Forecast Error (RMSFE) = 3.30 percentage points

III.2. ONE-SECTOR MMM OF THE U.S. SCIENCE SECTOR USING EXPENDITURES ON BASIC RESEARCH, APPLIED RESEARCH AND DEVELOPMENT.

a) Fitted equations

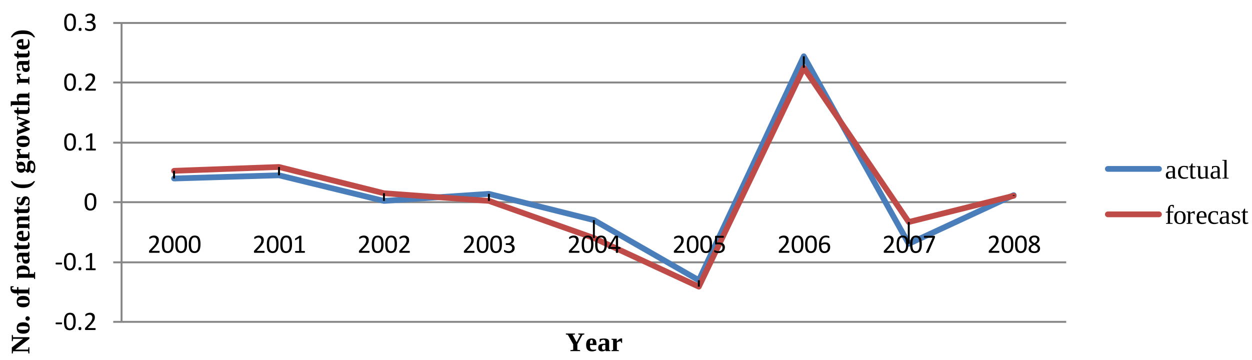
Once again, for our one-sector MMM of the US Science sector, we have fitted a transfer function obtained from the general formulation (see Eq. 1). In this case, we simply add the three input variables (*bas*, *appl*, *dev*) into the matrix x_{2t}.

Fig. 4 - Actual, Fitted and Residuals Series of total patents delivered in the US, 1989-2007



b) Forecast

Fig. 5 - Actual vs Forecast Series of Total Patents Delivered in the US, 2000 - 2008



MAFE = 1.63 percentage points

RMSFE = 1.91 percentage points

Beside the fact that our MMM of the U.S. Science sector fits remarkably well the data, its forecasting performance is commendable. While noting that the forecasting period is relatively short – eight years only - the MAFE and RMSFE are indeed really small and the model is able to forecast 100 percent of all the turning points.

The use of additional inputs related to the production of scientific outputs, as described in our model specification, has provided substantial improvement to both the fit and forecast of our one-sector MMM.

III.3. 16-SECTOR MMM OF THE US ECONOMY WITHOUT SPECIAL CONSIDERATION OF THE SCIENCE SECTOR AS INPUT TO OTHER SECTORS

a) Fitted equations (see Zellner and Ngoie, 2010)

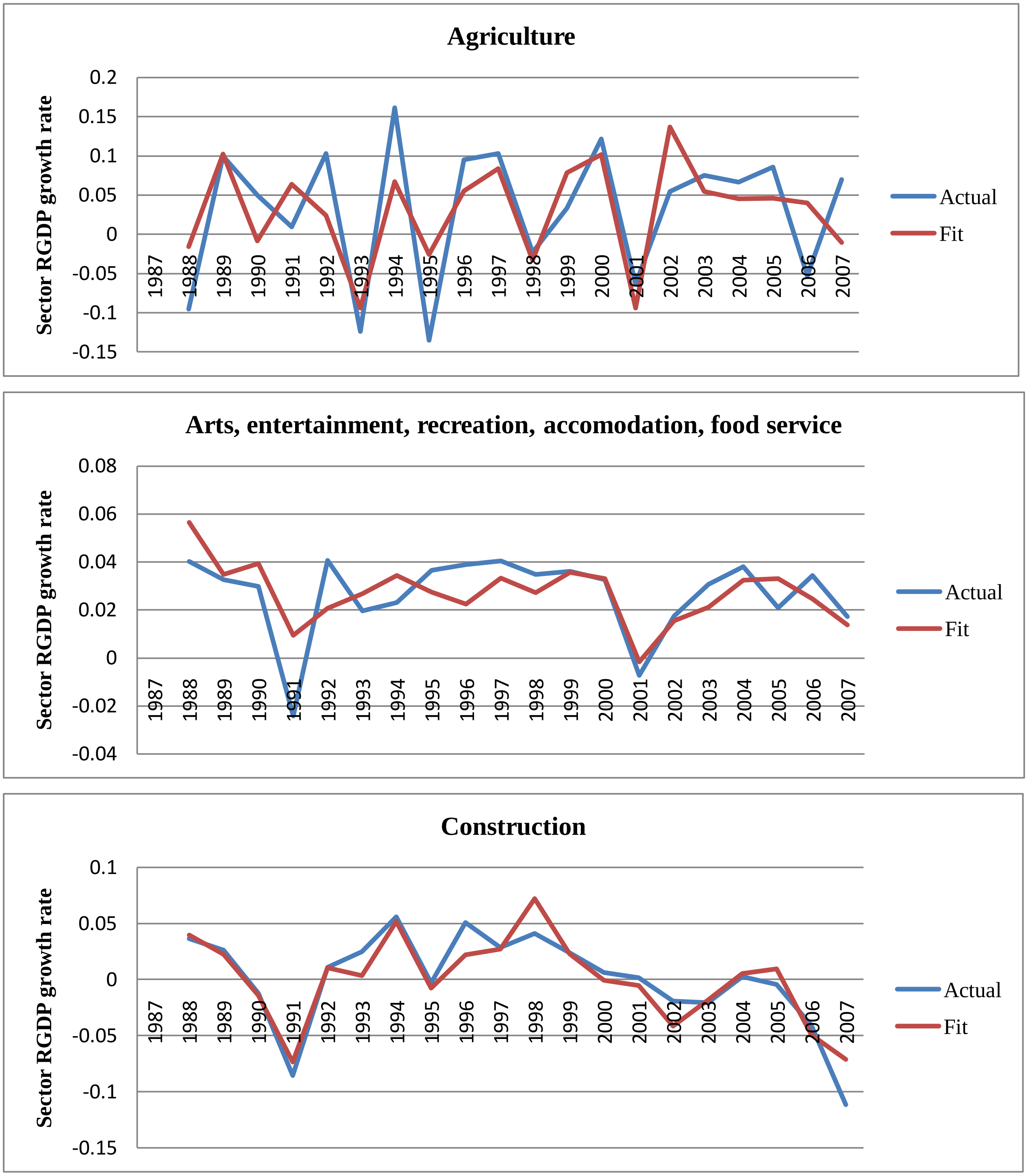
$$|H_{11}|x_{1it} = -H_{11}^{adj}H_{12}(L)x_{2it} + H_{11}^{adj}F_{11}(L)\varepsilon_{1it} \qquad (12)$$

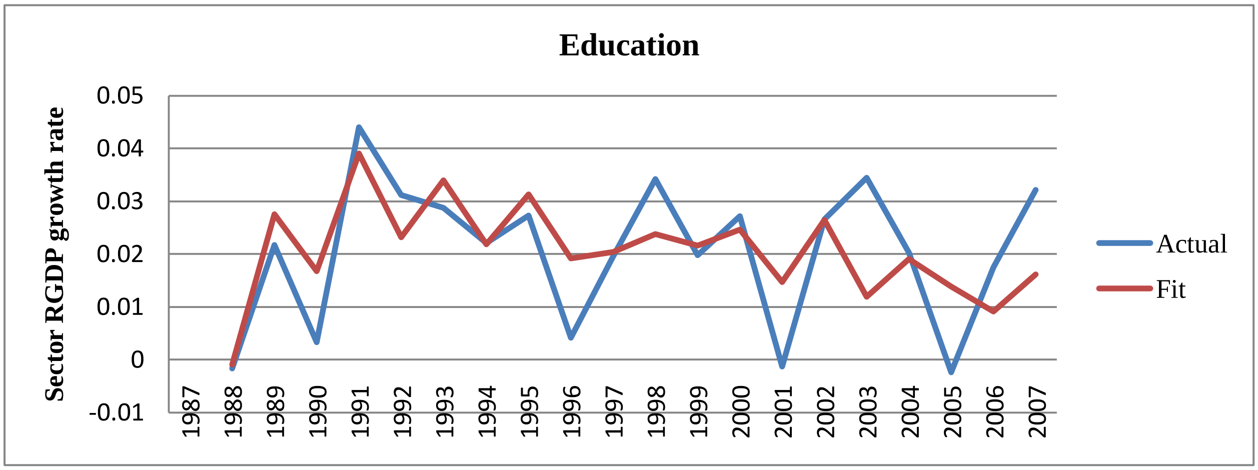
where $x_{1it} = (s_{it}, p_{it}, n_{it})'$ is the vector of endogenous variables,

$x_{2it} = (w_{it}, r_{it}, m2_t sp_t, ctax_{it}, y_t, open_t, h_t)'$ is the vector of exogenous variables, and

$\varepsilon_{1it} = (\mu_{1it}, \mu_{2it}, \mu_{3it})'$ is the vector of error terms. Again, in this study, for our 16-sector MMM we only fit one of the three transfer functions for each sector of the US economy, s_{it}.

Fig. 6 - Actual Versus Fitted Values of Growth Rates by Industrial Sectors




Education
Sector RGDP growth rate
0.05
0.04
0.03
0.02
0.01
0
-0.01
1987
1988
1989
1990
1991
1992
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1994
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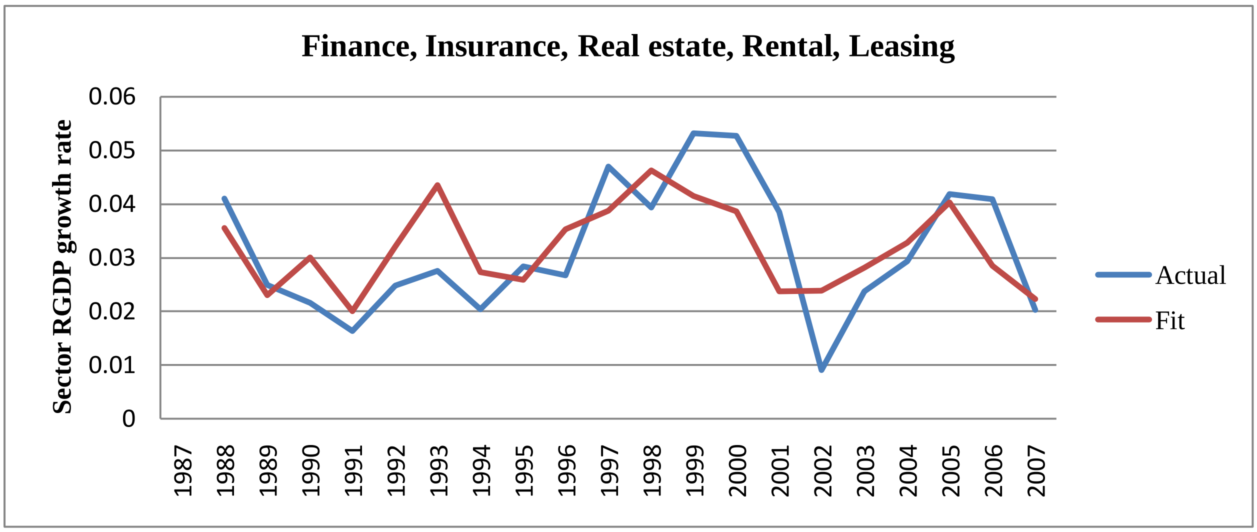
2004
2005
2006
2007
Actual
Fit


Finance, Insurance, Real estate, Rental, Leasing
Sector RGDP growth rate
0.06
0.05
0.04
0.03
0.02
0.01
0
1987
1988
1989
1990
1991
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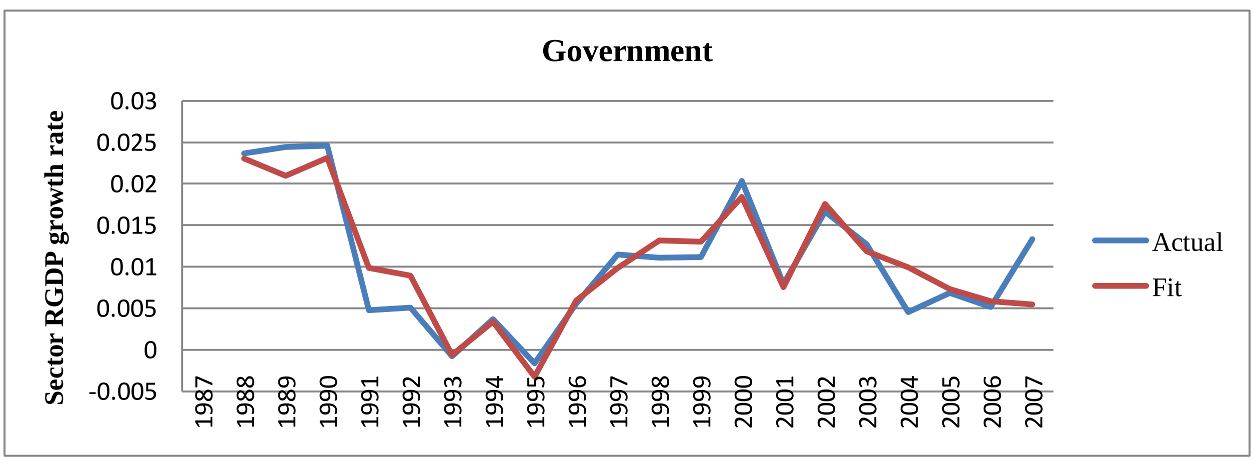
2006
2007
Actual
Fit


