UNIVERSIDAD CARLOS III DE MADRID
working papers

Working Paper 09-14
Economic Series (09)
February 2009

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The Structural Transformation Between Manufacturing and Services and the Decline in the U.S. GDP Volatility*

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First Version: September 2008 . This Version: February 2009

Abstract

For a single firm with a given volatility of total factor productivity at the gross output level (GTFP), the volatility of total factor productivity at the value added level (YTFP) increases with the share of intermediate goods in gross output. For a Cobb-Douglas production function in capital, labor and intermediate goods, YTFP volatility is equal to GTFP volatility divided by one minus the share of intermediate goods in gross output. In the U.S., this share is steadily around 0.6 for manufacturing and 0.38 for services during the 1960-2005 period. Thus, the same level of GTFP volatility in the two sectors implies a 55% larger YTFP volatility in manufacturing. This fact contributes to the higher measured YTFP volatility in manufacturing with respect to services. It follows that, as the services share in GDP increases from 0.53 in 1960 to 0.71 in 2005 in the U.S., GDP volatility is reduced. I construct a two-sector dynamic general equilibrium input-output model to quantify the role of the structural transformation between manufacturing and services in reducing the U.S. GDP volatility. Numerical results for the calibrated model economy suggest that the structural transformation can account for 32% of the GDP volatility reduction between the 1960-1983 and the 1984-2005 periods.

JEL Classification: C67, C68, E25, E32.

Keywords: Volatility Decline, Structural Change, Real Business Cycle, Total Factor Productivity.

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* I would like to thank Michele Boldrin, Javier Díaz Giménez and Nezih Guner for their guidance and Esteban Jaimovich and Vincenzo Merella for the useful comments as well as the participants at the seminars at Carlos III and at the University of Cagliari. The Region of Sardinia is kindly acknowledged for financial support. The usual disclaimers apply.

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1 Introduction

There is a large literature documenting the decline in output volatility in the U.S. over time.[1] Several explanations have been advocated to explain this process: improved inventory management techniques, better monetary policy (Leduc and Sill, 2007), better financial instruments (Jermann and Quadrini, 2006), decline in aggregate TFP volatility (Arias et al., 2007), and structural change between manufacturing and services. In particular, Alcala and Sancho (2003) show that when appropriate chain-weighted index numbers are considered, the increase of the share of services in GDP is responsible for 30% of the reduction in output volatility from 1950 to 2002. However, no attempt has been made to build a model that explains the link between the sectorial transformation and output volatility and can account for the reduction in the U.S. GDP volatility. This is the main purpose of this paper.[2]

I first study the behavior of the two broad sectors, manufacturing and services, and investigate how the increase in the services share of GDP reduces GDP volatility.[3] Using U.S. data from Jorgenson Dataset, 2007, I document two facts. First, total factor productivity (TFP) volatility at the gross output level is higher in manufacturing than in services during the period considered, 1960-2005. Second, manufacturing displays a higher share of intermediate goods in gross output with respect to services, 0.6 versus 0.38. As first shown in Bruno (1984) and Baily (1986), for a given volatility of TFP at the gross output level, value added TFP volatility is an increasing function of the share of intermediate goods in gross output.[4] That is, for a given volatility of TFP at the gross output level, the share of intermediate goods in gross output provides a multiplier on value added TFP volatility. The larger the

[1] See McConnell and Perez-Quiros (2000) and Blanchard and Simon (2001) for instance.

[2] In this paper, the term "structural transformation" refers to the transformation of the aggregate production function of the economy over time. As the weights of manufacturing and services in GDP change over time, the aggregate production function changes as well, as it will be shown along the paper.

[3] To avoid confusion with sectorial output, in the paper I always refer to aggregate output, also defined as aggregate value added, as GDP.

[4] See also EU KLEMS Growth and Productivity Accounts (2007).

share of intermediate goods, the larger this multiplier. Given the observed difference in the share of intermediate goods in the data, this implies that the same level of TFP volatility in the two sectors at the gross output level results in a TFP volatility at the value added level 55% larger in manufacturing than in services.

Aggregate TFP depends on sectorial value added TFP and on the share of each sector in GDP. The share of services in GDP in the U.S. is 0.53 in 1960 and 0.71 in 2005 according to Jorgenson Dataset. A larger share of services reduces aggregate TFP volatility for two reasons. First, services display a smaller TFP volatility at the gross output level with respect to manufacturing so that an increase in the services share of GDP contributes to reduce aggregate TFP volatility. Second, the multiplier effect due to the share of intermediate goods in gross output, that is created when gross output TFP volatility is converted into value added TFP volatility, is smaller for services than for manufacturing, so that aggregate TFP volatility is further reduced when the share of services in GDP increases. In turn, the reduction in aggregate TFP volatility is expected to induce a decline in GDP volatility.

To quantify the effect that the structural transformation between manufacturing and services had on the GDP volatility decline in the U.S., I construct a two-sector, input-output, dynamic, general equilibrium model. The two sectors, manufacturing and services, produce output using a Cobb-Douglas production function in capital, labor and intermediate goods purchased from the sector itself and from the other sector. Household's preferences are non-homothetic so that the elasticity of services with respect to income is greater than one and that of manufacturing is smaller than one.[5]

I then use the model to construct two steady states (SS). The first SS is found by calibrating the model so that the share of services in GDP matches the corresponding average share in the data for the period 1960-1983, 0.55. By using the same parametrization, I

[5] See Jorgenson and Slesnick (1987). For a theory of the rise in the service sector see Buera and Kaboski (2008).

construct a second SS, labeled 1984-2005 SS.[6] With respect to the 1960-1983 SS, gross output TFP has been multiplied by $(1+\varphi_m)$ in manufacturing and by $(1+\varphi_s)$ in services, where $(1+\varphi_m)$ and $(1+\varphi_s)$ are the growth factors of gross output TFP in manufacturing and services measured in the data for the period 1960-2005. As income in the 1984-2005 SS is higher than in the 1960-1983 SS, because of higher gross output TFP levels in the two sectors, the non-homothetic preferences imply that the services share of output enlarges while that of manufacturing shrinks. The implied share of services in the 1984-2005 SS is equal to the average share observed in the data during the corresponding period, 0.67.

I use the two steady states to perform linear quadratic approximations (LQ). First, I compute the stochastic processes for gross output TFP shocks in the two sectors for the 1960-1983 and the 1984-2005 periods. I then perform an LQ approximation around the 1960-1983 SS, where the standard deviations of TFP shocks in the two sectors are those measured in the 1960-1983 period. Next, I perform the same approximation around the 1984-2005 SS, where the standard deviations of the shocks are those measured in the data between 1984 and 2005. I find that GDP volatility is 58% larger in the 1960-1983 SS with respect to the 1984-2005 SS while in the data, GDP volatility is 56% larger in the 1960-1983 period with respect to the 1984-2005 period. Thus, the model so specified is able to explain the entire decline in GDP volatility observed in the data.

I then perform a decomposition experiment to quantify to what extent the sectorial transformation alone can account for the GDP volatility decline. To do this, I first compute the standard deviation of gross output TFP shocks in manufacturing and services during the whole period considered, 1960-2005. I then use these standard deviations to perform LQ approximations around the two steady states. Thus, in both LQ approximations the standard deviations of the sectorial TFP shocks are the same and equal to those observed

[6] The pre-1983 period and the post-1983 period are often considered in the literature to compare output volatility over time. See Arias et al. (2007), for instance.

in the data during the whole period 1960-2005. It follows that any decline in GDP volatility across steady states is due to the change in the weights of the two sectors in the economy. The model displays a GDP volatility 18% larger in the 1960-1983 SS with respect to the 1984-2005 SS. This implies that the sectorial transformation alone is able to explain 32% of the difference in GDP volatility observed in the data between the 1960-1983 and the 1984-2005 periods. This confirms the result found in Alcala and Sancho (2003).

The shift away from the manufacturing sector towards the services sector has been suggested as an explanation for lower output volatility in Dalsgaard et al. (2002). They suggest that the smaller share of inventories that services display over output with respect to manufacturing can be a source of smaller GDP volatility. In the model I present there is no inventory, and the reduction in GDP volatility is due to the change in the transmission mechanism of sectorial productivity shocks to the aggregate economy when the share of the services sector in GDP increases. The sectorial transformation explanation is not at work in reducing output volatility according to Blanchard and Simon (2001), Stock and Watson (2002) and McConnell and Perez-Quiros (2000). These papers perform simple counterfactual experiments to assess the contribution of structural change on GDP volatility. They construct counterfactual GDP series using the weights of the services sector in GDP in an early period and use the subsequent growth rates of the services sector. They do not find evidence of an increase in output volatility in this way. Alcala and Sancho (2003) show the limitations of this approach. They show that using appropriate indices with time varying weights the result in McConnell and Perez-Quiros (2000), Blanchard and Simon (2001) and Stock and Watson (2002) does not hold and find that structural change accounts for 30% of the reduction in output volatility. For this reason, in the quantitative exercises in this paper I use a time-varying Tornqvist index to compute changes in the model's GDP.

