

# The Structural Transformation Between Manufacturing and Services and the Decline in the US GDP Volatility\*

Alessio Moro<sup>†</sup>

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## Abstract

I construct a two-sector growth model to study the effect of the structural transformation between manufacturing and services on the decline in GDP volatility in the US. In the model, a change in the relative size of the two sectors affects the transmission mechanism that relates sectoral TFP shocks to endogenous variables. I calibrate the model to the US and show that, for given stochastic sectoral TFP processes in manufacturing and services, structural change generates a decline in the volatility of both aggregate TFP and GDP, in the volatility of each broad component of GDP (manufacturing consumption, services consumption and investment) and in the volatility of labor. Numerical results suggest that the structural transformation can account for 28% of the reduction in the US GDP volatility between the periods 1960-1983 and 1984-2005.

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<sup>†</sup>Department of Economics, University of Cagliari, amoro@unica.it.

# 1 Introduction

The decline in GDP volatility that occurred in the US during the second part of the last century is a well documented fact. During the same period, the US also experienced a dramatic process of structural transformation, i.e. an increase in the size of the services sector relative to manufacturing. In this paper, I study the relationship between the structural transformation and the decline in GDP volatility in the US in the context of a two-sector growth model. The main finding is that structural change in the calibrated model can account for 28% of the decline in GDP volatility observed in the US between the periods 1960-1983 and 1984-2005.

Previous studies suggest that the process of structural transformation has quantitatively relevant implications for the growth rate (Echevarria, 1997) and for the level of aggregate TFP (Herrendorf and Valentinyi, 2011), while others show how the emergence of aggregate fluctuations from independent sectoral shocks depends on the structure of the economy (Carvalho, 2007). It is thus reasonable to expect that the structural transformation might also determine changes in aggregate TFP volatility and, in turn, in the volatility of GDP. In the US, manufacturing production is more intensive in intermediate goods and displays a larger volatility of TFP at the sectoral level with respect to services. These differences suggest that an increase in the size of the services sector may have two effects on the economy: i) it may reduce aggregate TFP volatility because of a composition effect; ii) it may induce a change in the response of endogenous variables to shocks, because the structure of the economy has changed. Although the first effect is expected to imply a decline in GDP volatility, the second effect can have either a positive or a negative effect on the volatility of individual components of GDP, and so on GDP volatility.

The two-sector model presented allows me to study business cycles in an environment that is consistent with long-run structural transformation facts in the US. Structural change is generated by the interaction between exogenous TFP growth at the sectoral level and Stone-Geary preferences. This interaction implies that, in contrast with a standard one-sector growth model, the transmission mechanism of shocks to endogenous variables changes along the growth path, affecting the cyclical properties of the economy. In the calibrated model, for given stochastic sectoral TFP processes in manufacturing and services, structural change generates a decline in the volatility of both aggregate TFP and GDP, in the volatility

of each broad component of GDP (manufacturing consumption, services consumption and investment) and in the volatility of labor. Thus, structural change has the same effect of an exogenous reduction in aggregate TFP volatility in a one-sector growth model.

The structural transformation has previously been investigated as a possible source of the GDP volatility decline in the US by using model-free counterfactual experiments.<sup>1</sup> The standard argument is based on the observation that services value added is the least volatile component of GDP. Thus, with the increase in the share of services, GDP volatility should have declined because of a composition effect. This paper instead, presents a general equilibrium model that allows the study of all the links between the structural transformation and GDP volatility. The model shows that a change in the relative size of manufacturing and services does not only imply a composition effect on GDP volatility. Instead, when the share of services in GDP increases, the volatility of *each* component of GDP declines in equilibrium.

The mechanism proposed in this paper should be regarded as complementary to others proposed in the literature to explain the decline in GDP volatility.<sup>2</sup> Apart from the structural transformation, explanations advocated to explain the GDP volatility decline are: improved inventory management techniques (Davis and Kahn, 2008), better monetary policy (Clarida et al., 2000), better financial instruments (Jermann and Quadrini, 2006), a decline in aggregate TFP volatility (Arias et al., 2007) and demographic change (Jaimovich and Siu, 2009). This paper also relates to the literature on structural change and economic performance, e.g. Ngai and Pissarides (2007), Rogerson (2008), and Herrendorf, Rogerson and Valentinyi (2009), among others. However, with the exception of Da-Rocha and Restuccia (2006), who study the role of the size of the agricultural sector in determining aggregate volatility, the effect of structural change on GDP volatility has received little attention in the theoretical literature.