Government
Sector RGDP growth rate
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
1987
1988
1989
1990
1991
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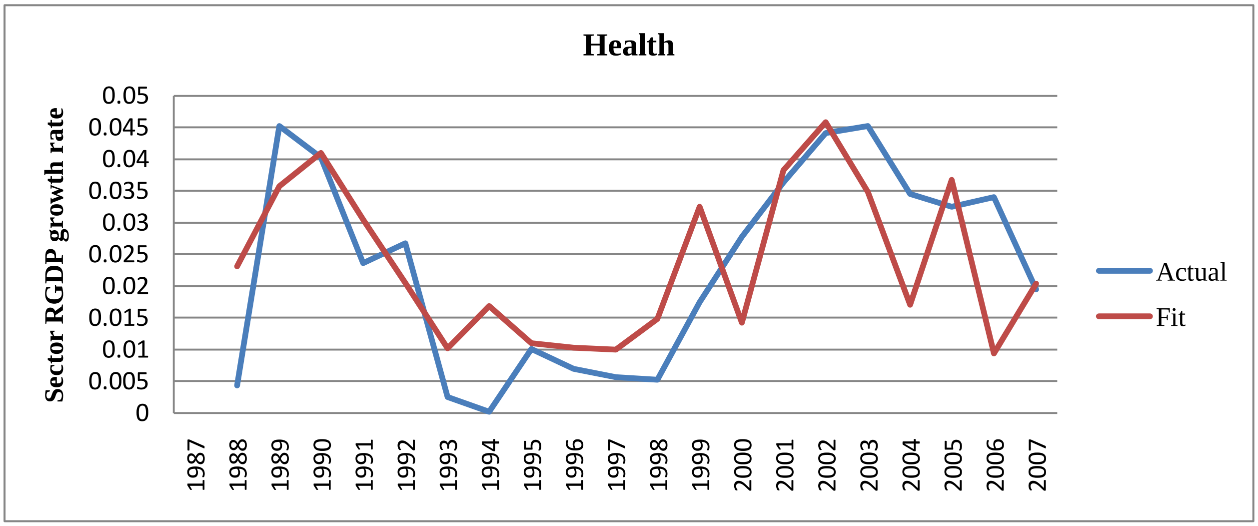
2004
2005
2006
2007
Actual
Fit


Health
Sector RGDP growth rate
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
1987
1988
1989
1990
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2000
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2006
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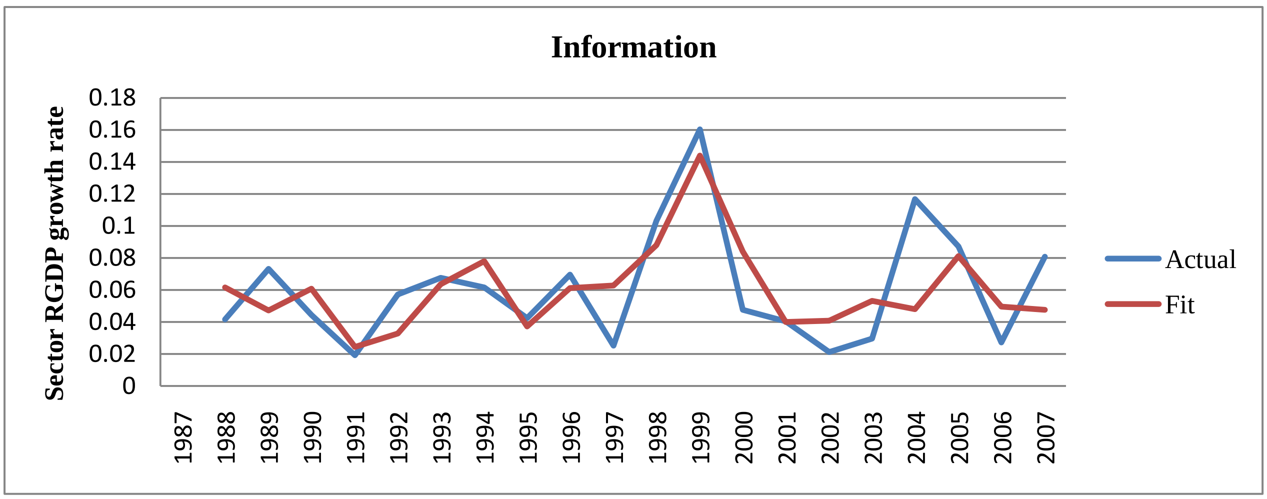
Actual
Fit


Information
Sector RGDP growth rate
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1987
1988
1989
1990
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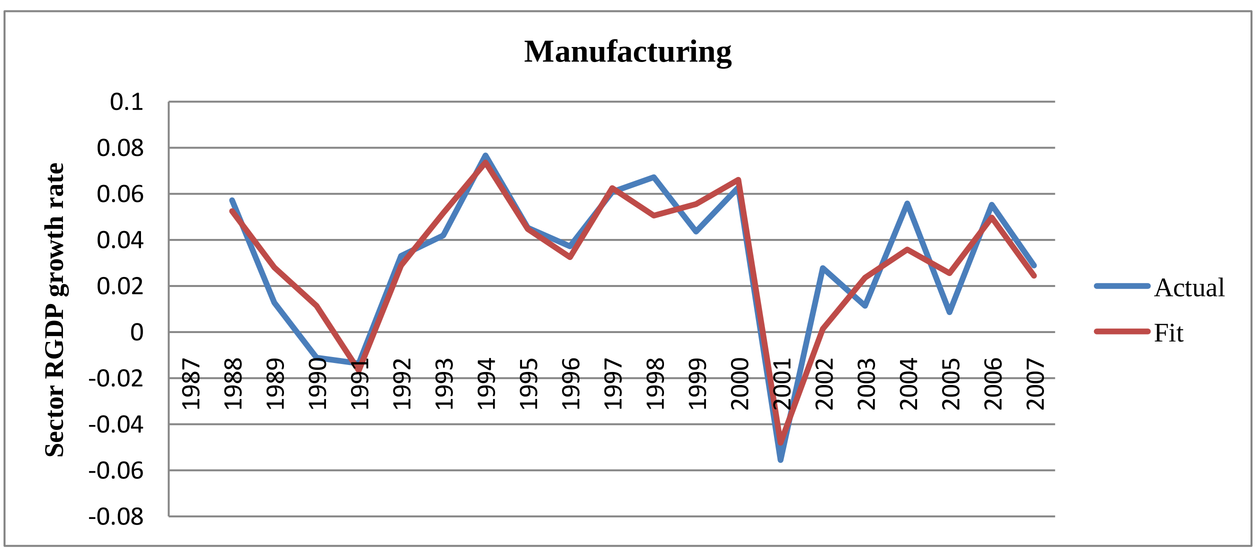
Actual
Fit


Manufacturing
Sector RGDP growth rate
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
1987
1988
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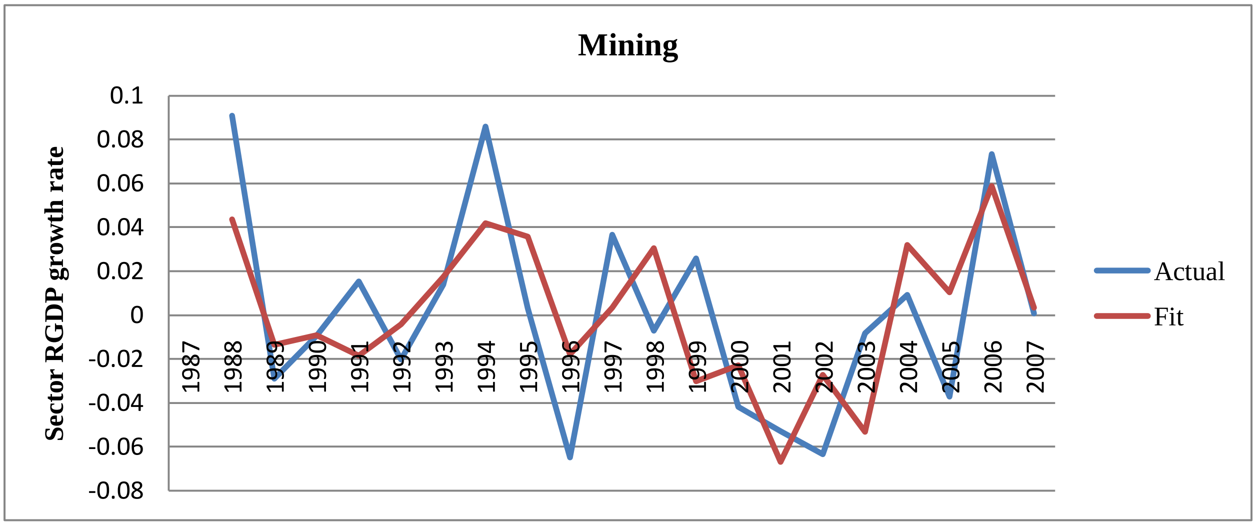
Actual
Fit


Mining
Sector RGDP growth rate
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
1987
1988
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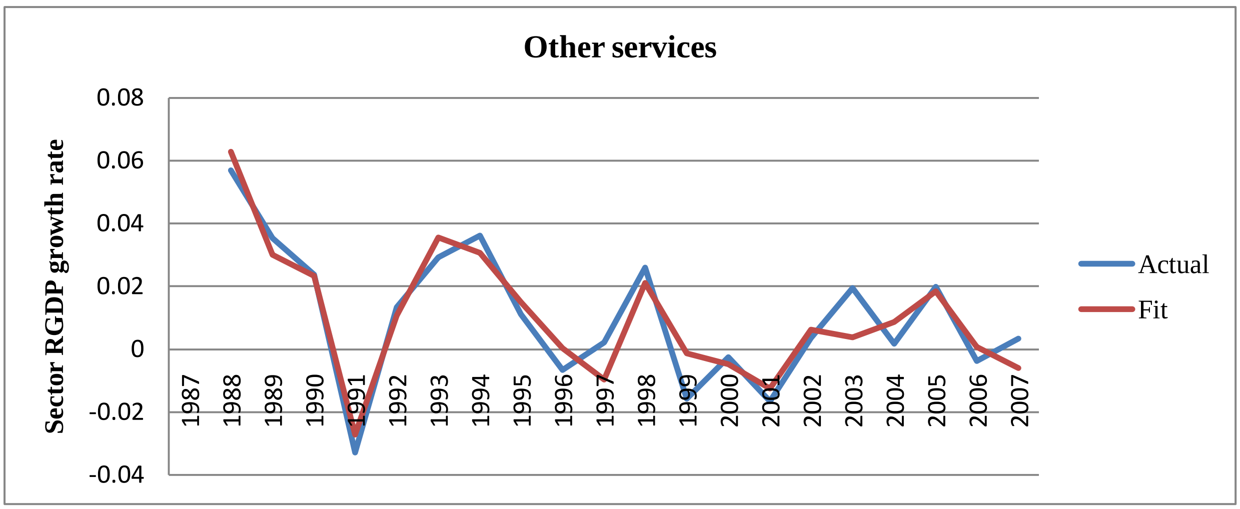
Actual
Fit


Other services
Sector RGDP growth rate
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1987
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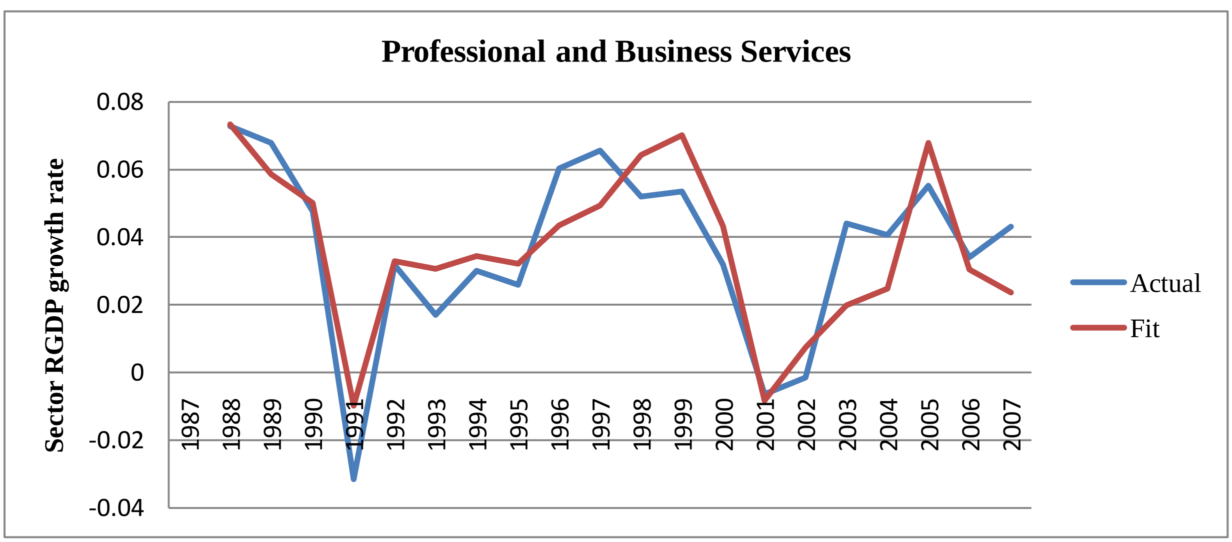
Actual
Fit