Finally, it is worth noting here that several papers in the literature on volatility decline take a structural break view. These papers consider the reduction in volatility between the pre-1983/84 and the post-1983/84 periods. However, the 1973-1983 period has been characterized by the oil shocks and high volatility of output and prices. When the pre-1973 and the post-1984 periods are considered, the difference in GDP volatility is around 22% instead of the 56% between the 1960-1983 and 1984-2005 periods. As shown in Blanchard and Simon (2001), the reduction in GDP volatility does not occur suddenly between the pre-1983/84 and the post-1983/84 periods, but it is a process that started at least in 1950 and was interrupted in the seventies and mid-eighties. Furthermore, output volatility has decreased across G7 countries.[7] These facts together suggest that changes in the characteristics of a single country, such as changes in monetary policy, cannot represent the entire explanation of the volatility decline across countries. Instead, the sectorial transformation between manufacturing and services is a feature shared by all industrialized countries.

2 Services and Manufacturing Production Functions

Figure 1 reports the nominal share of intermediate goods in the manufacturing and in the services sectors from 1960 to 2005 in the U.S. Given the small long-run variation of nominal input shares, assume that in each sector the representative firm produces gross output using a Cobb-Douglas production function in intermediate goods M and a function of capital and labor $f(K, N)$.[8] Markets are competitive so the firm takes the price of capital r, of labor w, of gross output p_g and of intermediate goods p_m as given. The profit maximization problem of the firm is the following

$$\max_{K,N,M} \left\{ p_g A f(K,N)^{\theta} M^{1-\theta} - rK - wN - p_m M \right\}, \tag{1}$$

where $Af(K,N)^{\theta}M^{1-\theta}$ is the gross output production function.

[7] See table 1 in Stock and Watson (2002) for instance.

[8] Assume $f(K, N)$ to be homogeneous of degree one in capital and labor.

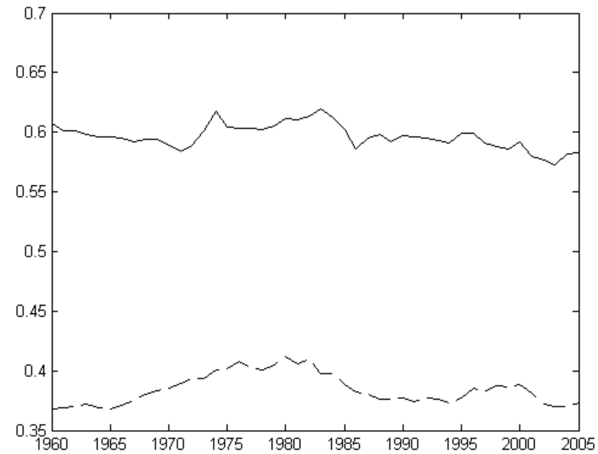

Figure 1: Nominal share of intermediate goods in manufacturing (continuous line) and in services (dashed line) in the U.S. Source: Jorgenson Dataset, 2007, and own calculations.

The first order condition of (1) with respect to intermediate goods implies that, at the optimal solution,

$$M = (1-\theta)^{\frac{1}{\theta}} \left(\frac{p_g}{p_m}\right)^{\frac{1}{\theta}} A^{\frac{1}{\theta}} f(K,N). \tag{2}$$

Using (2) in (1) I obtain

$$\max_{K,N} \left\{ p_v A^{\frac{1}{\theta}} f(K,N) - rK - wN \right\}. \tag{3}$$

In the reduced form problem (3), $A^{\frac{1}{\theta}} f(K,N)$ represents the real value added production function for the sector considered and $p_v = \theta(1-\theta)^{\frac{1-\theta}{\theta}} p_g^{\frac{1}{\theta}} p_m^{-\frac{1-\theta}{\theta}}$ its corresponding price.[9]

[9] Here real value added is defined, as in Sato (1976), as the contribution to output growth of primary inputs (capital and labor) and technical change. Sato (1976) shows that when the gross output production function is separable into intermediate goods and a function of primary inputs and technical change, the real value added index is unique and given by a Divisia index that satisfies

$$\frac{dV}{V} = \frac{1}{\theta}\frac{dG}{G} - \frac{(1-\theta)}{\theta}\frac{dM}{M}.$$

where V is the real value added index, G the gross output index, M the intermediate goods index and θ is the share of value added in gross output. Applying this formula to the production function (1) I obtain the Divisia index for real value added

$$\frac{dV}{V} = \frac{1}{\theta}\frac{dA}{A} + \frac{df(K,N)}{f(K,N)},$$

which is the rate of change of $A^{\frac{1}{\theta}} f(K,N)$ over time. Thus $A^{\frac{1}{\theta}} f(K,N)$ represents the real value added

Thus, (3) represents a standard value added maximization problem of a competitive firm.

It follows that TFP at the value added level is given by $A^{\frac{1}{\theta}}$. In the real business-cycle literature, the volatility of a variable is measured by the standard deviation of the log-deviations of that variable from its Hodrick-Prescott (HP) filter. For a variable A_t and its HP filter $\bar{A}_t$, the log-deviation $\hat{a}_t$ at time t is given by $\hat{a}_t = \log(A_t) - \log(\bar{A}_t)$. Instead, for the variable $A_t^{\frac{1}{\theta}}$ the log-deviation $\tilde{a}_t$ at t is given by $\tilde{a}_t = (1/\theta)[\log(A_t) - \log(\bar{A}_t)]$. As a result, the value of θ affects value added volatility through its effect on the sector's gross output TFP, A. Consider the difference between the services sector, where $\theta = 0.62$ and manufacturing, where $\theta = 0.40$, in the U.S.[10] If A displays the same volatility in the two sectors, that is, the same $\hat{a}$, the difference in θ across sectors implies a value added TFP volatility in manufacturing 55% larger than in services.[11] In this situation, even if the volatility of A remains constant across sectors and over time, an increase in the services sector relative to manufacturing in GDP implies a decline in aggregate TFP volatility. In the next section, I provide evidence on the cyclical and trend behavior of TFP in manufacturing and services.

3 Value Added and Gross Output TFP

In this section I analyze the behavior of TFP in the manufacturing and in the services sectors in the U.S. Figure 2 reports TFP in the two sectors both at the gross output level - first panel - and at the value added level - second panel. Details of the calculations are given in the Data Appendix. The first panel shows that TFP growth is similar in the two sectors at gross output level, with a growth factor between 1960 and 2005 of 1.33 for manufacturing and 1.25 for services. On the other hand, at the value added level the difference in TFP growth

production function and $p_v = \theta(1-\theta)^{\frac{1-\theta}{\theta}} p_g^{\frac{1}{\theta}} p_m^{-\frac{1-\theta}{\theta}}$ its price.

[10] Jorgenson Dataset, 2007.

[11] Note that this conclusion holds for any constant returns to scale gross output production function, separable between value added and intermediate goods. Separability is an implicit assumption in all macro models that disregard intermediate goods utilization.

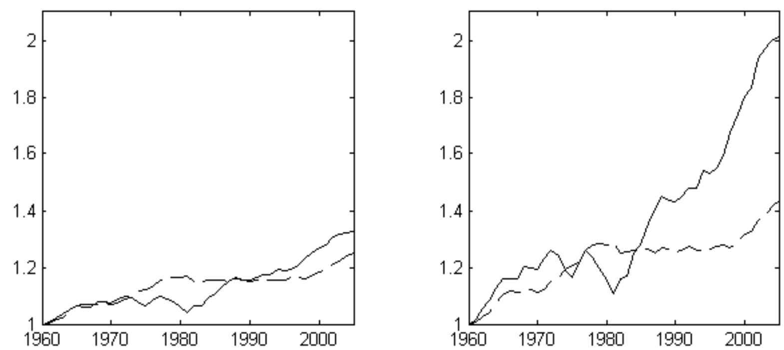

Figure 2: The first panel reports gross output TFP in manufacturing (continuous line) and services (dashed line). The second panel reports value added TFP in manufacturing (continuous line) and services (dashed line). Source: Jorgenson Dataset, 2007, and own calculations.

between the two sectors in more evident, with a 2.01 growth factor for manufacturing and a 1.44 for services. These numbers imply that the 1960-2005 growth factor of manufacturing is 6% larger than services at the gross output level while it is 40% larger at the value added level.