The remaining of the paper is organized as follows: section 2 analyzes TFP volatility in

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<sup>1</sup>McConnell and Perez-Quiros (2000), Blanchard and Simon (2001) Stock and Watson (2002), and Davis and Kahn (2008) use fixed weights counterfactual experiments, while Alcalá and Sancho (2003) use chain-weighted index numbers.

<sup>2</sup>According to Blanchard and Simon (2001), the reduction in GDP volatility in the US does not occur suddenly between the pre-84 and the post-84 periods, but is a process that started at least in 1950 and was interrupted in the seventies and mid-eighties. Interestingly, Buera and Kaboski (2009) show that the rise in the services sector in the US is also a phenomenon that started around 1950. Also, it is worth noting that the decline in GDP volatility occurred in most G7 countries (Stock and Watson, 2003) as the increase in the share of services in GDP.

manufacturing and services in the US; section 3 presents the model; section 4 discusses the quantitative analysis; finally, section 5 concludes.

## 2 Sectoral and value added TFP volatility

Table 1 reports the volatility of sectoral (gross output) TFP and value added TFP in manufacturing and services in the US.<sup>3</sup> The first column of table 1 reports sectoral TFP volatility in the two sectors during the 1960-2005 period. Sectoral TFP in manufacturing is 58% more volatile than in services during the whole sample period 1960-2005, 1.17% versus 0.74%. The second and third columns of table 1 report measures for two sub-periods which are usually considered in the literature to compare GDP volatility, before and after 1984. For both sectors, sectoral TFP volatility declines between the two periods, although the services sector displays a decline of 44%, compared to a 32% in manufacturing. Furthermore, in both subperiods manufacturing displays a larger volatility with respect to services, 1.35% versus 0.91%, and 0.92% versus 0.51%, respectively.

Table 1: TFP volatility in Manufacturing and Services in the US

Subperiod	Sectoral TFP			Value Added TFP		
	60-05	60-83	84-05	60-05	60-83	84-05
Manufacturing	1.17%	1.35%	0.92%	2.93%	3.38%	2.30%
Services	0.74%	0.91%	0.51%	1.19%	1.47%	0.82%
Ratio	1.58	1.48	1.80	2.46	2.30	2.80

The last three columns of table 1 report value added TFP volatility for the two sectors. This measure depends on both sectoral TFP volatility and on the share of intermediate goods in gross output in the sector considered. In particular, for a given level of sectoral TFP volatility, value added TFP volatility is an increasing function of the share of intermediate goods in gross output of the sector considered.<sup>4</sup> Figure 1 reports the share of intermediate goods in gross output in the manufacturing and in the services sectors from 1960 to 2005 in the US. The average share of intermediate goods is 0.6 in manufacturing and 0.38 in services. These numbers imply that if the volatility of sectoral TFP were the same in the

<sup>3</sup>Figures in this section are computed at a yearly frequency using Jorgenson Dataset, 2007. Series are logged and detrended using the Hodrick-Prescott filter before computing statistics. Manufacturing includes all non-services sectors. See the data appendix for details.

<sup>4</sup>See appendix A for details on the relationship between sectoral and value added TFP.

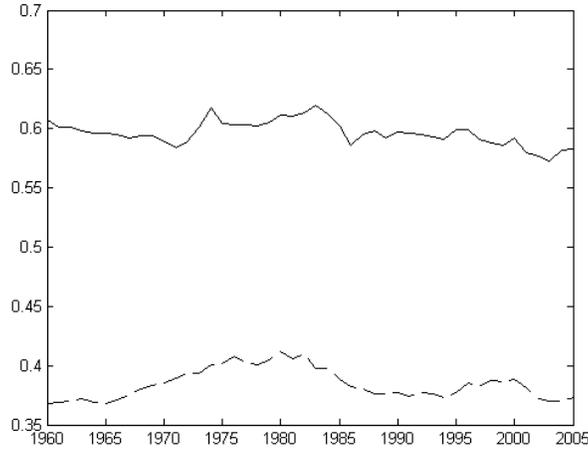


Figure 1: Nominal share of intermediate goods in manufacturing (continuous line) and in services (dashed line) in the U.S. Source: Jorgenson Dataset, 2007, and own calculations.