Professional and Business Services
Sector RGDP growth rate
0.08
0.06
0.04
0.02
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-0.02
-0.04
1987
1988
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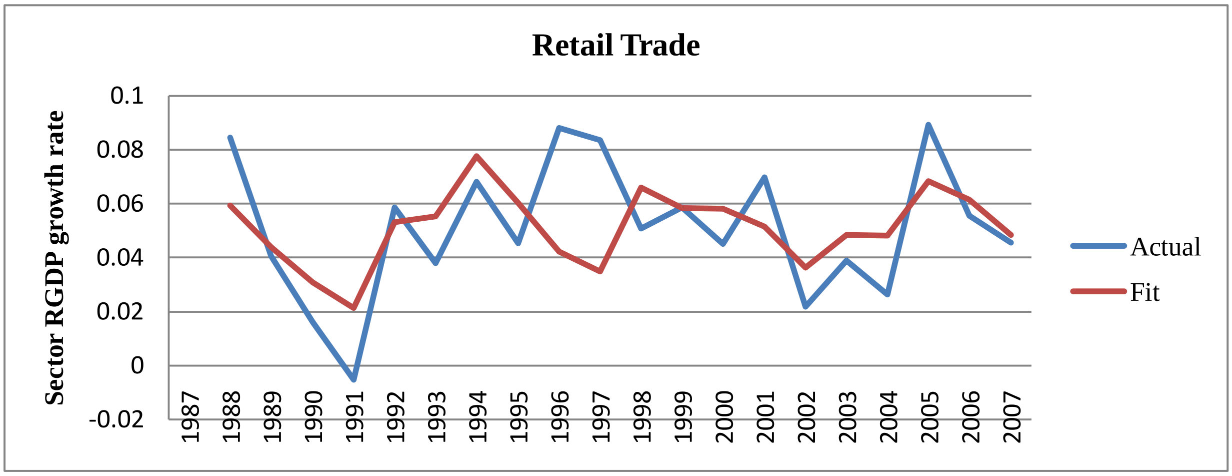
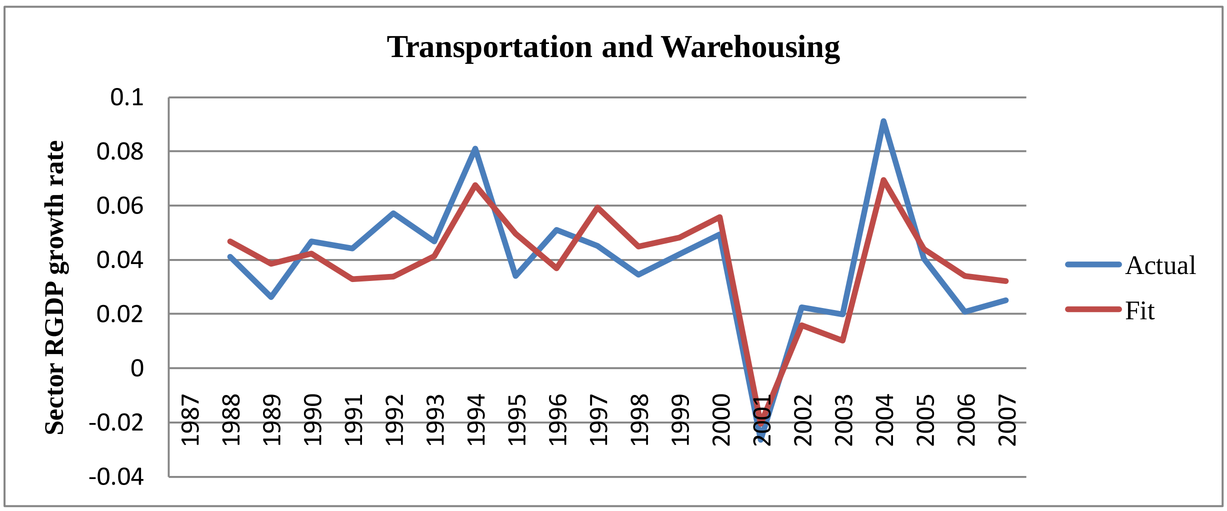
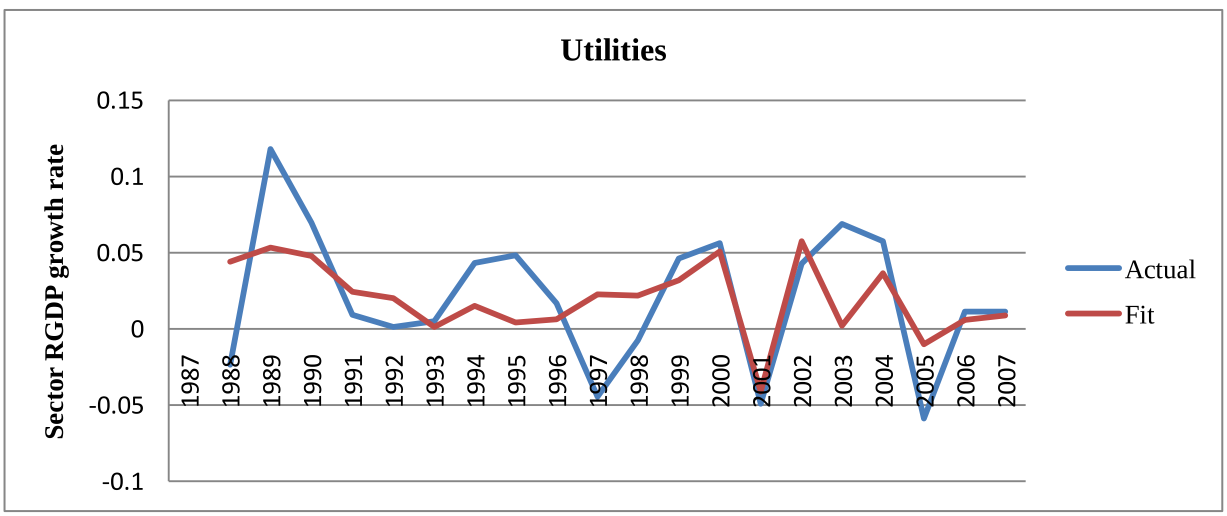
Actual
Fit


Retail Trade
Sector RGDP growth rate
0.1
0.08
0.06
0.04
0.02
0
-0.02
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Actual
Fit


Transportation and Warehousing
Sector RGDP growth rate
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Actual
Fit


Utilities
Sector RGDP growth rate
0.15
0.1
0.05
0
-0.05
-0.1
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Actual
Fit

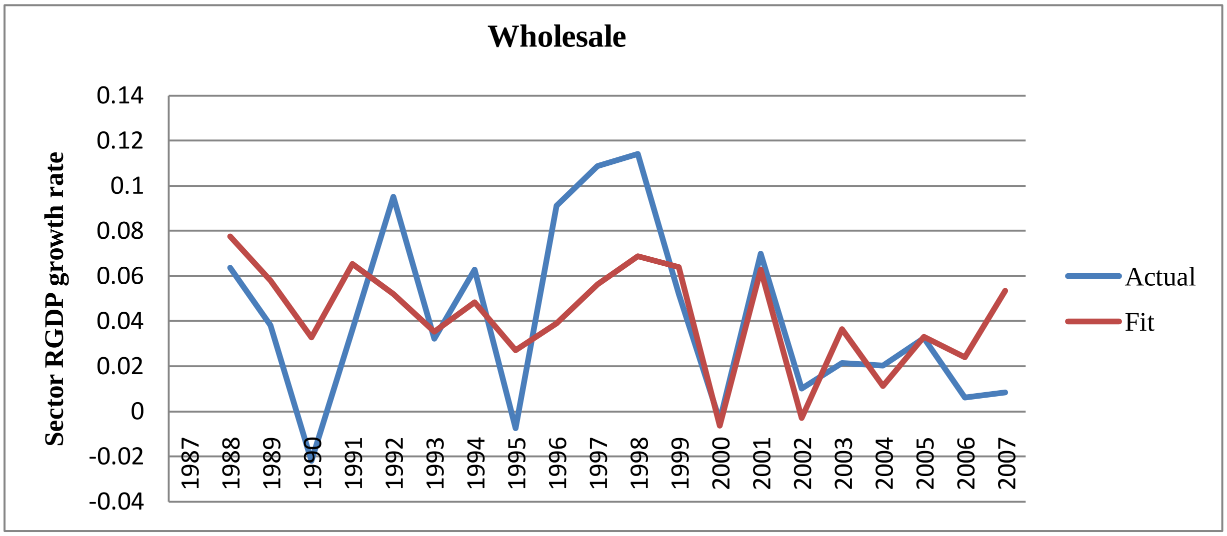


Table 1 - MAEs and RMSEs Fits by Industrial Sectors

Sector	Errors Based on Fitted Values* MAE	RMSE
Arts, entertainment, recreation, accommodation, food service	0.90 %	1.17 %
Construction	2.13 %	3.08 %
Education	1.09 %	1.01 %
Finance, Insurance, Real Estate, Rental, Leasing	0.82 %	1.06 %
Government	0.54 %	0.72 %
Health	1.26 %	1.69 %
Information	2.37 %	2.87 %
Manufacturing	1.45 %	1.79 %
Mining	3.11 %	3.96 %
Other services, except Government	0.79 %	1.07 %
Professional and Business Services	1.13 %	1.55 %
Retail Trade	1.70 %	2.16 %
Transportation and Warehousing	1.02 %	1.26 %
Utilities	3.06 %	3.64 %
Wholesale Trade	2.80 %	3.62 %
Agriculture	5.15 %	5.92 %

Note: Due to insufficient number of observations for cross-section SUR estimation (the number of periods must exceed the number of Pool cross-section members) we were unable to provide one-year ahead errors forecasts based on many years. However, for the few points forecast obtained, the errors are significantly lower for the 16-sector MMM.

*Errors expressed in percentage points

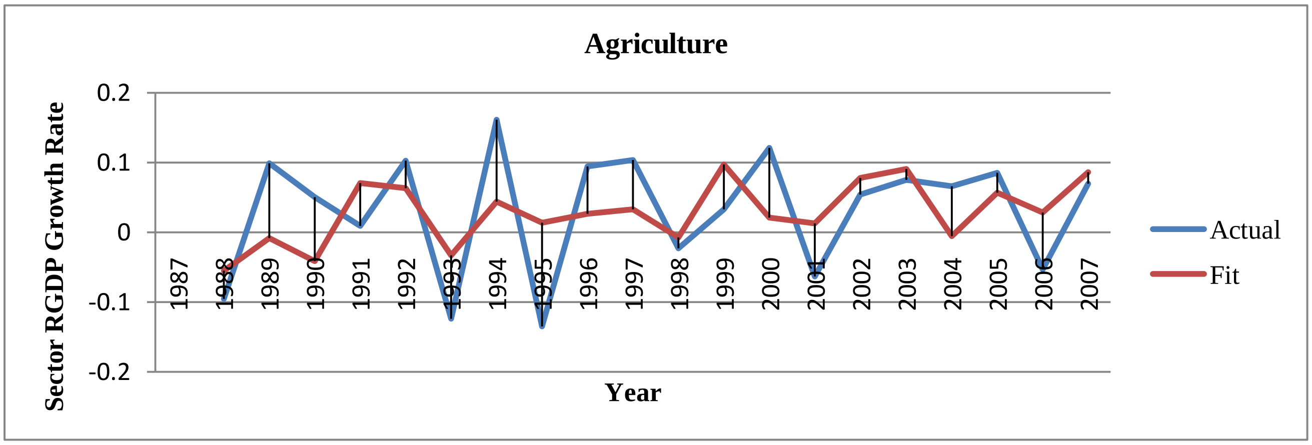
III.4. 17-SECTOR MMM OF THE US ECONOMY WITH SPECIAL CONSIDERATION OF THE IMPACT OF ADVANCES IN SCIENCE SECTOR ON OTHER SECTORS OF THE US ECONOMY