As showed in the previous section, when TFP at the gross output level is A, TFP at the value added level is $A^{\frac{1}{\theta}}$, where θ is the capital and labor share in gross output, equal to 0.4 in manufacturing and to 0.62 in services. According to this analysis, the higher value added TFP growth commonly measured in manufacturing with respect to services is mainly due to different production technologies at the gross output level - different θ -, rather than to different growth rates of A. To see this, note that the yearly average growth rate of TFP at the gross output level is 0.64% in manufacturing and 0.5% in services. That is, manufacturing TFP displays a 28% larger average growth rate than services at the gross output level. At the value added level, the yearly average growth rate of TFP is 1.56% in manufacturing and 0.81% in services. In this case manufacturing average TFP growth rate is 93% larger than services. Thus, the difference in growth rates observed at the value added level is attributable only for one-third (28/93) to differences in gross output TFP growth.

The remaining two-thirds are due to the different θ in the two sectors.

Thus, economies that are more intensive in manufacturing than in services are likely to display a higher aggregate TFP growth rate with respect to economies that are more intensive in services, even when manufacturing and services TFP at the gross output level display similar growth rates. Echevarria (1997) shows that the transition from manufacturing to services implies a decline in aggregate TFP growth due to the smaller growth rate of services value added TFP with respect to manufacturing. On this point, the above analysis suggests that it is mainly the different intensity of intermediate goods in the production of manufacturing and services that implies large differences in the growth rates of TFP at the value added level, and, consequently affects aggregate TFP when the structure of the economy changes.[12]

The different intensity of intermediate goods in manufacturing and services is also able to rationalize the correlation between growth and volatility. Economies whose production is more intensive in manufacturing tend to grow faster and have higher volatility with respect to economies more intensive in services. For a given growth rate and volatility component for TFP at the gross output level, A, the corresponding growth rate and volatility component at the value added level are determined by the value of $1/\theta$. A small θ implies both a high growth rate and a high volatility of value added TFP.

Table 1

Standard deviations of Gross Output TFP

Subperiod	60-05	60-83	84-05	60-72	73-83
Manufacturing	1.13%	1.28%	0.93%	0.73%	1.67%
Services	0.76%	0.95%	0.5%	0.97%	0.91%

Table 1 reports the cyclical behavior of gross output TFP for manufacturing and services

[12] In fact, it is possible to show that the TFP of two countries that have the same supply side model economy - that is, including the same growth rate of gross output TFP growth in manufacturing and services - as the one I present in this paper, can grow at different rates depending on the share of services and manufacturing in GDP. I study the effects of sectorial composition on GDP growth in this sort of models in parallel research.

in the U.S. for different sub-periods. Each number in the table represents the standard deviation of the log-deviations of gross output TFP from its Hodrick-Prescott filter for the period considered. Manufacturing is 49% more volatile than services over the whole 1960-2005 period. In the second and third columns of the table I report measures for two sub-periods which are usually considered in the literature to show the reduction in GDP volatility, before and after 1983. For both sectors TFP volatility is lower in the second period, although the services sector displays a larger decline, 47% instead of 27%.

Finally, consider the pre-oil shocks era, the 1960-1972 period. During this time period TFP volatility is larger in services than in manufacturing, 0.97% versus 0.73%. During the oil-shocks period, 1973-1983, TFP volatility increases in manufacturing, to 1.67%, but declines in services, to 0.91%. After 1984, TFP volatility declines in both sectors with respect to the 1973-1983 period. However, manufacturing TFP displays a larger volatility with respect to the pre-1973 period. Thus, the sectorial analysis suggests that the two sectors display substantial differences in gross output TFP volatility.

Given the evidence provided, three effects on aggregate TFP volatility can be identified. One is due to the reduction in gross output TFP volatility in manufacturing and services between the 1960-1983 and the 1984-2005 periods. The second effect comes from the fact that the sector with the higher TFP volatility at the gross output level (manufacturing) shrinks with respect to the other (services). The third effect is due to the shrinking of the sector with the larger multiplier on TFP due to intermediate goods (again manufacturing) with respect to the other sector (again services). In the next section I construct a model that allows me to separate the first effect from the other two and assess the contribution of the structural change to the GDP volatility reduction in the U.S.

4 The Model

In this section I specify a two-sector, input-output, general equilibrium model to quantify the effect of the sectorial transformation on GDP volatility.

4.1 Firms

There are two sectors in the economy, manufacturing and services. The representative firm in each sector produces gross output using a Cobb-Douglas production function in capital, labor, manufactured intermediate goods and intermediate services. The manufacturing production function is

$$G_m = B_m \left(K_m^{\alpha} N_m^{1-\alpha}\right)^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}\right)^{1-\nu_m}, \tag{4}$$

and that of services is

$$G_s = B_s \left(K_s^{\alpha} N_s^{1-\alpha}\right)^{\nu_s} \left(M_s^{1-\varepsilon_s} S_s^{\varepsilon_s}\right)^{1-\nu_s}, \tag{5}$$

where $0 < \alpha < 1$, $0 < \nu_j < 1$, $0 < \varepsilon_j < 1$, K_j and N_j are the amounts of capital and labor, M_j is the manufactured intermediate good, S_j is intermediate services and B_j is gross output TFP, with $j = m, s$.

The manufacturing producing firm solves

$$\max_{K_m, N_m, M_m, S_m} \left[p_m G_m - r K_m - w N_m - p_m M_m - p_s S_m\right] \tag{6}$$

subject to (4),

where p_m is the price of manufacturing, p_s is the price of services, r is the rental price of capital and w the wage rate.[13]

The services producing firm solves

$$\max_{K_s, N_s, M_s, S_s} \left[p_s G_s - r K_s - w N_s - p_m M_s - p_s S_s\right] \tag{7}$$

[13] In Appendix A I show how to derive the representative firm problem (6) from a more general problem with a continuum of firms in manufacturing and services.

subject to (5).

I exploit the Cobb-Douglas form of the production function to derive the *net production function* of each sector, defined as the amount of gross output of a sector minus the intermediate goods produced and used in the same sector. The net production function for manufacturing is obtained by solving the following problem

$$Y_m = \max_{M_m} \left\{ B_m \left(K_m^{\alpha} N_m^{1-\alpha} \right)^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m} \right)^{1-\nu_m} - M_m \right\}, \tag{8}$$

and it is equal to

$$Y_m = \Phi_{m1} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}} K_m^{\frac{\alpha\nu_m}{1-\varepsilon_m(1-\nu_m)}} N_m^{\frac{(1-\alpha)\nu_m}{1-\varepsilon_m(1-\nu_m)}} S_m^{\frac{(1-\varepsilon_m)(1-\nu_m)}{1-\varepsilon_m(1-\nu_m)}},$$

where $\Phi_{m1} = [1 - \varepsilon_m (1 - \nu_m)] [\varepsilon_m (1 - \nu_m)]^{\frac{\varepsilon_m(1-\nu_m)}{1-\varepsilon_m(1-\nu_m)}}$. TFP in the net production function Y_m, $\Phi_{m1} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}}$, is a function of gross output TFP, B_m, but also depends on the elasticity of manufacturing gross output with respect to manufactured intermediate goods, $\varepsilon_m (1 - \nu_m)$.[14] Equation (8) can be re-written as

$$Y_m = A_m \left(K_m^{\alpha} N_m^{1-\alpha} \right)^{\theta} S^{1-\theta}, \tag{9}$$

where

$$A_m = \Phi_{m1} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}}, \tag{10}$$

$0 < \theta < 1$ is equal to $\frac{\nu_m}{1-\varepsilon_m(1-\nu_m)}$ and $S_m = S$. The problem of the firm in the manufacturing sectors becomes

$$\max_{K_m, N_m, S} [p_m Y_m - r K_m - w N_m - p_s S] \tag{11}$$

subject to (9).

The net production function in the services sector is accordingly found and it is given by

$$Y_s = A_s \left[(K_s)^{\alpha} (N_s)^{1-\alpha} \right]^{\gamma} M^{1-\gamma}, \tag{12}$$

[14] Note also that the price of G_m and Y_m is the same.

where $0 < \gamma < 1$, K_s and N_s are the amounts of capital and labor and M is the amount of manufacturing used as intermediate good in the services sector. Finally, $A_{s,t} = \Phi_{s1} B_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}}$.[15] The problem of the representative firm in services becomes

$$\max_{K_s, N_s, M} \left[p_s Y_s - r K_s - w N_s - p_m M \right] \tag{13}$$

subject to (12).