two sectors, the different share of intermediates in gross output would deliver a value added TFP volatility 55% larger in manufacturing than in services. Thus, with respect to sectoral TFP volatility, the difference between the two sectors in value added TFP volatility is larger, because of the higher share of intermediates in production in manufacturing with respect to services. Value added TFP volatility in manufacturing is 2.46 times larger than in services during the whole sample, 2.93% versus 1.19%, 2.30 times larger in the first subperiod, 3.38% versus 1.47%, and 2.80 times larger in the second one, 2.30% versus 0.82%.

In the US, the average share of services in GDP during the 1960-1983 period is 0.55 while the average share during the 1984-2005 period is 0.67. Aggregate TFP is computed using GDP as a measure of output, where GDP coincides with aggregate real value added. Thus, three effects potentially able to impact the volatility of the economy can be identified over time. The first one is the reduction in sectoral TFP volatility in manufacturing and services occurred between the 1960-1983 and the 1984-2005 periods. The second derives from the fact that the sector with the highest sectoral TFP volatility (manufacturing) shrinks with respect to the other (services). Finally, the third effect is due to the shrinking of the sector with the largest share of intermediate goods (again manufacturing) with respect to the other sector (again services). The last two effects are due to the process of structural transformation and have two main implications: first, to reduce the volatility of aggregate TFP; and second to

induce a change in the transmission mechanism of sectoral shocks to endogenous variables. The next section presents a model of structural change that allows me to isolate the effect of the structural transformation on GDP volatility.

## 3 The Model

### 3.1 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

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

and that of services is

$$G_s = B_s (K_s^\alpha N_s^{1-\alpha})^{\nu_s} (M_s^{1-\varepsilon_s} S_s^{\varepsilon_s})^{1-\nu_s}, \quad (2)$$

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 sectoral TFP, with  $j = m, s$ .<sup>5</sup> Sectoral TFP  $B_j$  is assumed to follow a stochastic process, unspecified for the time being.

The manufacturing producing firm solves

$$\max_{K_m, N_m, M_m, S_m} [p_m G_m - r K_m - w N_m - p_m M_m - p_s S_m] \quad (3)$$

subject to (1),

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. The services producing firm solves

$$\max_{K_s, N_s, M_s, S_s} [p_s G_s - r K_s - w N_s - p_m M_s - p_s S_s] \quad (4)$$

subject to (2).

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<sup>5</sup>Some studies report estimates of the elasticity of substitution between value added and intermediate goods smaller than one for the manufacturing sector (see Bruno, 1984, for instance). However, figure 1 shows that the share of intermediates goods in gross output remains roughly constant in the long run in both sectors. This observation supports the unit elasticity of substitution between value added and intermediate goods assumed in (1) and (2).

The production structure given by (1) and (2) implies that the production possibility frontier of this economy is linear and can be solved in closed form. The points in which the frontier crosses the manufacturing and the services axis at time  $t$  are given by

$$V_{m,t} = \Theta_m B_{m,t}^{f_1} B_{s,t}^{f_2} K_t^\alpha N_t^{1-\alpha}, \quad (5)$$

for manufacturing, and by

$$V_{s,t} = \Theta_s B_{m,t}^{f_3} B_{s,t}^{f_4} K_t^\alpha N_t^{1-\alpha}, \quad (6)$$