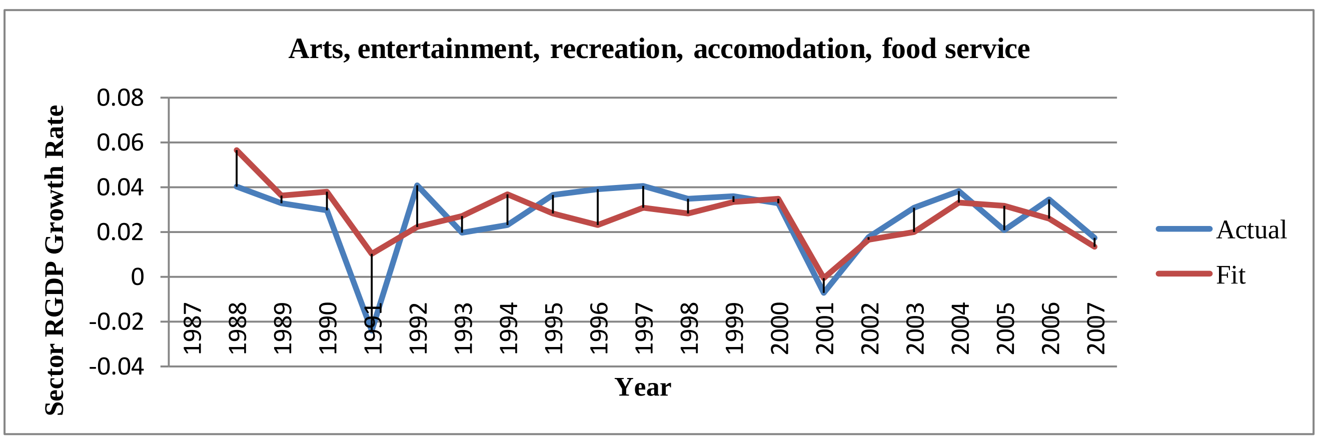
a) Fitted equations

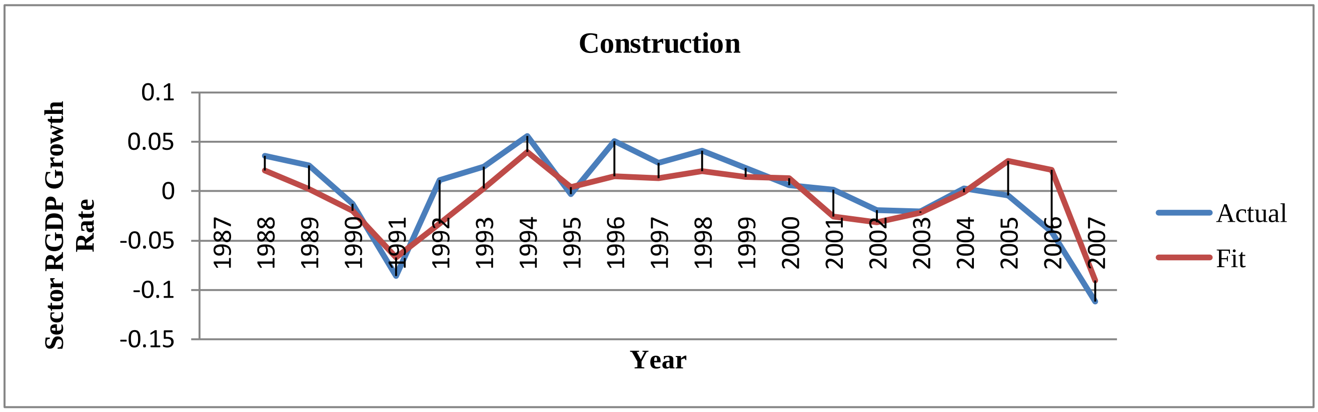
$$|H_{11}|x_{1it} = -H_{11}^{adj}H_{12}(L)x_{2it} + H_{11}^{adj}F_{11}(L)\varepsilon_{1it} \qquad (4)$$

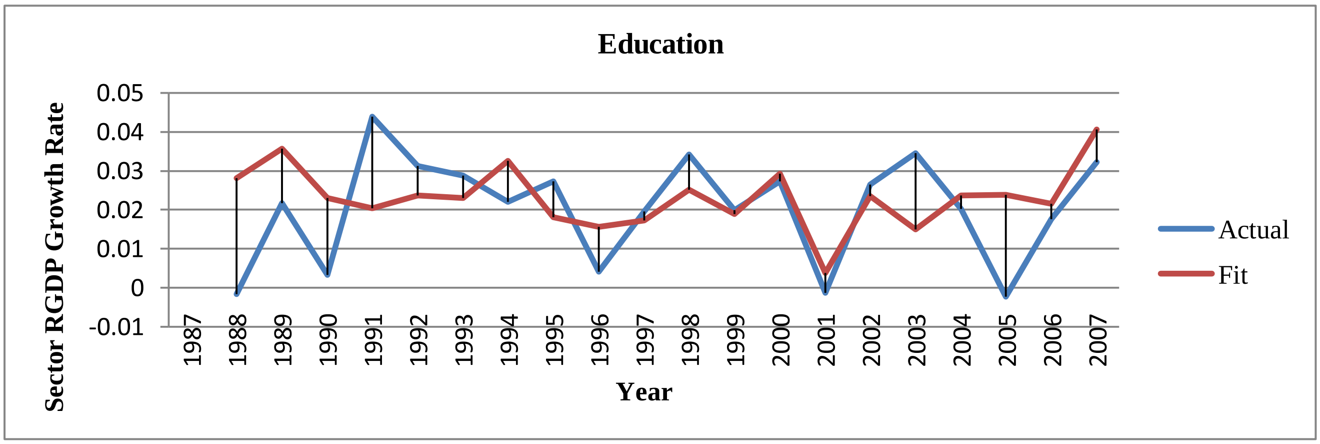
where $x_{1it} = (s_{it}, p_{it}, n_{it})'$ is the vector of endogenous variables, $x_{2it} = (w_{it}, r_{it}, m2_t sp_t, ctax_{it}, y_t, open_t, h_t, bas_t, appl_t, dev_t)'$ is the vector of exogenous variables, and $\varepsilon_{1it} = (\mu_{1it}, \mu_{2it}, \mu_{3it})'$ is the vector of error terms. Again, in this study, for our 17-sector MMM we only fit one of the three transfer functions for each sector of the US economy.

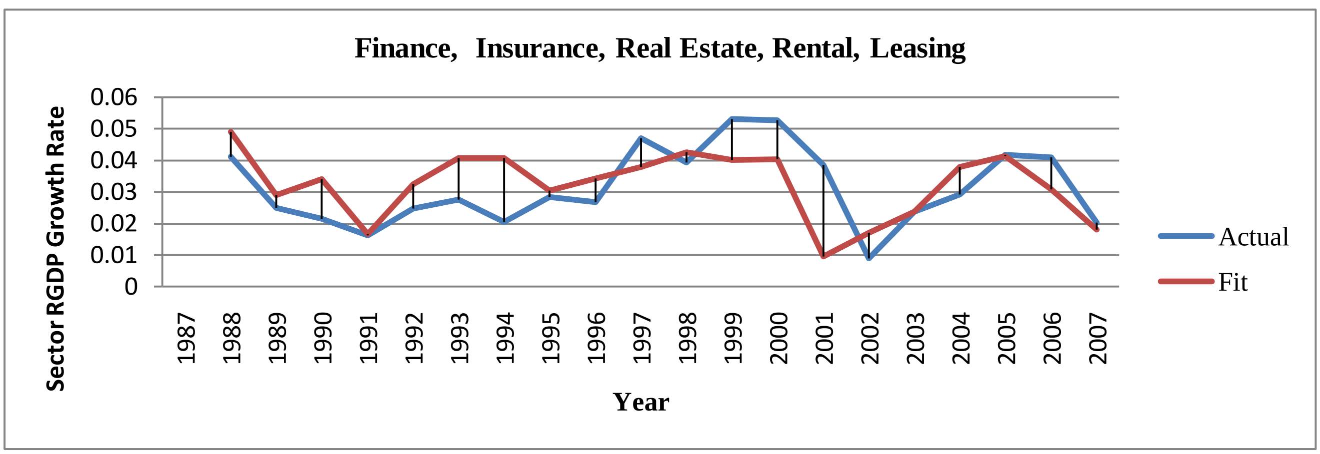
Fig. 7 - Actual Versus Fitted Values of Growth Rates by Industrial Sectors

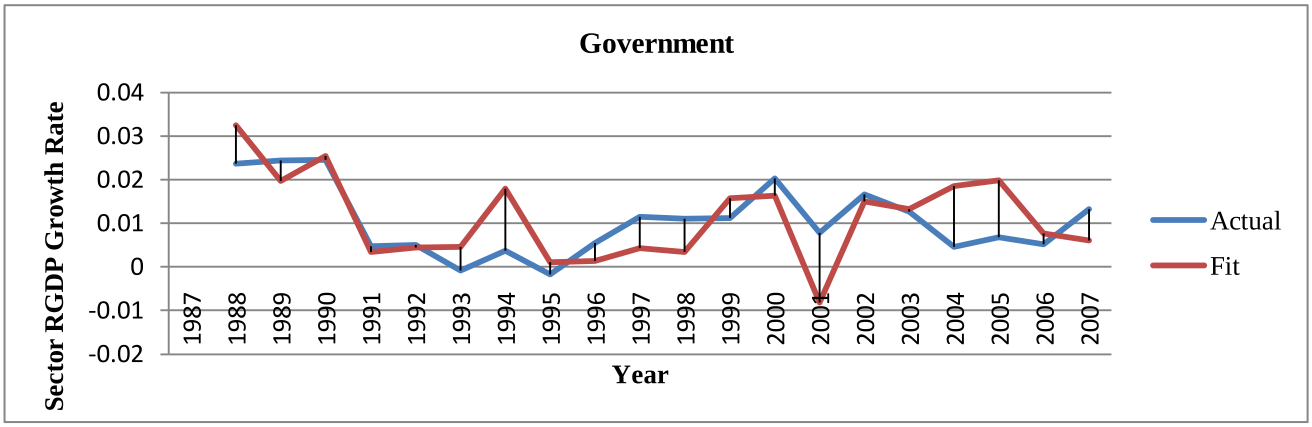


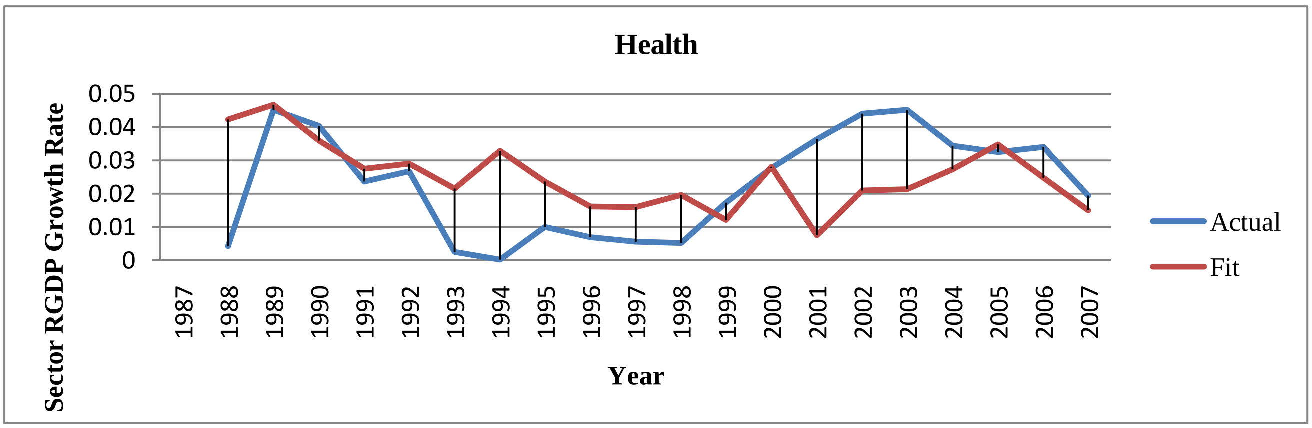


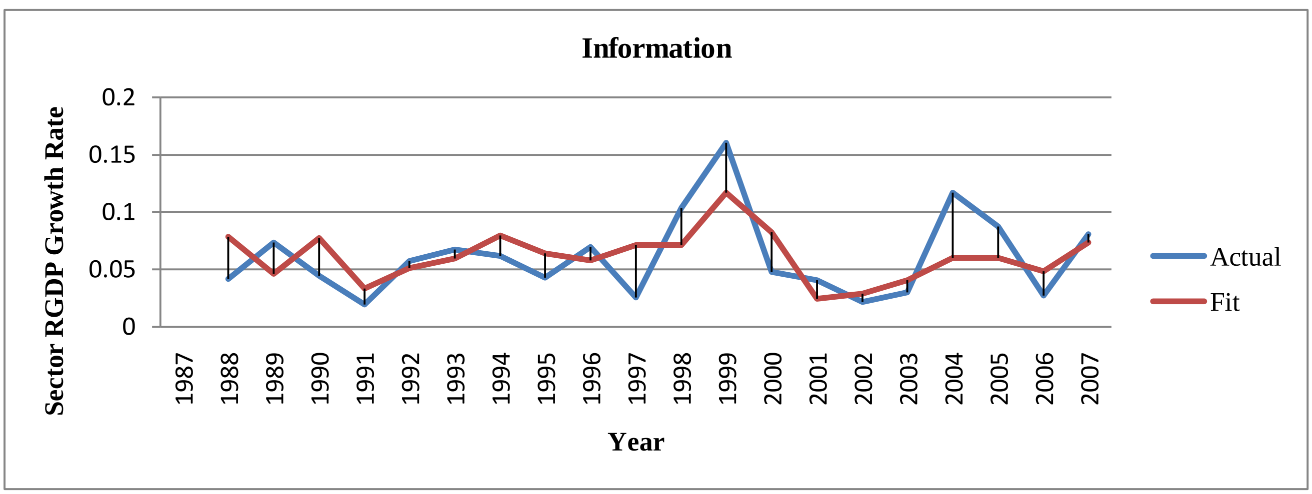

Construction
Sector RGDP Growth Rate
0.1
0.05
0
-0.05
-0.1
-0.15
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Actual
Fit