Given the structure of the supply side of this economy, the relative price of services with respect to manufacturing, p_s/p_m, is independent of the quantities produced of the two goods. To see this, note that in a competitive market each firm sets the price equal to the marginal cost. The price of the manufacturing good is then

$$p_m = \frac{\left(r^\alpha w^{1-\alpha}\right)^\theta p_s^{1-\theta}}{\Phi_{m2} A_m}, \tag{14}$$

and that of services

$$p_s = \frac{\left(r^\alpha w^{1-\alpha}\right)^\gamma p_m^{1-\gamma}}{\Phi_{s2} A_s}, \tag{15}$$

where Φ_{m2} is a function of α and θ and Φ_{s2} is a function of α and γ.[16] By solving (14) and (15) for p_m and p_s I can write

$$\frac{p_s}{p_m} = \frac{\left(\Phi_{m2} A_m\right)^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{\left(\Phi_{s2} A_s\right)^{\frac{\theta}{\gamma+\theta-\theta\gamma}}}. \tag{16}$$

The relative price of the two goods is technologically determined, that is, it depends only on the parameters of the production functions and not on the quantity produced in the two sectors. This result depends on the input-output structure of the model together with the same capital and labor aggregator for the two firms, $K_j^\alpha N_j^{1-\alpha}$, with $j = m, s$.[17]

[15] $\Phi_{s1} = \left[1 - \varepsilon_s (1 - \nu_s)\right] \left[\varepsilon_s (1 - \nu_s)\right]^{\frac{\varepsilon_s(1-\nu_s)}{1-\varepsilon_s(1-\nu_s)}}$

[16] $\Phi_{m2} = (\alpha\theta)^{\alpha\theta} \left[(1-\alpha)\theta\right]^{(1-\alpha)\theta} (1-\theta)^{1-\theta}$ and $\Phi_{s2} = (\alpha\gamma)^{\alpha\gamma} \left[(1-\alpha)\gamma\right]^{(1-\alpha)\gamma} (1-\gamma)^{1-\gamma}$.

[17] As the aggregator for capital and labor is the same for the two sectors, the non-substitution theorem applies. See Samuelson (1951) and Mas-Colell et al. (1995).

4.2 Households

The model economy is inhabited by a measure one of households indexed in the interval $i \in [0,1]$. Households in this economy have preferences over manufacturing and services and are endowed with one unit of labor time each period which they supply inelastically. The consumption index at date t is given by

$$c_t = \left[b c_{m,t}^{\rho} + (1-b)\left(c_{s,t} + \bar{s}\right)^{\rho}\right]^{\frac{1}{\rho}}, \tag{17}$$

with $\bar{s} > 0$, $\rho < 1$ and $0 < b < 1$, where $c_{m,t}$ and $c_{s,t}$ are the per capita consumption levels of manufacturing and services.[18] The parameter $\bar{s}$ is interpreted as home production of services.[19] The utility function in (17) displays an income elasticity of demand smaller than one for manufacturing and larger than one for services.[20] Given prices, as income increases the expenditure share on services increases with respect to that of manufacturing.

Households solve the following problem

$$\max_{c_t} E \sum_{t=0}^{\infty} \beta^t [\log c_t] \tag{18}$$

subject to

$$p_{s,t} c_{s,t} + p_{m,t} c_{m,t} + p_{m,t}\left[k_{t+1} - (1-\delta)k_t\right] = r_t k_t + w_t.$$

where E is the expectations operator, β the subjective discount factor and δ the depreciation rate of the capital stock. Each period t, the household decides how much to consume of services, $c_{s,t}$, of manufacturing, $c_{m,t}$, and how much to invest, $k_{t+1} - (1-\delta)k_t$, given the rent from the capital stock owned, k_t, and the wage from labor services offered. It is assumed that the capital stock is produced only in the manufacturing sector so its price is p_m.[21]

[18] As households are identical I avoid the use of the index i for the time being. This will be used for the market clearing conditions in section 4.4.

[19] See, for instance, Kongsamut, Rebelo and Xie (2001) for this interpretation.

[20] See Jorgenson and Slesnick (1987) for empirical estimates of these elasticities.

[21] This is the same assumption as in Echevarria (1997) and Kongsamut, Rebelo and Xie (2001) and finds support in the data. Kongsamut, Rebelo and Xie (2001) find that manufacturing and construction produced between 90% and 93% of investment during the period 1958-1987.

4.3 Two Aggregate Production Functions

In this section I determine, for each period, the aggregate resources available for consumption and investment purposes. This is accomplished by defining the appropriate aggregate production function.

An aggregate production function for this economy can be obtained by solving the following static maximization problem

$$\max_{K_{m,t},N_{m,t},M_t,S_t} \left[A_{m,t} \left(K_{m,t}^{\alpha} N_{m,t}^{1-\alpha} \right)^{\theta} S_t^{1-\theta} - M_t \right] \tag{19}$$

subject to

$$A_{s,t} \left[(K_t - K_{m,t})^{\alpha} (N_t - N_{m,t})^{1-\alpha} \right]^{\gamma} M_t^{1-\gamma} = S_t,$$

where $Y_{m,t} = A_{m,t} \left(K_{m,t}^{\alpha} N_{m,t}^{1-\alpha} \right)^{\theta} S_t^{1-\theta}$ and $Y_{s,t} = A_{s,t} \left[(K_t - K_{m,t})^{\alpha} (N_t - N_{m,t})^{1-\alpha} \right]^{\gamma} M_t^{1-\gamma}$ are the production functions defined in (9) and (12) and K_t and N_t are the amounts of capital and labor available in the economy at t. The solution of problem (19) gives the maximum amount of manufacturing that can be produced in the economy when $c_{s,t} = 0$ for all households, that is, when the services sector serves only as an intermediate sector. This solution is

$$V_{m,t} = \Phi_{m3} A_{m,t}^{\frac{1}{\gamma+\theta-\theta\gamma}} A_{s,t}^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}} K_t^{\alpha} N_t^{1-\alpha}, \tag{20}$$

where Φ_{m3} is a function of γ and θ.[22] By dividing (20) by (16) it is possible to obtain the maximum amount of services that can be produced when the manufacturing sector produces only intermediate goods

$$V_{s,t} = \Phi_{s3} A_{m,t}^{\frac{1-\gamma}{\gamma+\theta-\theta\gamma}} A_{s,t}^{\frac{1}{\gamma+\theta-\theta\gamma}} K_t^{\alpha} N_t^{1-\alpha}, \tag{21}$$

where Φ_{s3} is a function of γ and θ.[23]

[22] $\Phi_{m3} = [1-(1-\theta)(1-\gamma)][(1-\theta)(1-\gamma)]^{\frac{1-\theta-\gamma+\theta\gamma}{\theta+\gamma-\theta\gamma}} \left(\frac{\theta}{\gamma+\theta-\gamma\theta}\right)^{\frac{\theta}{\theta+\gamma-\theta\gamma}} \left(\frac{\gamma.(1-\theta)}{\gamma+\theta-\gamma\theta}\right)^{\frac{\gamma(1-\theta)}{\theta+\gamma-\theta\gamma}}$

[23] $\Phi_{s3} = \Phi_{m3} / \left(\frac{(\Phi_{m2})^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{(\Phi_{s2})^{\frac{\theta}{\gamma+\theta-\theta\gamma}}} \right)$.

Using the definition of A_m given by (10) and the corresponding definition of A_s, (20) becomes

$$V_{m,t} = \Phi_{m3} \Phi_{m1}^{\frac{1}{\gamma+\theta-\theta\gamma}} \Phi_{s1}^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}} B_{m,t}^{\frac{1}{1-\varepsilon_m(1-\nu_m)} \frac{1}{\gamma+\theta-\theta\gamma}} B_{s,t}^{\frac{1}{1-\varepsilon_s(1-\nu_s)} \frac{1-\theta}{\gamma+\theta-\theta\gamma}} K_t^{\alpha} N_t^{1-\alpha}, \tag{22}$$

and (21) becomes

$$V_{s,t} = \Phi_{s3} \Phi_{m1}^{\frac{1-\gamma}{\gamma+\theta-\theta\gamma}} \Phi_{s1}^{\frac{1}{\gamma+\theta-\theta\gamma}} B_{m,t}^{\frac{1}{1-\varepsilon_m(1-\nu_m)} \frac{1-\gamma}{\gamma+\theta-\theta\gamma}} B_{s,t}^{\frac{1}{1-\varepsilon_s(1-\nu_s)} \frac{1}{\gamma+\theta-\theta\gamma}} K_t^{\alpha} N_t^{1-\alpha}. \tag{23}$$

Equations (22) and (23) represent the economy's resources in two extreme cases, one in which only manufacturing is consumed - or invested - and services is just an intermediate sector, and another in which the opposite situation holds. Note that TFP is different in the two cases and TFP growth and volatility also, because of the different exponents of $B_{m,t}$ and $B_{s,t}$ in (22) and (23). Using Jorgenson 2007 data I compute the exponent of $B_{m,t}$ and $B_{s,t}$ in (22) and (23). The values are reported in Table 2.