for services, where  $K_t$  and  $N_t$  are the total amounts of capital and labor employed in the economy. Here  $\Theta_m$ ,  $f_1$ ,  $f_2$ ,  $\Theta_s$ ,  $f_3$  and  $f_4$  are functions of  $\nu_m$ ,  $\nu_s$ ,  $\varepsilon_m$  and  $\varepsilon_s$ .<sup>6</sup> Note that (5) and (6) also represent the aggregate production function in two extreme cases in which the economy produces, respectively, only manufacturing and only services. As long as  $f_1 \neq f_3$  or  $f_2 \neq f_4$ , the transmission of sectoral TFP shocks to aggregate TFP is different in (5) and (6). Consider the case in which sectoral TFP in manufacturing and services is driven by a common process,  $B_{m,t} = B_{s,t} = B_t$ , at any  $t$ . By using the explicit functional forms of  $f_1$ ,  $f_2$ ,  $f_3$  and  $f_4$  it is possible to show that aggregate TFP volatility is larger in (5) than in (6) if and only if  $\nu_s > \nu_m$ , that is, if the share of intermediates in gross output is larger in manufacturing than in services. This, as shown in figure 1 is the empirically relevant case. Thus, the relative size of the two sectors determines the volatility of aggregate TFP, which declines along the production possibility frontier when reallocating capital and labor from manufacturing to services.<sup>7</sup>

## 3.2 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 each period. Instantaneous utility is given by

$$U(c_m, c_s, n) = \log [bc_m^\rho + (1-b)(c_s + \bar{s})^\rho]^{\frac{1}{\rho}} + \varphi \log(1-n), \quad (7)$$

with  $\bar{s} > 0$ ,  $\rho < 1$ ,  $0 < b < 1$ , and  $\varphi > 0$ . In (7),  $c_{m,t}$  and  $c_{s,t}$  are the per-capita consumption levels of manufacturing and services and  $n$  is labor. As households are identical I avoid

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<sup>6</sup>These are cumbersome expressions not reported for convenience. The online appendix presents the complete derivation of (5), (6) and the explicit functional forms of  $f_1$ ,  $f_2$ ,  $f_3$ ,  $f_4$ ,  $\Theta_m$  and  $\Theta_s$ .

<sup>7</sup>Note that because the capital and labor aggregator is the same in (5) and (6), and because the production possibility frontier of the economy is linear, aggregate TFP is always a linear combination of that in (5) and (6), with weights given by the proportions in which capital and labor are used in the two sectors.

the use of the index  $i$  for the time being. The parameter  $\bar{s}$ , which is interpreted as home production of services, implies that the income elasticity of services consumption is larger than one.

Households also make investment decisions. At each  $t$  they can transform an amount  $I_t$  of the manufactured good into new capital  $\bar{k}_t$  through the function  $\bar{k}_t = \frac{1}{\omega} \left( \frac{I_t}{k_t} \right)^\nu k_t$ , where  $k_t$  is the capital stock,  $\omega > 0$  and  $0 < \nu \leq 1$ .<sup>8</sup> This implies that the resulting law of motion of the capital stock is

$$k_{t+1} = (1 - \delta)k_t + \frac{1}{\omega} \left( \frac{I_t}{k_t} \right)^\nu k_t, \quad (8)$$

where  $\delta$  is the depreciation rate of capital and  $k_{t+1} - (1 - \delta)k_t = \bar{k}_t$ .<sup>9</sup>

Thus, households solve the following problem

$$\max_{c_{m,t}, c_{s,t}, n_t} E \sum_{t=0}^{\infty} \beta^t U(c_{m,t}, c_{s,t}, n_t) \quad (9)$$

subject to (7), to (8) and to

$$p_{s,t}c_{s,t} + p_{m,t}c_{m,t} + p_{m,t}I_t = r_t k_t + w_t n_t,$$

where  $E$  is the expectations operator and  $\beta$  is the subjective discount factor.

### 3.3 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  $\{c_{m,t}, c_{s,t}, n_t, k_{t+1}, I_t, K_{m,t}, N_{m,t}, K_{s,t}, N_{s,t}, M_{m,t}, M_{s,t}, S_{m,t}, S_{s,t}\}_{t=0}^{\infty}$  such that:

a) Given prices,  $c_{m,t}, c_{s,t}, n_t, I_t$  and  $k_{t+1}$  solve the representative household's problem (9) at each  $t$ ;

b) Given prices,  $K_{m,t}, N_{m,t}, M_{m,t}$  and  $S_{m,t}$  solve the manufacturing representative firm problem (3) and  $K_{s,t}, N_{s,t}, M_{s,t}$  and  $S_{s,t}$  solve the services representative firm problem (4) at each  $t$ ;

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<sup>8</sup>The assumption that investment is produced in the manufacturing sector is the same 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 in the US.