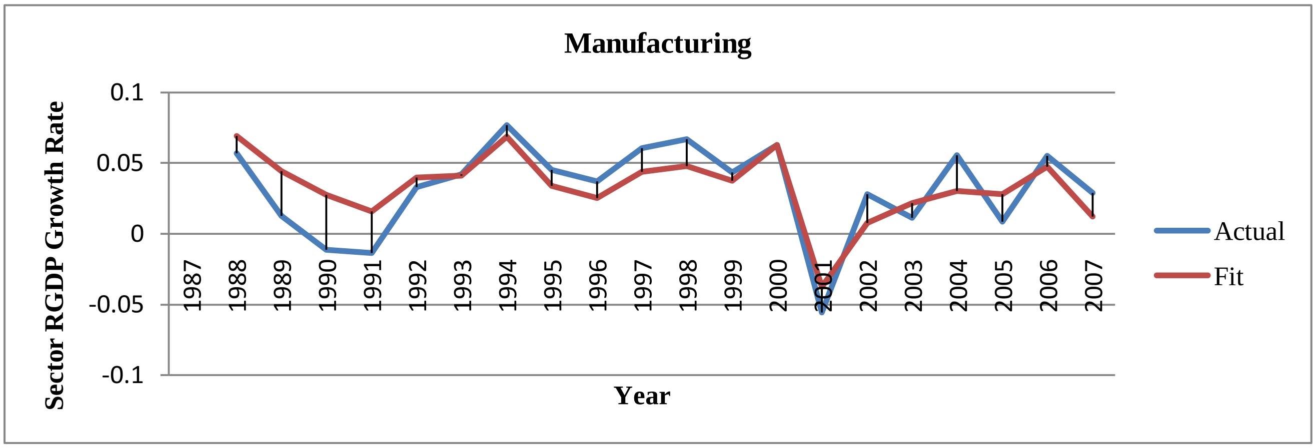

Education
Sector RGDP Growth Rate
0.05
0.04
0.03
0.02
0.01
0
-0.01
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Actual
Fit

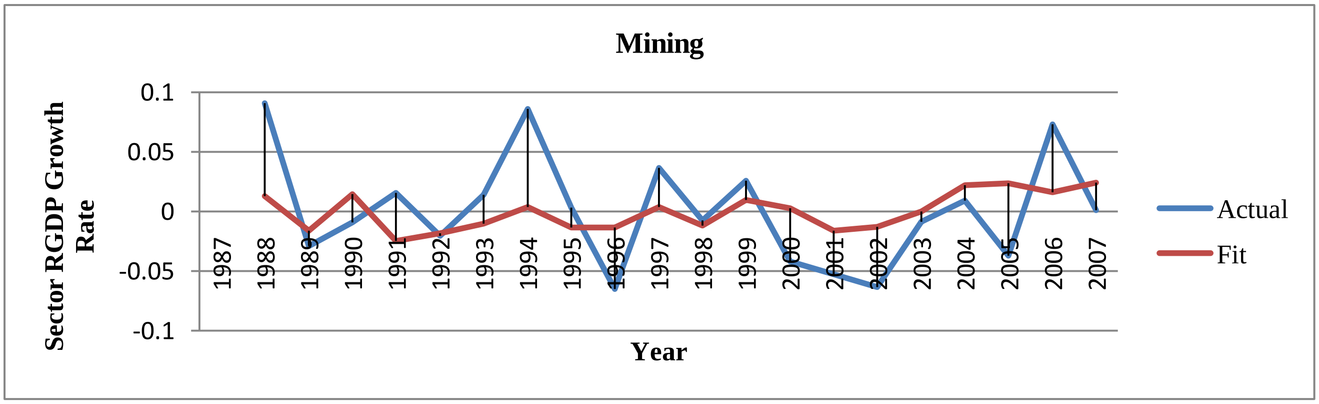

Finance, Insurance, Real Estate, Rental, Leasing
Sector RGDP Growth Rate
0.06
0.05
0.04
0.03
0.02
0.01
0
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Actual
Fit

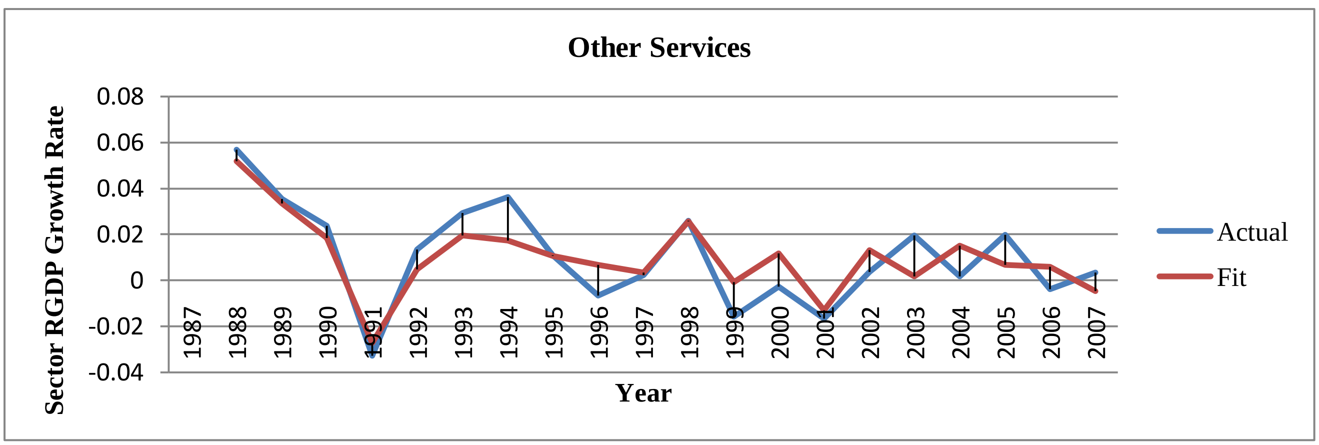

Government
Sector RGDP Growth Rate
0.04
0.03
0.02
0.01
0
-0.01
-0.02
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit

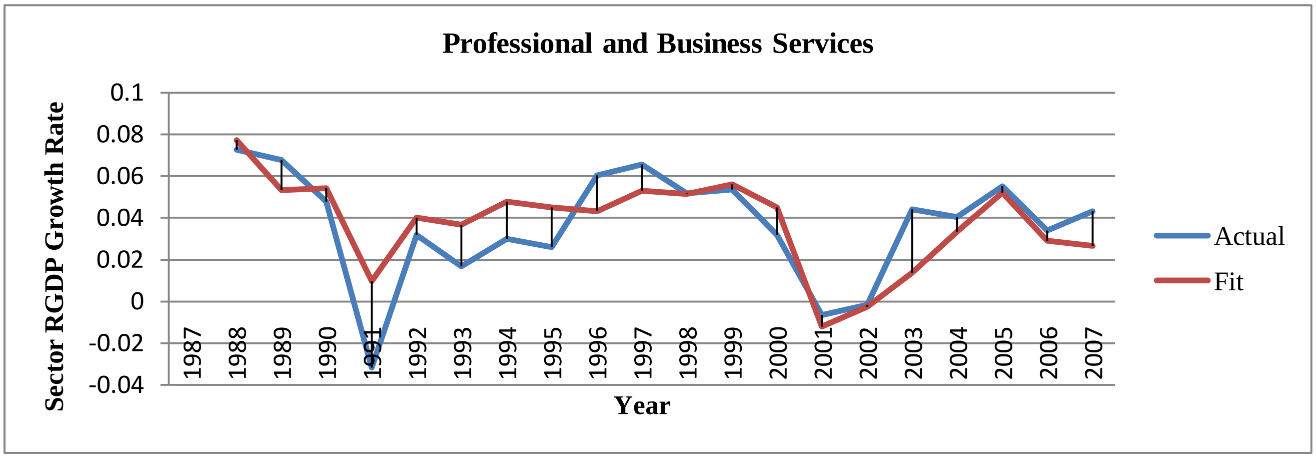

Health
Sector RGDP Growth Rate
0.05
0.04
0.03
0.02
0.01
0
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit

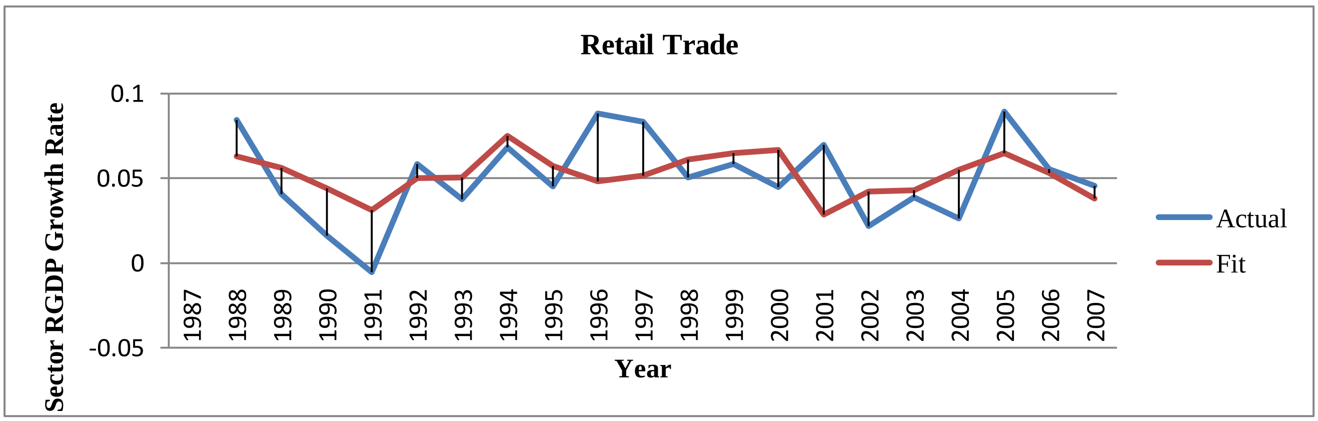

Information
Sector RGDP Growth Rate
0.2
0.15
0.1
0.05
0
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit

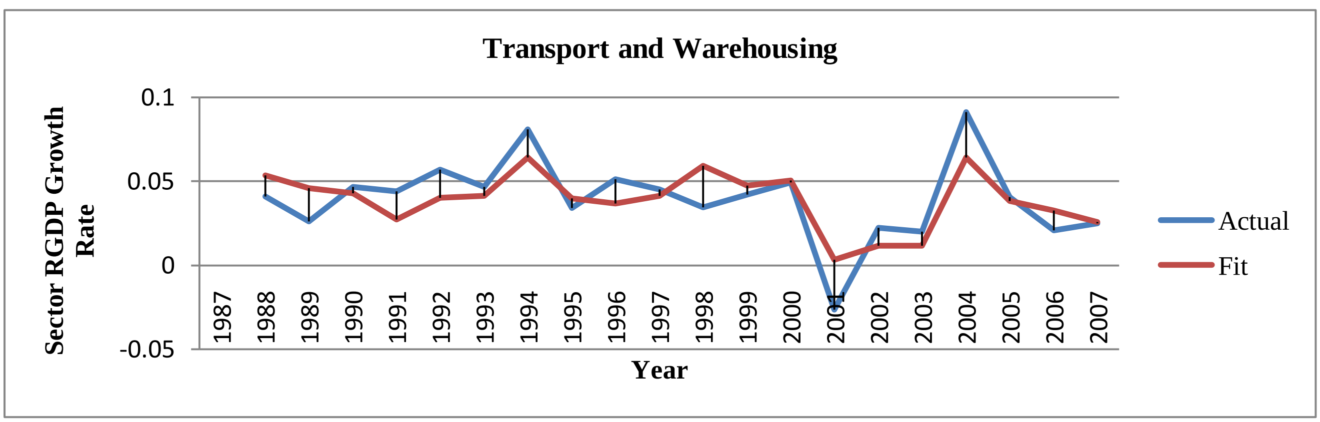

Manufacturing
Sector RGDP Growth Rate
0.1
0.05
0
-0.05
-0.1
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit

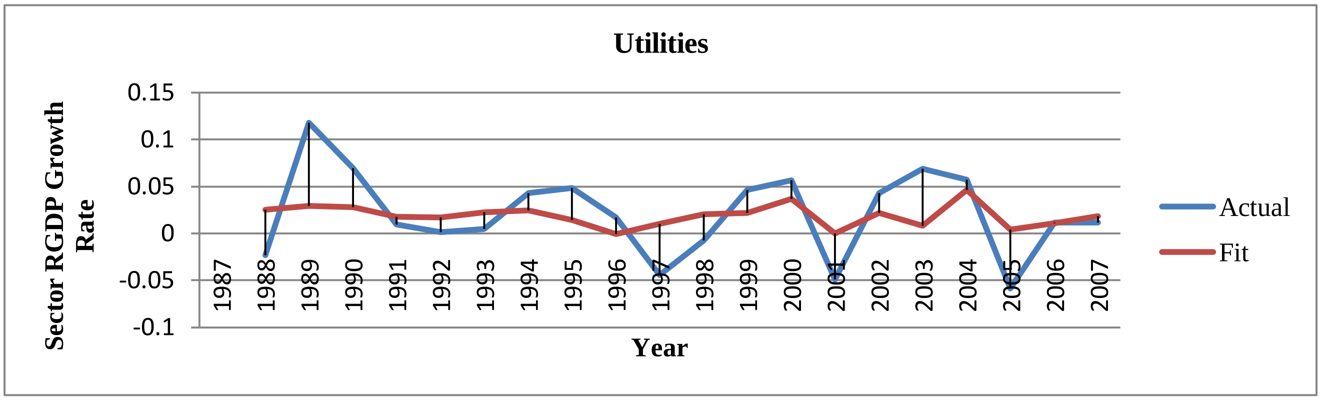

Mining
Sector RGDP Growth Rate
0.1
0.05
0
-0.05
-0.1
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit

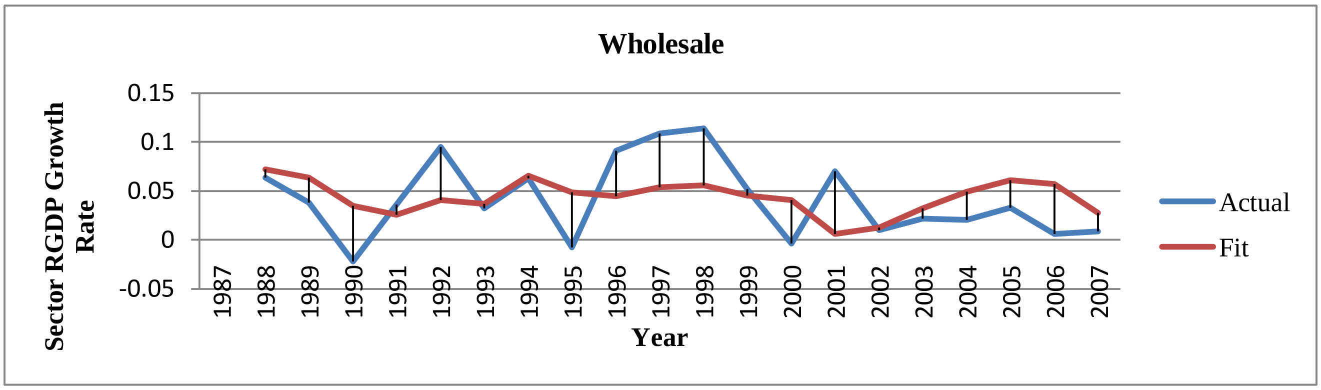

Other Services
Sector RGDP Growth Rate
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit


Professional and Business Services
Sector RGDP Growth Rate
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit


Retail Trade
Sector RGDP Growth Rate
0.1
0.05
0
-0.05
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit


Transport and Warehousing
Sector RGDP Growth Rate
0.1
0.05
0
-0.05
1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Year
Actual
Fit





Forecasts

Table 2 - MAEs and RMSEs Forecasts by Industrial Sectors

	Errors Based on Fitted Values*	
Sector	**MAE**	**RMSE**
Arts, entertainment, recreation, accommodation, food service	**0.89 %**	**1.21 %**
Construction	**1.07 %**	**1.57 %**
Education	**0.76 %**	**1.01 %**
Finance, Insurance, Real Estate, Rental, Leasing	**0.77 %**	**0.90 %**
Government	**0.20 %**	**0.28 %**
Health	**0.87 %**	**1.10 %**
Information	**2.03 %**	**2.54 %**
Manufacturing	**0.97 %**	**1.22 %**
Mining	**2.83 %**	**3.28 %**
Other services, except Government	**0.60 %**	**0.72 %**
Professional and Business Services	**1.09 %**	**1.30 %**
Retail Trade	**1.66 %**	**2.08 %**
Transportation and Warehousing	**1.05 %**	**1.18 %**
Utilities	**2.78 %**	**3.59 %**
Wholesale Trade	**2.42 %**	**3.02 %**
Agriculture	**5.05 %**	**5.90 %**

Comparing Table 1 and 2, we realize that the use of science as an additional sector that supplies inputs to other sectors of the economy helps reduce forecasting errors for all the sectors of the U.S. economy. Needless to say better data of the science sector will provide even higher improvement.

IV. POLICY SHOCKS PER SECTOR

In this section, we have implemented a set of policy shocks aimed at assessing the impact of raised research spending on the outcome of the U.S. Science sector.

Table 3 – U.S. Science Total Patents in Growth Terms Resulting from Implemented Reforms

Reform types	Reform Size (percentage point)	No. of patents in growth terms (percentage point after 1 year)
Increase Basic Research	1	1.32 (1.11)
	5	5.71 (1.29)
Increase Applied Research	1	4.69 (1.98)
	5	15.01 (2.11)
Increase Development	1	0.83 (0.91)
	5	4.01 (1.19)
Cut Corporate Income Tax	1	4.01 (1.51)
	5	18.2 (2.05)

Note: Table 3 presents elasticities on the policy variables used for the reform. Estimates have been obtained using the one-sector MMM transfer function of the US economy with the three additional research inputs. The values in parentheses represent the predictive standard errors corresponding to each shock[‡].

In Table 3 we introduce a set of reforms (1 and 5 percentage points increase) on spending for Basic Research, Applied Research and Development and present their impact on the growth rate of the total number of patents approved. As expected, increasing spending on Applied Research produces much larger effects than other increases. Applied Research has faster impact on scientific outputs than other research components. Also, we can see that Corporate Income Tax cut provides large incentive for research development.

[‡] The predictive standard errors constitute summarized measure of the estimated variance of the equation's residual.

Table 4 -- Estimated One-Year Effects of Science Output on Sectors of the US Economy: Reforms are implemented in 2007

Sector	Percentage point increase in the sector's annual GDP growth rate
Agriculture	**1.16** (0.16)
Arts, entertainment, recreation, accommodation, food service	**0.32** (0.26)
Construction	**0.39** (0.68)
Education	**2.60** (0.31)
Finance, Insurance, Real Estate, Rental, Leasing	**1.08** (0.23)
Government	**1.47** (1.60)
Health	**4.09** (0.36)
Information	**9.21** (0.61)
Manufacturing	**7.65** (0.39)
Mining	**0.77** (0.86)
Other services, except Government	**2.58** (0.22)
Professional and Business Services	**2.10** (0.33)
Retail Trade	**1.03** (0.47)
Transportation and Warehousing	**0.78** (0.31)
Utilities	**0.29** (0.79)
Wholesale Trade	**1.39** (0.43)

Note: These results have been obtained using iterative seemingly unrelated regressions of our 17-sector MMM and values in parentheses represent standard errors.

In Table 4, we present the effects of increased scientific outputs (one percentage point shock) on other sectors of the U.S. economy. Overall, advances in science have a positive impact on all the sectors of the U.S. economy although the amplitude of the effects differs from one sector to another. Most numbers seem obvious and easy to reconcile with general expectations and further work need to be done to deeper disentangle the pure effects generated by the shocks from other market and non-market adjustment effects.

IV. CONCLUSION

In this paper we have analyzed the production process of scientific outputs and its implications on the overall U.S. economy using variants of a disaggregated Marshallian Macroeconomic Model (MMM). We have modeled the U.S. science sector using a one-sector MMM that fits the data and provides reliable forecasts adding to Jeffrey's inputs the traditional economic production inputs such as capital and labor. Moreover we have embedded science as an additional input and an additional sector in our 17-sector MMM of the overall U.S. economy. We have assumed that firms use expected product prices and form their expectations as Bayesian learners. Throughout a set of policy simulations, this research provides measured information on how selected science policies i.e. public spending on research (Basic, Applied and Development) versus corporate tax cut, affect the science sector and the U.S. economy overall. Both variants of our MMM that have been estimated using transfer functions. This study has helped improving our understanding of the production process of scientific outputs in the U.S. economy.

We recognize that further disaggregation of the science sector is much needed for a better investigation of the production process of scientific outputs. Therefore, in future work, we propose to disaggregate the science sector into (1) public operating units, (2) private operating units, (3) academic based units, (4) non-academic based units, etc. Using our data relating to private, government and university science sector, we intend to describe and compare their inputs and outputs over time. As regards modeling the operations of laboratories in the government and university sectors, a fundamental problem remains: the derivation of a model that explains and predicts the operation of an individual laboratory. For labs in the private sector, we assume that they are profit-maximizers, an assumption that is inappropriate for units in the public sector. For labs in the non-profit sectors, the technology of producing scientific output is assumed the same as in the private science sector. However, we consider the assumption that their main objective is to spend a given budgeted amount for each time period. The budgeted amount will be among exogenous variables used in the production process of a given lab in the public sector. With this assumption, we will be able to derive a supply function for a particular government lab and aggregate the supply functions. This will help obtaining the government science sector supply function with the given demand for the output of the government science sector and an entry-exit relation for labs in the government sector. This will complete the product market for the government science sector. Similar consideration can be given to the formulation of a product market for the university science sector. Besides, we propose to expand our MMM to include not only domestic markets but also foreign markets for both products and factors of production. This is particularly important with respect to the science sector that has a great deal of international interactions in both the product and factor markets.

Further, Schumpeterian innovation leading to the creation of new industries will be introduced in future studies. We understand the need for a model to predict new innovations and fortunately enough, we will make reference to the Bass model.

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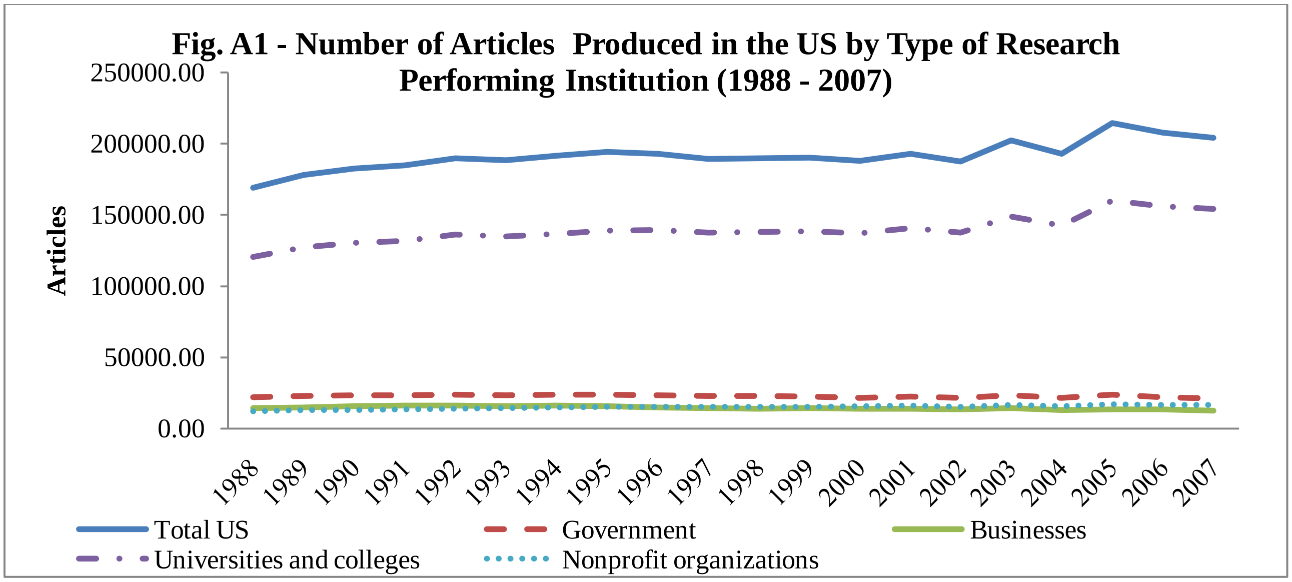
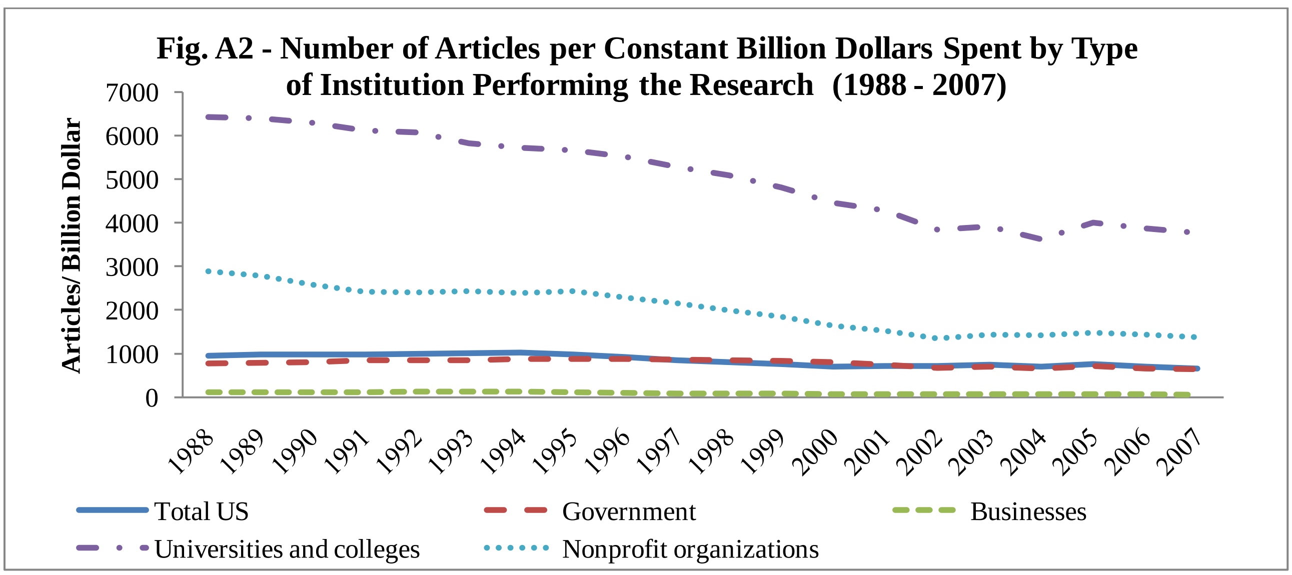
APPENDIX