Table 2	
$\frac{1}{1-\varepsilon_m(1-\nu_m)} \frac{1}{\gamma+\theta-\theta\gamma}$	1.82
$\frac{1}{1-\varepsilon_s(1-\nu_s)} \frac{1-\theta}{\gamma+\theta-\theta\gamma}$	0.44
$\frac{1}{1-\varepsilon_m(1-\nu_m)} \frac{1-\gamma}{\gamma+\theta-\theta\gamma}$	0.28
$\frac{1}{1-\varepsilon_s(1-\nu_s)} \frac{1}{\gamma+\theta-\theta\gamma}$	1.44

Assume that $B_{m,t}$ and $B_{s,t}$ are driven by a common stochastic process, so that $B_{m,t} = B_{s,t} = B_t$ for any t. In this case, the exponent of B_t is $(1.82 + 0.44) = 2.26$ in (22) and $(0.28 + 1.44) = 1.72$ in (23), with a difference between the two cases of 31%. That is, TFP volatility and growth depend on the units output is measured in. In U.S. data, GDP composition changes over time becoming more intensive in services with respect to manufacturing. Equations (22) and (23) suggest that the structural change that occurs between manufacturing and services can account for a part of the reduced output volatility in the U.S.

4.4 The Competitive Equilibrium

A competitive equilibrium for the economy under study is a set of prices $\{p_{m,t}, p_{s,t}, r_t, w_t\}_{t=0}^{\infty}$ and allocations $\{c_{m,t}, c_{s,t}, k_{t+1}, K_{m,t}, N_{m,t}, K_{s,t}, N_{s,t}, M_t, S_t\}_{t=0}^{\infty}$ such that:

a) Given prices, $c_{m,t}, c_{s,t}$ and k_{t+1} solve the representative household's problem (18) at each t;

b) Given prices, $K_{m,t}$, $N_{m,t}$ and S_t solve the manufacturing representative firm problem (11) and $K_{s,t}$, $N_{s,t}$ and M_t solve the services representative firm problem (13) at each t;

c) Markets clear:

$$k_t = \int_0^1 k_t di = K_t = K_{m,t} + K_{s,t},$$

$$N_t = N_{m,t} + N_{s,t} = 1,$$

$$\int_0^1 c_{m,t} di = c_{m,t},$$

$$\int_0^1 c_{s,t} di = c_{s,t},$$

$$Y_{m,t} = c_{m,t} + k_{t+1} - (1-\delta)k_t + M_t,$$

$$Y_{s,t} = c_{s,t} + S_t,$$

and

$$\frac{p_{s,t}}{p_{m,t}} c_{s,t} + c_{m,t} + k_{t+1} - (1-\delta)k_t = V_{m,t}.$$

4.5 The Planner's Problem

In the model presented there are no distortions so an equal-weight Pareto problem delivers the competitive equilibrium solution. A benevolent social planner in this economy solves the following dynamic program problem

$$V(k, z_m, z_s) = \max_{c_m, c_s, k'} \{\log(c) + \beta E[V(k', z_m', z_s') | z_m, z_s]\}, \tag{24}$$

subject to

$$c = \left[bc_m^{\rho} + (1-b)\left(c_s + \bar{s}\right)^{\rho}\right]^{\frac{1}{\rho}}, \tag{25}$$

$$\phi c_s + c_m + k' - (1-\delta)k = V_m, \tag{26}$$

$$\phi = \frac{\left(\Phi_{m1}\Phi_{m2}B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}}\right)^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{\left(\Phi_{s1}\Phi_{s2}B_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}}\right)^{\frac{\theta}{\gamma+\theta-\theta\gamma}}}, \tag{27}$$

$$B_m = \bar{B}_m e^{z_m} \text{ and } B_s = \bar{B}_s e^{z_s}, \tag{28}$$

$$z'_m = \rho_z z_m + \epsilon'_m, \text{ with } \epsilon_m \sim N(0, \sigma_m^2), \tag{29}$$

and

$$z'_s = \rho_z z_s + \epsilon'_s, \text{ with } \epsilon_s \sim N(0, \sigma_s^2), \tag{30}$$

where the prime indicates the value of a variable in the next period, $V(k, z_m, z_s)$ is the value function, and E is the expectations operator. Manufacturing is the numeraire of the economy, c_s, c_m, and $k' - (1-\delta)k$ are consumption in the services sector, consumption in the manufacturing sector and investment - which is a manufactured good - all in per capita terms. The aggregate production function, V_m, is given by (22). As population in the economy is constant over time and equal to one, the aggregate and the per-capita production functions coincide. The marginal rate of transformation between manufacturing and services, ϕ, is given by (16).[24] TFP at the gross output level in each sector, B_m and B_s, is the product of a level component, $\bar{B}_m$ and $\bar{B}_s$ respectively, and a cycle component, e^{z_m} and e^{z_s}, respectively. Each period, a shock affects the cycle component of each sector's total factor productivity. The process for this shock is $z'_m = \rho_z z_m + \epsilon'_m$ for manufacturing and $z'_s = \rho_z z_s + \epsilon'_s$ for services. The shocks ϵ_m and ϵ_s are i.i.d. over time with zero mean.

[24] As the first and the second welfare theorems hold, the relative price of services with respect to manufacturing in the competitive equilibrium, p_s/p_m, is equal to the marginal rate of transformation between services and manufacturing in the centralized economy, ϕ.

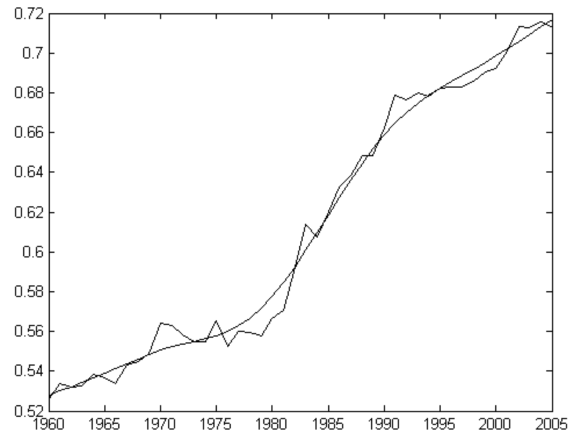

Figure 3: Nominal share of services in GDP and Hodrick-Prescott filter. Source: Jorgenson Dataset, 2007, and own calculations.

Finally, note that the real value added concept, needed to construct aggregate value added, requires the existence of the appropriate price index to deflate nominal value added. In the planner's economy there are no prices by construction but the correspondence with the competitive equilibrium can be used to resort to the real value added concept. In Appendix C, I show how the value added price indices in the two sectors are obtained in the competitive equilibrium. Once the equilibrium is found in the planned economy, these prices can be used to obtain real value added in the two sectors. Once real value added in the two sectors is obtained, aggregate value added is computed as a Tornqvist index of sectorial real value added. Aggregate value added is the model's counterpart of GDP in the data.

5 Strategy and Results

In the previous sections I provided evidence that points to a reduction of GDP volatility when the size of the services sector increases with respect to manufacturing. In the U.S. the share of services in GDP increased from 0.53 in 1960 to 0.71 in 2005. Figure 3 reports the pattern of this share for the period 1960-2005.

The purpose of this section is to use the planner problem presented in section 4.5 to quantify the role of the structural change in reducing GDP volatility in the U.S. To do this, I perform linear quadratic (LQ) approximations of the model around two steady states that differ in the size of the services sector in the economy.[25] The idea is that, when the services sector has a larger share in the economy, GDP volatility will be influenced to a larger extent by the volatility of the service sector and to a smaller extent by volatility in manufacturing. As the services sector displays a smaller value added TFP volatility for the reasons discussed above, GDP volatility should decline when the relative size of services in the economy increases.

To parametrize the model I use Jorgenson dataset, 2007. One model period corresponds to one year in the data. The parameters defining the elasticity of output with respect to inputs in the production functions (4) and (5) are directly computed from the data given the Cobb-Douglas assumption. The depreciation rate $\delta = 0.05$, the subjective discount factor $\beta = 0.96$, and the autoregressive parameter $\rho_z = 0.95$ are taken from Cooley and Prescott (1995).[26] The parameter governing the elasticity of substitution between manufacturing and services, $\rho = -1.5$, is consistent with the values used in Ngai and Pissarides (2007), Rogerson (2008) and Duarte and Restuccia (2008). Finally, the deterministic part of gross output TFP in manufacturing, $\bar{B}_m$, and in services, $\bar{B}_s$, are normalized to one.

Apart from the standard deviations of the productivity shocks in the two sectors, σ_m and σ_s, that will be discussed later, there are two parameters left, $\bar{s}$ and b. I calibrate the

[25] See Appendix B for the derivation of the non-stochastic steady state of the economy. Note also, that the two-sector model presented in this paper does not display a balanced growth path (BGP). In general, multi-sector growth models do not display a BGP, unless under restrictive assumptions on the utility or the production functions, as in Kongsamut, Rebelo and Xie (2001) and Ngai and Pissarides (2007). The latter authors provide conditions for BGP existence in a model with structural change and intermediate goods. In the class of models they consider, all sectors have the same Cobb-Douglas technology in capital, labor and intermediate goods, and different TFP levels. The model presented here does not possess these characteristics, as the production functions of the two sectors differ both in the elasticity parameters and in the TFP levels. As a BGP for this economy does not exist I perform steady state comparisons.