<sup>9</sup>Equation (8) implies that there are adjustment costs of installing new capital so that the (shadow) price of new capital,  $q_t$ , relative to the price of manufacturing is, in equilibrium,

$$\frac{q_t}{p_{m,t}} = \frac{\omega}{\nu} \left( \frac{I_t}{k_t} \right)^{1-\nu}.$$

c) Markets clear:

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

$$\int_0^1 n_t di = n_t = N_{m,t} + N_{s,t},$$

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

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

$$G_{m,t} = c_{m,t} + I_t + M_{m,t} + M_{s,t},$$

and

$$G_{s,t} = c_{s,t} + S_{m,t} + S_{s,t}.$$

Note that the sectoral real value added concept, needed to construct aggregate value added, requires the existence of the appropriate price index to deflate sectoral nominal value added. In appendix A I show how the value added price indices in the two sectors are obtained in the competitive equilibrium. Once the equilibrium is found, these prices can be used to obtain real value added in the two sectors, and aggregate real value added is computed as a chain-weighted Fisher quantity index. Aggregate real value added is the model's counterpart of real GDP in the data, which is also computed as a chain-weighted Fisher quantity index (Bureau of Economic Analysis, 2006).

## 4 Strategy and Quantitative Results

In this section I use a calibrated version of the model to quantify the role of the structural transformation in reducing GDP volatility in the US. The strategy adopted is that of studying the cyclical properties of linearized versions of the model around two steady states that differ in the size of the services sector in the economy.<sup>10</sup> This strategy is similar to Da-Rocha and Restuccia (2006), who study the effect of a different size of the agricultural sector on GDP volatility. They compare economies in which the share of agriculture differ due to different values of the weight of agriculture in standard CES preferences. In this paper, structural

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<sup>10</sup>See appendix B for the derivation of the non-stochastic steady state. 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 particular assumptions on the utility or the production functions, as in Kongsamut, Rebelo and Xie (2001) and Ngai and Pissarides (2007). An alternative approach here would be to compute the complete stochastic unbalanced growth path between steady states. However, the approach presented represents a simpler and more tractable way to assess the importance of the structural transformation between manufacturing and services on GDP volatility.

change between steady states is endogenously generated by the interaction of sectoral TFP growth and non-homothetic preferences. Herrendorf, Rogerson and Valentinyi (2009) show that the type of non-homothetic preference in (7) can account for the evolution of expenditure shares in the US. Thus, this paper represents a first attempt to analyze business cycles in a two-sector model consistent with long run facts of structural change in the US.<sup>11</sup>

I perform counterfactual experiments around two sets of steady states. The first experiment is performed around two steady states that display the share of services in GDP in the US in 1960 and 2005, respectively. The second experiment is performed around two steady states that display the average share of services in GDP in the US in the periods 1960-1983 and 1984-2005, respectively. Consider the calibration for the first set of steady states. The model is parametrized using Jorgenson dataset, 2007. One model period corresponds to one quarter in the data. The parameters defining the elasticity of output with respect to inputs in the production functions,  $\nu_m = 0.40$ ,  $\nu_s = 0.62$ ,  $\varepsilon_m = 0.71$  and  $\varepsilon_s = 0.72$ , are directly computed from the data given the Cobb-Douglas assumption. The depreciation rate  $\delta = 0.012$  and the subjective discount factor  $\beta = 0.985$  are taken from Cooley and Prescott (1995). The parameter governing the elasticity of substitution between manufacturing and services,  $\rho = -1.5$ , is consistent with the values used in Rogerson (2008) and Duarte and Restuccia (2010).