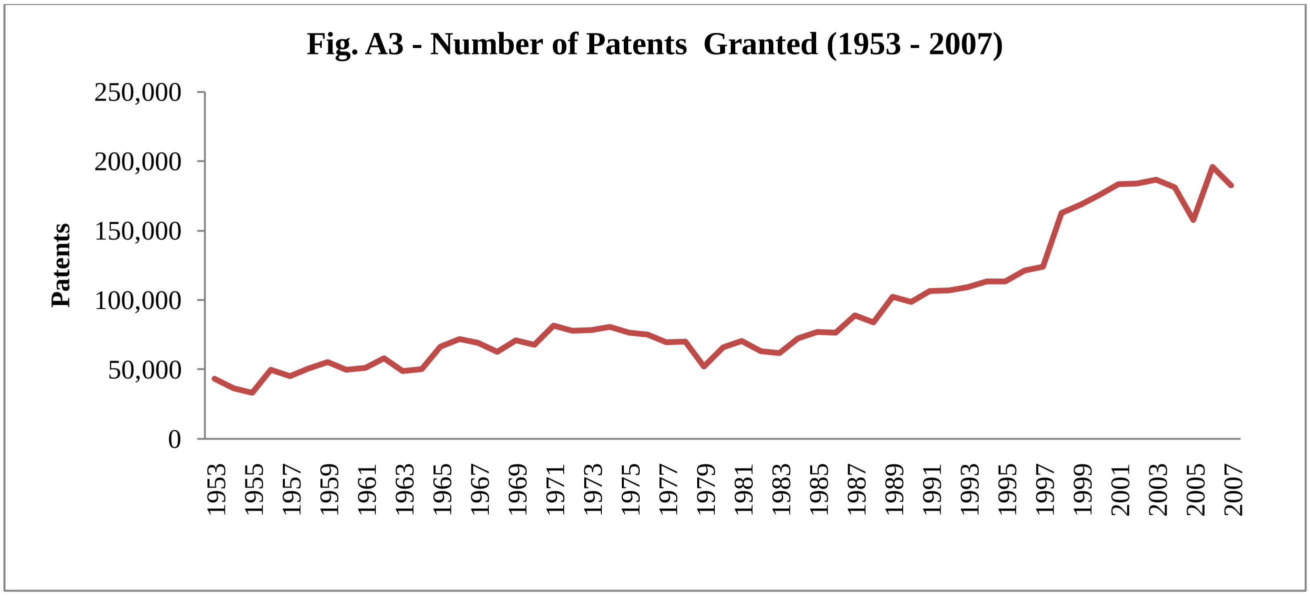
SOME MEASURES OF PRODUCTIVITY OF THE SCIENCE SECTOR IN THE US



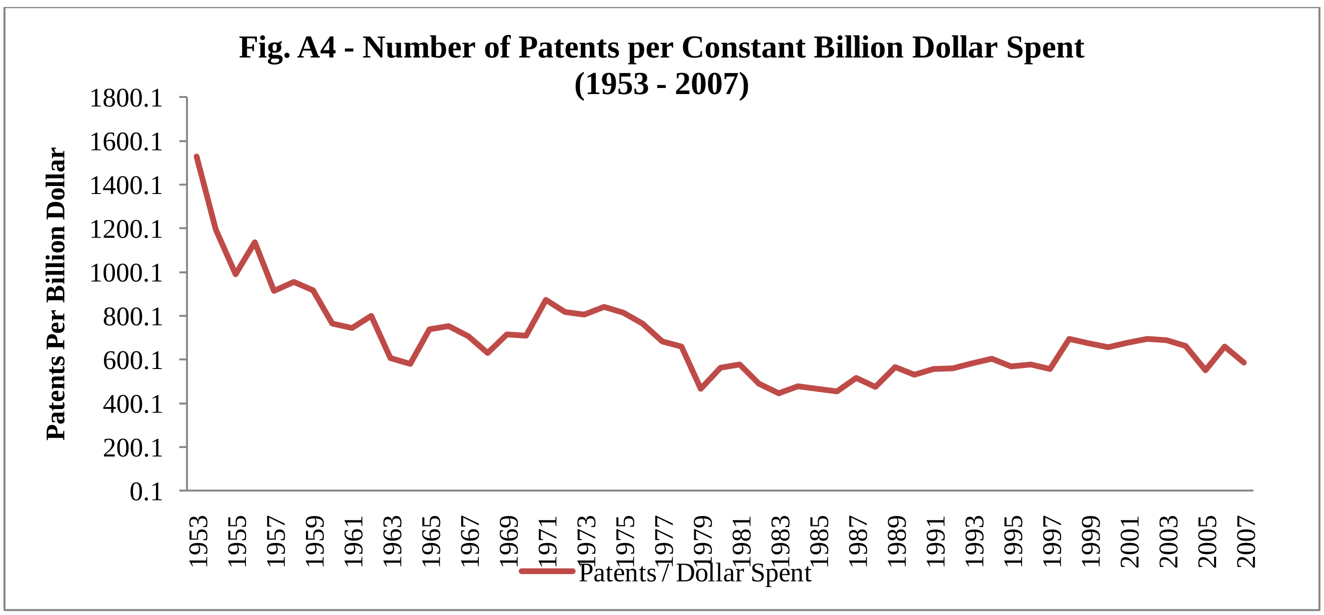
Source: NSF
Description: The graph shows the number of articles in Science and Engineering produced in the US between 1998 and 2007 by type of institution performing the research



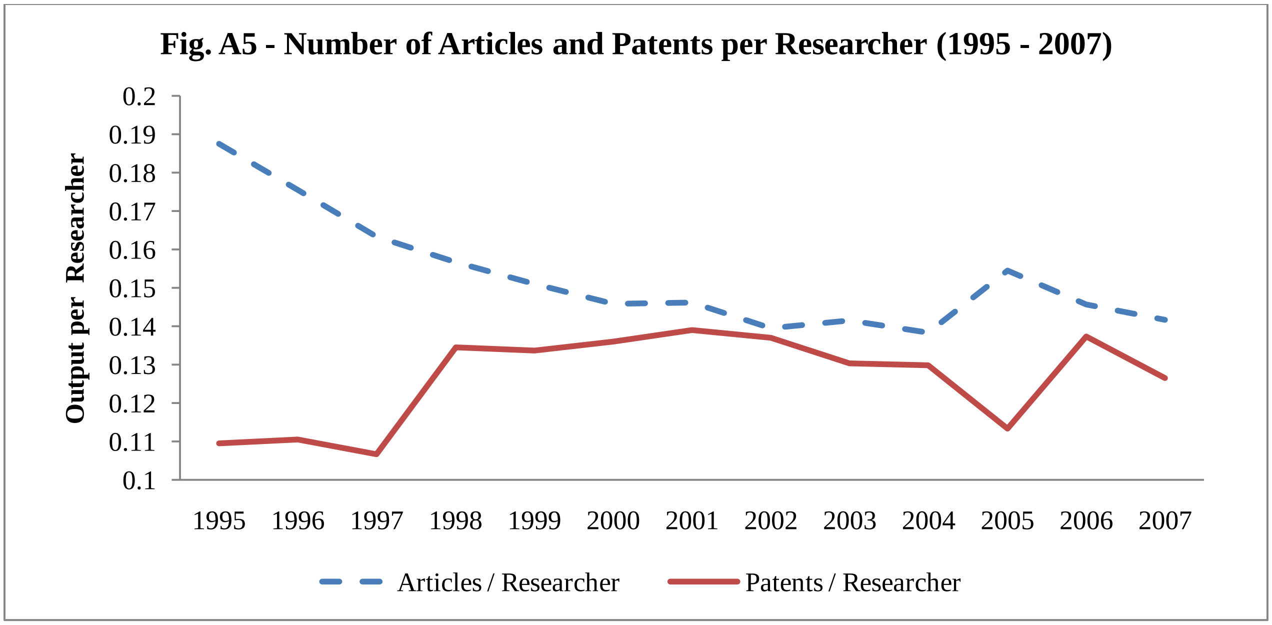
Source: NSF
Description: The graph shows the number of articles in Science and Engineering produced in the US per billion dollars (constant dollars of 2000) spent on research between 1998 and 2007 by type of institution performing the research.



Source: United States Patent and Trademark Office
Description: The graph shows the total number of patents awarded to US institutions/citizens between 1953 and 2007



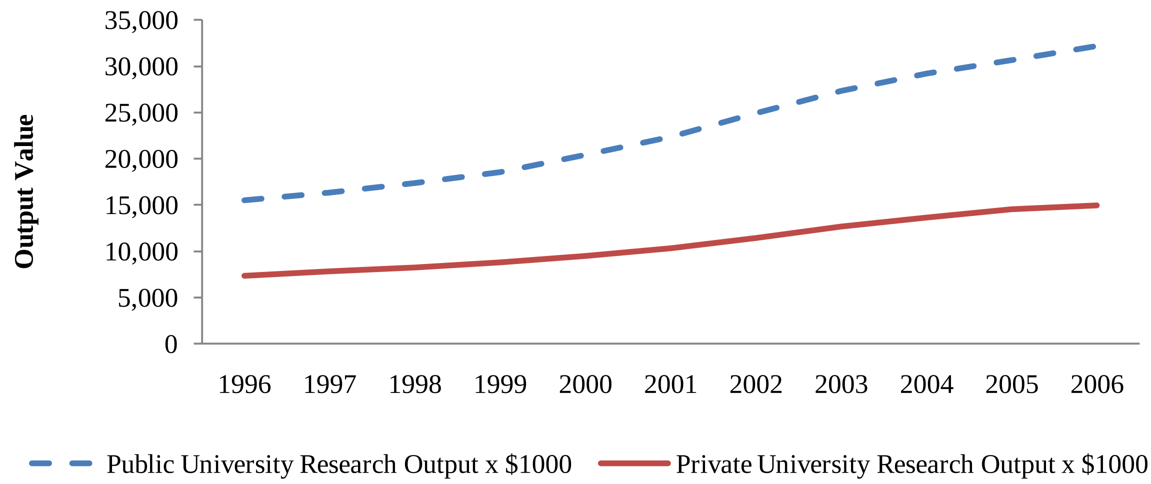
Source: United States Patent and Trademark Office, NSF
Description: The graph shows the total number of patents awarded to US institutions/citizens per dollar spent on research (constant dollars of 2000) between 1953 and 2007



Source: United States Patent and Trademark Office, NSF
Description: The graph shows the total number of patents awarded to US institutions/citizens and the number of Science & Engineering Journal Articles produced in the US between 1995 and 2007 per researcher. The number of researchers is calculated as FTE employees.