[26] Note that Cooley and Prescott (1995) use quarterly data while here I use yearly data. The parameters are then accordingly computed.

two parameters by using the average share of services in GDP in the period 1960-1983 and that in the 1984-2005 period. I proceed as follows. Given $\bar{s}$ and b, the share of services in GDP in the non-stochastic steady state is required to be 0.55. I label this the 1960-1983 steady state. I am now interested in constructing a second steady state, labelled 1984-2005, in which the share of service in GDP is 0.67, which is the average share during the 1984-2005 period. The only structural difference - i.e., difference in the parameters - between the two steady states is the gross output TFP level in the two sectors: in the 1984-2005 steady state this is $\bar{B}_m(1+\varphi_m)$ in manufacturing and $\bar{B}_s(1+\varphi_s)$ in services, where $(1+\varphi_m) = 1.33$ and $(1+\varphi_s) = 1.25$ are the growth factors of gross output TFP in the two sectors between 1960 and 2005.[27] Thus, given $\bar{s}$ and b, the model is required to deliver a share of services in GDP equal to 0.67 in the 1984-2005 steady state. Table 3 reports all parameter values.

Table 3

Parameter	Definition	Value	Source
α	Share of K in value added	0.34	Data
ν_m	Share of K_m and N_m in G_m	0.40	Data
ε_m	Share of M in manufac. interm.	0.71	Data
θ	Share of K_m and N_m in Y_m	0.70	Data
ν_s	Share of K_s and N_s in G_s	0.62	Data
ε_s	Share of S in services interm.	0.72	Data
γ	Share of K_s and N_s in Y_s	0.85	Data
φ_m	Growth rate of manu. GTFP 60/05	0.33	Data
φ_s	Growth rate of serv. GTFP 60/05	0.25	Data
β	Subject. discount rate	0.96	Literature
δ	Depreciation rate	0.05	Literature
ρ	Elasticity between manu. and serv.	-1.5	Literature
ρ_z	Autoregressive parameter	0.95	Literature
$\bar{B}_s$	Initial GTFP level in services	1	Normaliz.
$\bar{B}_m$	Initial GTFP level in manufacturing	1	Normaliz.
$\bar{s}$	Home production of services	0.4	Calibrated
b	Weight of manuf. in preferences	0.0005	Calibrated

To interpret the parameter $\bar{s}$, note that the calibration implies a consumption of market services c_s in total services consumption, $c_s + \bar{s}$, of 15% in the 1960-1983 SS and of 30% in

[27] See figure 2.

the 1984-2005 SS. This is consistent with the shift from home to market production observed over time.[28]

Table 4	
Period	SD of GDP
1960-2005	1.88%
1960-1983	2.23%
1984-2005	1.43%

In table 4, I report the standard deviation of GDP in the U.S. economy for the sub-periods 1960-1983 and 1984-2005 and for the whole period 1960-2005.[29] The standard deviation in the first sub-period is 56% larger than in the second sub-period. This confirms the general result encountered in the literature of a large decline in volatility between the two sub-periods.

In Table 5, I report volatility of GDP in the model when GDP is expressed in manufacturing value added units, GDPm, and when it is expressed in services GDP units, GDPs. The numbers in the table are average results of 1000 simulations of a 120 years long economy.[30] The volatility of the error terms for the stochastic processes of the two sectors is arbitrarily set to $\sigma_m = 1\%$ and $\sigma_s = 1\%$. When the economy consumes no services, GDP is represented only by manufacturing. In this case, GDP volatility is 2.31%. When the economy consumes

Table 5		
Standard Deviations of the Simulated Economy		
GDPm	**GDPs**	**Ratio**
2.31%	**1.53%**	**1.51**

only services, instead, GDP volatility is 1.53%. Thus, GDP volatility is 51% larger in the

[28] See Freeman and Shettkatt (2001, 2005).

[29] Standard deviations are computed as in standard business cycle exercises. The Hodrick-Prescott parameter used to filter the series is $\lambda = 100$, consistent with annual data. The series used is the yearly real GDP series from the St. Louis FED.

[30] For the methodology to perform linear quadratic approximations I follow Diaz-Gimenez (1999).

Table 6								
	Sigma Manufact.	Sigma Services	Services Share in GDP		S.D. of GDP		Ratio S.D. (1960-1983)/(1984-2005)	
			Model	Data	Model	Data	Model	Data
SS 1960-1983	1.17%	0.87%	0.55	0.55	1.52%	2.23%	1.58	1.56
SS 1984-2005	0.85%	0.67%	0.67	0.67	0.96%	1.43%		

first with respect to the second of these two extreme situations. Note that the result holds being the standard deviation of TFP shocks the same in the two sectors.

I now turn to perform LQ approximations around the two steady states by using the value of σ_m of σ_s implied by the data. Results in the following tables are average of 2000 simulations of the model economy run for 120 years. The Hodrick-Prescott parameter used to filter the series is $\lambda = 100$, consistent with yearly data.

I first compute in the data the standard deviations of the error terms in the two sectors, σ_m and σ_s, for the periods 1960-1983 and 1984-2005. I then perform linear quadratic approximations around the 1960-1983 SS by using the computed values of σ_m and σ_s for the 1960-1983 period and around the 1984-2005 SS by using the computed values of σ_m and σ_s for the 1984-2005 period. The values are $\sigma_m = 1.17\%$ and $\sigma_s = 0.87\%$ for the first period and $\sigma_m = 0.85\%$ and $\sigma_s = 0.67\%$ for the second period. Table 6 reports the results. The standard deviation of GDP is 1.52% in the 1960-1983 SS, compared to a 2.23% found in the data during the corresponding time period. In the 1984-2005 SS GDP volatility becomes 0.96%, compared to a 1.43% in the data. Although the model is not able to generate as much volatility as in the data, the ratio of the standard deviations of GDP in the two subperiods is virtually the same in the model, 1.58, as in the data, 1.56. Thus, with this specification, the model is able to replicate the entire reduction in GDP volatility observed in the data between the two subperiods.

The results in table 6 derive from two effects. One effect comes from the reduction in gross output TFP volatility in manufacturing and services between the two periods 1960-1983 and

Table 7								
	Sigma Manufact.	Sigma Services	Services Share in GDP		S.D. of GDP		Ratio S.D. (1960-1983)/(1984-2005)	
			Model	Data	Model	Data	Model	Data
SS 1960-1983	1.08%	0.78%	0.55	0.55	1.39%	2.23%	1.18	1.56
SS 1984-2005			0.67	0.67	1.18%	1.43%		

1984-2005. The second effect is due to the increase in the share of services in GDP between the two steady states. As services is the less volatile component of GDP, an increase in the services share reduces GDP volatility. To quantify the effect of the sectorial transformation I perform a decomposition experiment. I run LQ approximations around the two steady states by using the σ_m and σ_s measured for the entire 1960-2005 period, 1.08% and 0.78%, in both simulations. In this way, the reduction in GDP volatility observed between steady states derives from the sectorial transformation between services and manufacturing only, and not from a reduction in the sectors' gross output TFP volatility.

The first row of table 7 reports the 1960-1983 steady state in the decomposition experiment. GDP volatility is 1.39% in the model, compared to the 2.23% in the data. The second row reports the 1984-2005 SS. The volatility of GDP is 1.18%. The ratio of volatility in the 1960 over the 2005 steady states is 1.18. Thus, volatility in the 1960-1983 SS is 18% larger than in the 1984-2005 SS. In the data, the difference between the two periods is 56%. This implies that the structural transformation alone is able to explain around 32% of the difference in GDP volatility between the two periods.[31] The results encountered confirm that the structural change contributes substantially to the decline in GDP volatility in the U.S.

[31] $(18\%)/(56\%) \simeq 32\%$.

6 Conclusions

The structural transformation between manufacturing and services in modern economies is a well established fact. At the same time, the reduction in GDP volatility appears to be a continuous process. In this paper I show that in the U.S., the same TFP volatility at the gross output level for the manufacturing and the services sector delivers a difference in TFP volatility at the value added level of 55% between the two sectors. The reason lies in the manufacturing technology at the gross output level, more intensive in intermediate goods than services. The quantitative analysis suggests that the sectorial transformation can account for up to 32% of the difference observed in GDP volatility between the 1960-1983 and the 1984-2005 periods.

The different intensity of intermediate goods in the production of manufacturing and services have also important implications for the growth rate of an economy. Echevarria (1997) shows that the sectorial transformation between manufacturing and services implies a decline in aggregate TFP growth because services display a lower valued added TFP growth with respect to manufacturing. The analysis presented in this paper supports this finding, while also showing that a large part of the difference in TFP growth rates at the value added level is due to the different intensity of intermediate goods in the technology of the two sectors, rather than to a different TFP growth rate at the gross output level. This fact is important because it implies that, even when gross output TFP grows at the same rate in the two sectors, aggregate TFP is not uniquely determined but depends on the weights of the two sectors in GDP. It follows that the demand side (internal or external to the economy), which determines the size of the two sectors in the economy through preferences, affects aggregate TFP. I study the implications of sectorial transformation on growth in parallel research.

7 Data Appendix

All data except the GDP series are from Jorgenson Dataset, 2007.[32] The series for GDP is the annual Real GDP series from the Federal Reserve Bank of St. Louis.[33]

Jorgenson dataset, 2007, provides data for 35 sectors from 1960 to 2005. It reports, for each sector, the value and the price of output and the value and the price of capital, labor and 35 intermediate goods coming from each of the 35 sectors. Values are in millions of current dollars and prices are normalized to 1 in 1996. Variables are defined as: $q_k = quantity\ of\ capital\ services$, $p_k = price\ of\ capital\ services$, $q_l = quantity\ of\ labor\ inputs$, $p_l = price\ of\ labor\ inputs$, $q_{m,j} = quantity\ of\ intermediate\ goods\ inputs\ from\ sector\ j$ and $p_{m,j} = price\ of\ intermediate\ goods\ inputs\ from\ sector\ j$. For gross output, p^p is the $price\ of\ output\ that\ producers\ receive$, and q the quantity of gross output. Thus, $q = (q_k p_k + q_l p_l + q_m p_m)/p^p$, where q_m is an index of individual $q_{m,j}$ and p_m is an index of individual $p_{m,j}$.

I use the first 27 sectors to construct the manufacturing sector and the last 8 to construct the services sector. The manufacturing sector includes 1) Agriculture, forestry and fisheries, 2) Metal mining, 3) Coal mining, 4) Crude oil and gas extraction, 5) Non-metallic mineral mining, 6) Construction, 7) Food and kindred products, 8) Tobacco manufactures, 9) Textile mill products, 10) Apparel and other textile products, 11) Lumber and wood products, 12) Furniture and fixtures, 13) Paper and allied products, 14) Printing and publishing, 15) Chemicals and allied products, 16) Petroleum refining, 17) Rubber and plastic products, 18) Leather and leather products, 19) Stone, clay and glass products, 20) Primary metals, 21) Fabricated metal products, 22) Non-electrical machinery, 23) Electrical machinery, 24) Motor vehicles, 25) Other transportation equipment, 26) Instruments, 27) Miscellaneous manufacturing. Services include 28) Transportation and warehousing, 29) Communications, 30) Electric utilities (services), 31) Gas utilities (services), 32) Wholesale and retail trade,

[32] Downloadable at http://www.economics.harvard.edu/faculty/jorgenson.

[33] Downloadable at http://research.stlouisfed.org/fred2/categories/106

33) Finance, insurance and real estate, 34) Personal and business services, 35) Government enterprises.

Using individual sectors, I construct indices of gross output, capital, labor and intermediate goods for the two broad sectors, manufacturing and services. Gross output for each broad sector is constructed using chain-weighted Fisher indices.[34] The aggregate labor series in each broad sector, manufacturing and services, is computed as

$$\Delta \ln N_t = \sum_{j=1}^{I} \bar{\chi}_{jt}^{n} \Delta \ln N_{jt}, \tag{31}$$

where each $\Delta \ln N_{jt}$ is the growth rate of the labor index in sector j at t. $I = 27$ for manufacturing and $I = 8$ for services. The weight $\bar{\chi}_{jt}^{n}$ represents the average of the previous and current period share of labor compensation of sector j in total labor compensation of the broad sector - manufacturing or services.[35]

The aggregate capital series in each broad sector, manufacturing and services, is computed as

$$\Delta \ln K_t = \sum_{j=1}^{I} \bar{\chi}_{jt}^{k} \Delta \ln K_{jt}, \tag{32}$$

where each $\Delta \ln K_{jt}$ is the growth rate of the capital index in sector j at t. $I = 27$ for manufacturing and $I = 8$ for services. The weight $\bar{\chi}_{jt}^{k}$ represents the average of the previous and current period share of capital compensation of sector j in total capital compensation of the broad sector - manufacturing or services.

The index of intermediate goods in the broad manufacturing sector is constructed as a chain-weighted Fisher quantity index of all 27 manufacturing sectors. The index of intermediate goods in the aggregate services sector is constructed as a chain-weighted Fisher quantity index of all 8 services sectors.

[34] This type of index is suggested by the U.S. National Product and Income Accounts (NIPA) to construct real value added. See Bureau of Economic Analysis (2006) for details.

[35] For a description of the methodology used to constructed sectorial labor and capital series, see Jorgenson, Gollop, and Fraumeni (1987).

Gross output TFP in manufacturing and services is constructed in each period as

$$TFP_{GO}^{i} = \frac{G_i}{\left(K_i^{\alpha_i} N_i^{1-\alpha_i}\right)^{\nu_i} \left(R_i\right)^{1-\nu_i}},$$

where, $i = manufacturing$, $services$, G_i is the gross output quantity index for sector i, K_i, N_i, and R_i are the capital, labor and intermediate goods indices, $1 - \nu_i$ is the intermediate goods share in gross output and α_i is the capital share of value added for sector i. Value added TFP is constructed as

$$TFP_{VA}^{i} = \left(TFP_{GO}^{i}\right)^{\frac{1}{\nu_i}}.$$

8 Appendix A: From Atomistic Sectors to the Representative Firm

In this appendix I show how to derive the problems of the representative firms in manufacturing and services (6) and (7) from a more general problem with a continuum of atomistic sectors in each of the two broad sectors - manufacturing and services.

Assume a continuum of identical sectors in manufacturing $j \in [0,1]$ and in services $h \in [0,1]$. Each sector j and h includes a large number of identical firm. Thus, I can define a representative firm for the atomistic sector l in manufacturing. This firm has access to the production function

$$G_l = B_m \left(K_l^{\alpha} N_l^{1-\alpha}\right)^{\nu_m} \left(M_l^{\varepsilon_m} S_l^{1-\varepsilon_m}\right)^{1-\nu_m}, \tag{33}$$

where K_l and N_l are the amounts of capital and labor used by firm l. I define the index of manufactured intermediate goods as

$$M_l = \left[\int_0^1 \left(M_l^j\right)^{\varkappa} dj\right]^{\frac{1}{\varkappa}}, \tag{34}$$

and the index of intermediate services as

$$S_l = \left[\int_0^1 \left(S_l^h\right)^{\varkappa} dh\right]^{\frac{1}{\varkappa}}. \tag{35}$$

where M_l^j is the amount of output of sector j used as an intermediate manufacturing good, S_l^h is the amount of output of sector h used as an intermediate service by the representative firm of sector l and $\varkappa$ governs the elasticity of substitution between intermediate goods and between intermediate services. The problem of the representative firm of sector l becomes

$$\max_{K_l,N_l,M_l^j,S_l^h} \left[p_m^l G_l - rK_l - wN_l - \int_0^1 p_m^j M_l^j dj - \int_0^1 p_s^h S_l^h dh\right], \tag{36}$$

subject to

$$(33), (34) \text{ and } (35),$$

where p_m^j is the price of output of sector j in manufacturing and p_s^h is the price of output of sector h in services. Problem (36) states that the representative firm of sector l maximizes profits given by the value of output minus the cost of all inputs used in productions. In particular, this firm purchases intermediate goods from all other sectors in manufacturing and all sector in services.