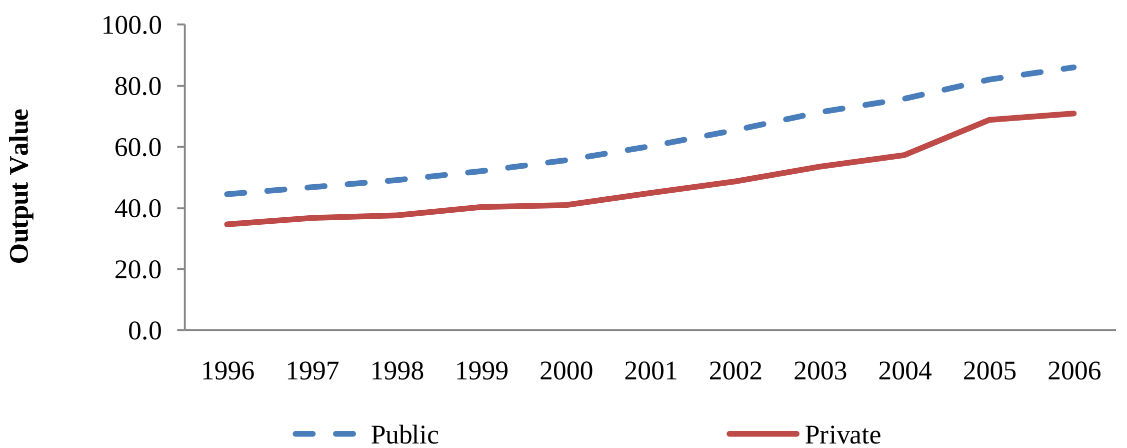
PRODUCTIVITY OF THE SCIENCE SECTOR IN US UNIVERSITIES PUBLIC vs PRIVATE

Fig. A6 - Research Output Value at Universities (1996 - 2006)

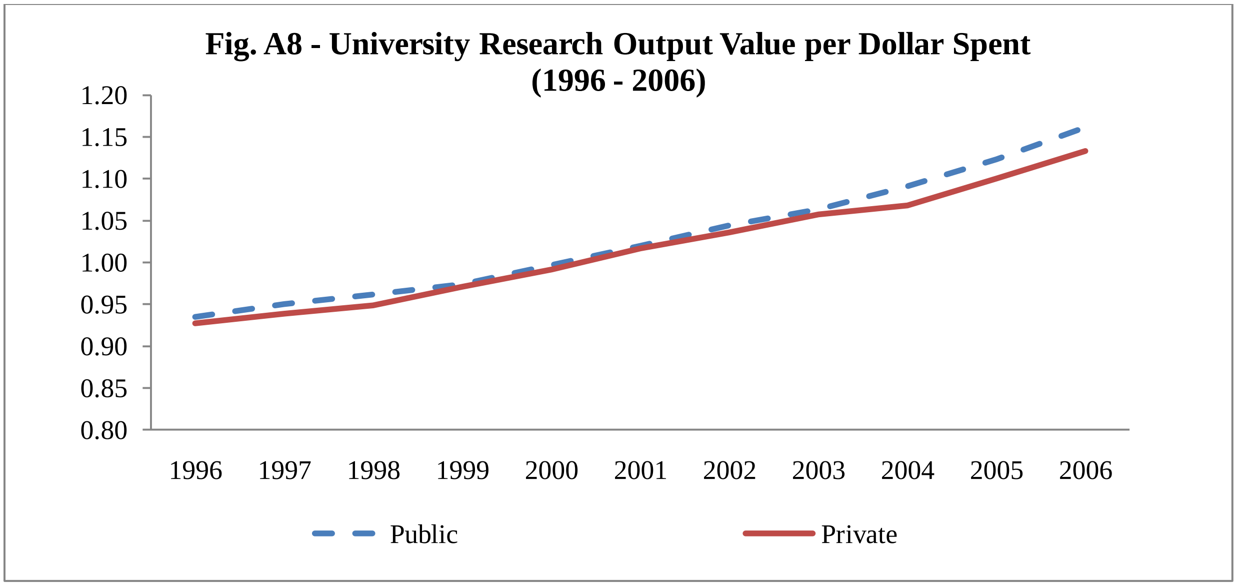


Source: Center for Measuring University Performance
Description: The graph shows the value of the research produced by public and private universities between 1996 and 2006.

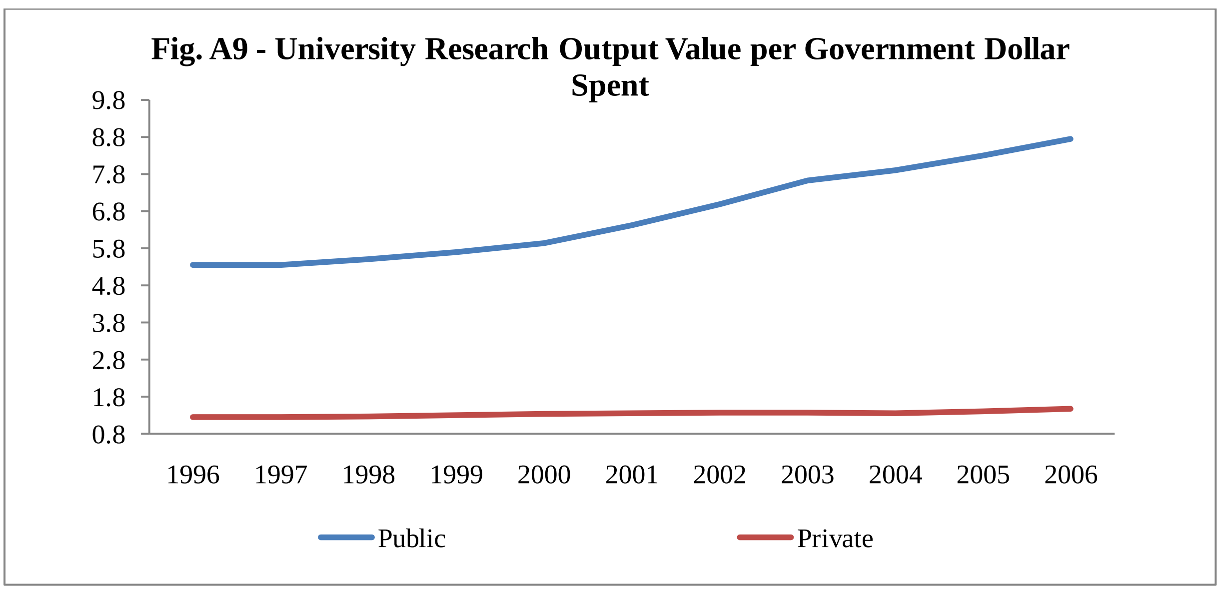
Fig. A7 - University Research Output Value per Number of Institutions (1996 - 2006)



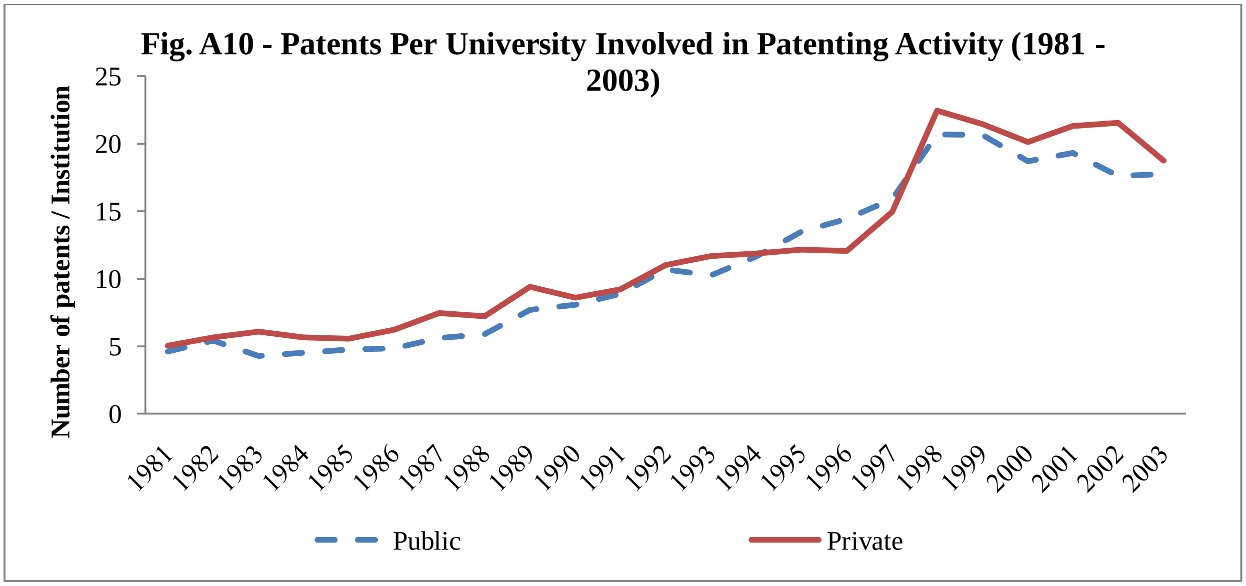
Source: Center for Measuring University Performance
Description: The graph shows the value of the research produced by public and private universities per institution reporting any research activity between 1996 and 2006.



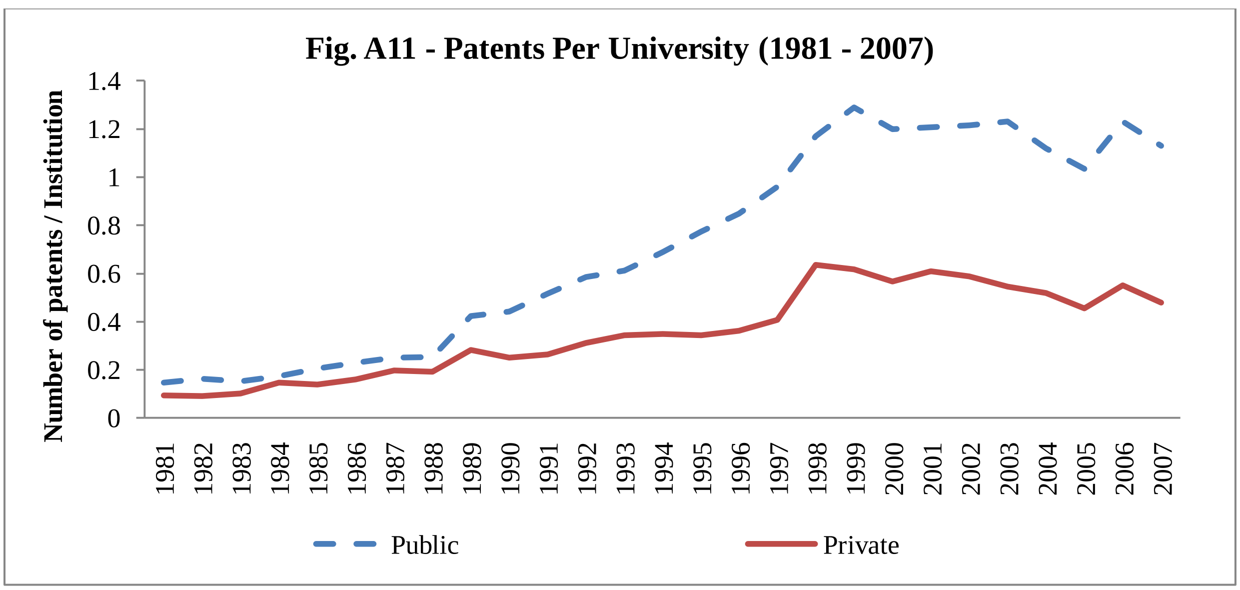
Source: Center for Measuring University Performance, NSF
Description: The graph shows the value of the research produced by public and private universities per billion dollars spent on research (constant dollars of 2000) between 1996 and 2006.



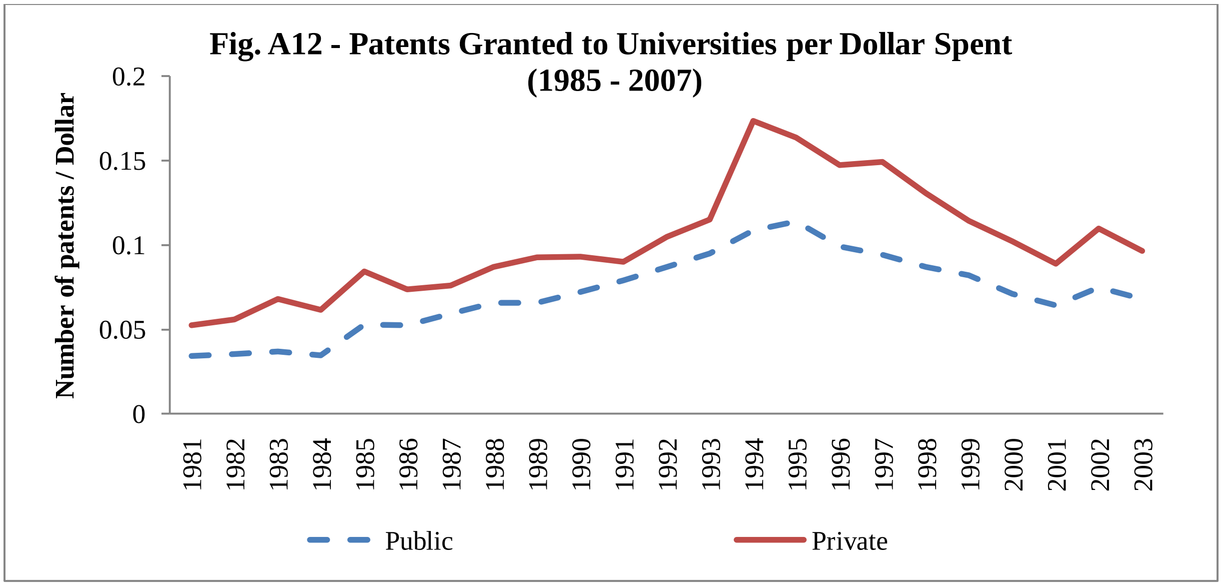
Source: Center for Measuring University Performance, NSF
Description: The graph shows the value of the research produced by public and private universities per billion dollars spent on research funded by the government (constant dollars of 2000) between 1996 and 2006.



Source: United States Patent and Trademark Office, NSF
Description: The graph shows the number of patents per institution reporting patenting activity by public and private universities between 1981 and 2003.



Source: United States Patent and Trademark Office, NSF
Description: The graph shows the number of patents per existing institution by public and private universities between 1981 and 2007.



Source: United States Patent and Trademark Office, NSF
Description: The graph shows the number of patents per billion dollar spent (constant dollars of 2000) by public and private universities between 1985 and 2007.