The Dixit-Stiglitz aggregator (34) implies that, given an amount M_l that the firm is willing to use in the production process, there is an optimal combination of the M_l^j's that minimizes the cost $\int_0^1 p_m^j M_l^j dj$. Given (34), the minimum price of one unit of M_l is

$$p_m = \left[\int_0^1 \left(p_m^j\right)^{-\frac{\varkappa}{1-\varkappa}} dj\right]^{-\frac{1-\varkappa}{\varkappa}}, \tag{37}$$

and the corresponding minimum price of one unit of S_l is

$$p_s = \left[\int_0^1 \left(p_s^h\right)^{-\frac{\varkappa}{1-\varkappa}} dh\right]^{-\frac{1-\varkappa}{\varkappa}}. \tag{38}$$

As the firm always chooses to minimize its cost I can rewrite (36) as

$$\max_{K_l,N_l,M_l,S_l} \left[p_m^l G_l - rK_l - wN_l - p_m M_l - p_s S_l\right], \tag{39}$$

subject to

$$(33), (34), (35), (37) \text{ and } (38).$$

As the reduced form problem (39) is the same for the representative firm of each sector $j \in [0,1]$, each firm will set the same price of output $p_m^j = \bar{p}_m$ so

$$p_m = \left[\int_0^1 (\bar{p}_m)^{-\frac{\varkappa}{1-\varkappa}} dj\right]^{-\frac{1-\varkappa}{\varkappa}} = \bar{p}_m.$$

The same argument holds for firms in the services sector that have identical production technologies. It follows that, as all firms in the services sector set the price of output $p_s^h = \bar{p}_s$,

$$p_s = \left[\int_0^1 (\bar{p}_s)^{-\frac{\varkappa}{1-\varkappa}} dh\right]^{-\frac{1-\varkappa}{\varkappa}} = \bar{p}_s.$$

Furthermore, each representative firm of sectors $j \in [0,1]$ will choose the same amount of capital, labor, intermediate manufacturing goods and intermediate services, $K_j = K_m$, $N_j = N_m$, $M_j = M_m$, $S_j = S_m$ and produce the same amount of gross output $G_j = G_m$. The problem of the representative firm l in the manufacturing sector, (39), can be written as

$$\max_{K_l, N_l, M_l, S_l} \left[p_m G_m - r K_m - w N_m - p_m M_m - p_s S_m\right] \tag{40}$$

subject to

$$G_m = B_m \left(K_m^\alpha N_m^{1-\alpha}\right)^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}\right)^{1-\nu_m}.$$

Finally, note that aggregate output and inputs in the manufacturing sectors are

$$\int_0^1 G_m dj = G_m,\ \int_0^1 K_m dj = K_m,\ \int_0^1 N_m dj = N_m,$$

$$\int_0^1 M_m dj = M_m,\ \int_0^1 S_m dj = S_m.$$

It follows that (40) is the profit maximization problem of the representative firm in the manufacturing sector as stated in (6). The same argument can be developed for the services sector, to state problem (7).

9 Appendix B: Non-Stochastic Steady State

To derive the non-stochastic steady state of the model, I write the deterministic version of the planner's problem where $z_{m,t} = z_{s,t} = 0$ at each t. This is given by

$$\max_{c_{m,t},c_{s,t}} \sum_{t=0}^{\infty} \beta^t \log \left\{ \left[bc_{m,t}^{\rho} + (1-b)\left(c_{s,t}+\bar{s}\right)^{\rho} \right]^{\frac{1}{\rho}} \right\} \tag{41}$$

subject to

$$\phi c_{s,t} + c_{m,t} + k_{t+1} - (1-\delta)k_t = V_{m,t},$$

and

$$\phi = \frac{\left(\Phi_{m1}\Phi_{m2}\bar{B}_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}} \right)^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{\left(\Phi_{s1}\Phi_{s2}\bar{B}_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}} \right)^{\frac{\theta}{\gamma+\theta-\theta\gamma}}}.$$

Here, the aggregate production function in manufacturing terms is given by (22). I define

$$\Theta = \Phi_3 \Omega_m^{\frac{1}{\gamma+\theta-\theta\gamma}} \Omega_s^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}} \bar{B}_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}\frac{1}{\gamma+\theta-\theta\gamma}} \bar{B}_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}\frac{1-\theta}{\gamma+\theta-\theta\gamma}},$$

and set N_t equal to one so I can write $V_{m,t} = \Theta k_t^{\alpha}$.[36] The first order conditions of (41) with respect to $c_{s,t}$, $c_{m,t}$ and k_{t+1} deliver the following two conditions

$$c_{s,t} = \frac{c_{m,t}}{\phi^{1/(1-\rho)}} \left(\frac{1-b}{b} \right)^{1/(1-\rho)} - \bar{s} \tag{42}$$

and

$$\frac{1}{\beta} \frac{c_{m,t}^{\rho-1}}{\left[bc_{m,t}^{\rho} + (1-b)\left(c_{s,t}+\bar{s}\right)^{\rho} \right]} \frac{\left[bc_{m,t+1}^{\rho} + (1-b)\left(c_{s,t+1}+\bar{s}\right)^{\rho} \right]}{c_{m,t+1}^{\rho-1}} = \alpha\Theta k_t^{\alpha-1} + 1 - \delta \tag{43}$$

In steady state $c_{m,t} = c_m$, $c_{s,t} = c_s$, and $k_t = k$ so (43) becomes

$$\frac{1}{\beta} = \alpha\Theta k^{\alpha-1} + 1 - \delta,$$

[36] Given that $N_t = 1$ in each period, the aggregate and per-capita production functions are the same, that is, $V_{m,t} = \Theta K_t^{\alpha} = \Theta k_t^{\alpha}$

which can be solved for the steady state per capita capital level

$$k = \left(\frac{\alpha \Theta}{1/\beta - 1 + \delta} \right)^{\frac{1}{1-\alpha}}. \tag{44}$$

By using (44) in the production function $V_{m,t}$, I am able to obtain the per-capita steady state value added (GDP) in manufacturing gross output units

$$V_m = \Theta \left(\frac{\alpha \Theta}{1/\beta - 1 + \delta} \right)^{\frac{\alpha}{1-\alpha}}.$$

Finally, in steady state, $k_{t+1} - (1-\delta)k_t = k - (1-\delta)k = \delta k$. The budget constraint becomes

$$\phi c_s + c_m + \delta k = V_m. \tag{45}$$

By using (42) in (45) I obtain

$$c_m = \frac{V_m - \delta k + \phi \bar{s}}{\phi^{-\frac{\rho}{1-\rho}} \left(\frac{1-b}{b}\right)^{\frac{1}{1-\rho}} + 1}, \tag{46}$$

and using (46) in (42) I obtain the steady state level of c_s.

10 Appendix C: Real Value Added

Consider the maximization problem (6).

$$\max_{K_m, N_m, M_m, S_m} \left[p_m G_m - r K_m - w N_m - p_m M_m - p_s S_m \right] \tag{47}$$

$$\text{subject to } G_m = B_m \left(K_m^{\alpha} N_m^{1-\alpha} \right)^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m} \right)^{1-\nu_m}.$$

Define first $R_m = M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}$ as the intermediate goods index in the manufacturing sector. Given the Cobb-Douglas form of this index, the price of R_m is $p_r = \frac{p_m^{\varepsilon_m} p_s^{1-\varepsilon_m}}{\varepsilon_m^{\varepsilon_m} (1-\varepsilon_m)^{1-\varepsilon_m}}$. Problem (47) can be written as

$$\max_{K_m, N_m, R_m} \left[p_m G_m - r K_m - w N_m - p_r R_m \right] \tag{48}$$

$$\text{subject to } G_m = B_m \left(K_m^{\alpha} N_m^{1-\alpha} \right)^{\nu_m} \left(R_m \right)^{1-\nu_m}.$$

The first order condition of (48) with respect to R_m delivers the following condition,

$$R_m = (1-\nu_m)^{\frac{1}{\nu_m}} \left(\frac{p_m}{p_r}\right)^{\frac{1}{\nu_m}} B_m^{\frac{1}{\nu_m}} K_m^{\alpha} N_m^{1-\alpha}. \tag{49}$$

By plugging (49) into (48) I obtain the reduced form problem

$$\max_{K_m, N_m} \left[p_{vm} VA_m - rK_m - wN_m\right] \tag{50}$$

$$\text{subject to } p_{vm} VA_m = \nu_m (1-\nu_m)^{\frac{1-\nu_m}{\nu_m}} \left(\frac{p_m}{p_r^{1-\nu_m}}\right)^{\frac{1}{\nu_m}} B_m^{\frac{1}{\nu_m}} K_m^{\alpha} N_m^{1-\alpha}.$$

Here $p_{vm} VA_m$ represents nominal value added - value added in gross output units. Real value added VA_m is defined, as in Sato (1975), as the contribution to output growth of primary inputs (capital and labor) and technical change.[37] It follows that the real value added function is given by $VA_m = B_m^{\frac{1}{\nu_m}} K_m^{\alpha} N_m^{1-\alpha}$ and its price is $p_{vm} = \nu_m (1-\nu_m)^{\frac{1-\nu_m}{\nu_m}} \left(\frac{p_m}{p_r^{1-\nu_m}}\right)^{\frac{1}{\nu_m}}$ where $p_r = \frac{p_m^{\varepsilon_m} p_s^{1-\varepsilon_m}}{\varepsilon_m^{\varepsilon_m} (1-\varepsilon_m)^{1-\varepsilon_m}}$. The value added price for services is accordingly constructed.

To obtain real value added in the two sectors I take the equilibrium allocations of problem (24), and express them in gross output units of the market economy. These are $p_m(c_{m,t} + k_{t+1} - (1-\delta)k_t)$ in manufacturing and $p_s c_{s,t}$ in services. It follows that real value added is $VA_m = (p_m/p_{vm})(c_{m,t} + k_{t+1} - (1-\delta)k_t)$ in manufacturing and $VA_s = (p_s/p_{vs})c_{s,t}$ in services, where p_{vs} is the price of value added in the services sector.

[37] See note 8 for a discussion of the real value added concept.

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