Sectoral TFP at time  $t$  is defined as  $B_{j,t} = \bar{B}_j e^{z_{j,t}}$ ,  $j = m, s$ , where  $\bar{B}_j$  is a constant and  $z_{j,t}$  a random component. The deterministic part of TFP in the first steady state,  $\bar{B}_{m1}$  and  $\bar{B}_{s1}$ , is normalized to one in both sectors while it is set to  $\bar{B}_{m2} = 1 + \gamma_m$  and  $\bar{B}_{s2} = 1 + \gamma_s$  in the second steady state, where  $\gamma_m = 0.30$  and  $\gamma_s = 0.27$  are the growth rates of sectoral TFP measured in the two sectors between 1960 and 2005. The stochastic component follows an AR(1) process  $z_{j,t} = \rho_{z,j} z_{j,t-1} + \epsilon_{j,t}$ , with  $\epsilon_{j,t} \sim N(0, \sigma_j^2)$ ,  $j = m, s$ , and i.i.d. over time. The autoregressive parameter is estimated using sectoral TFP series and is equal to  $\rho_{z,m} = 0.95$  in manufacturing and to  $\rho_{z,s} = 0.92$  in services.

To calibrate the preference parameters  $\bar{s}$ ,  $b$ , and  $\varphi$ , one strategy is to require that, given

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<sup>11</sup>In general, non-homothetic preferences are not crucial to generate an increase in the share of services in GDP. As value added TFP growth in services is lower than in manufacturing, this can be accomplished through CES preferences with a low elasticity of substitution (as in Ngai and Pissarides, 2007, for instance). However, as documented in Buera and Kaboski (2009), in the US both the relative price and the relative quantity of services with respect to manufacturing increase over time. For the model to generate an increase both in the relative quantity and in the relative price, an income effect coming from non-homothetic preferences is needed.

the growth in  $\bar{B}_m$  and  $\bar{B}_s$ , the model matches the share of services in GDP measured in 1960 in the first steady state, the share in 2005 in the second steady state and an amount of labor of 1/3 in both steady states. However, the non-homothetic component  $\bar{s}$  in the utility function implies that the steady state amount of labor is an increasing function of sectoral TFP in the two sectors.<sup>12</sup> As in the second steady state  $\bar{B}_m$  and  $\bar{B}_s$  are larger with respect to the first one, any (positive) value of  $\varphi$  implies that the amount of labor is also larger in the second steady state. Thus, it is necessary to impose a larger  $\varphi$  in the second steady state to have a labor supply of 1/3 in both.<sup>13</sup> I define  $\varphi_1$  and  $\varphi_2$  the values of  $\varphi$  in the two steady states. With the calibrated  $\bar{s}$ ,  $b$ , and  $\varphi_1$ , the model matches, in the first steady state, the share of services in GDP measured in 1960, 0.53, and an amount of labor of 1/3. I label this the 1960 steady state. In the second steady state, called 2005, sectoral TFP levels are higher, and the non-homotheticity of preferences implies that the services share in GDP is also higher. With the calibrated  $\bar{s}$ ,  $b$  and  $\varphi_2$ , the model matches a share of services in GDP equal to 0.71, which is the share measured in the data in 2005, and an amount of labor of 1/3. Parameter values are  $\bar{s} = 1.2730$ ,  $b = 0.000023$ ,  $\varphi_1 = 0.0822$  and  $\varphi_2 = 0.1590$ .

The small value of the parameter  $b$  is due to the fact that the capital good is produced in the manufacturing sector only, together with home production of services. This implies that, to match the share of manufacturing in GDP observed in the data, the weight of manufacturing in preferences must be close to zero. The calibration implies that in the 1960 steady state, the proportion of manufacturing consumption is 0.34 of nominal aggregate value added while in the 2005 it is 0.16. In addition, manufacturing consumption over total manufacturing is 0.72 in the 1960 steady state and 0.55 in the 2005 steady state.

Finally, I need to calibrate the parameters governing capital adjustment costs,  $\omega$  and  $\nu$ , and standard deviations of sectoral TFP shocks in the two sectors. The efficiency parameter in capital accumulation is set to  $\omega = 2.0260$  such that in both steady states the (shadow) price of one unit of new capital relative to the price of manufacturing is one. The standard deviations of the error terms in the two sectors,  $\sigma_m$  and  $\sigma_s$  are calibrated using sectoral Solow

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<sup>12</sup>See appendix B for details.

<sup>13</sup>When departing from standard log utility, it is often necessary to increase over time the disutility of working to have a constant amount of labor along the growth path (see for instance the utility specification in Neumeyer and Perri, 2005). I also perform simulations of a version of the model without endogenous labor supply, i.e. with  $\varphi = 0$ . In that case, the disutility of working is constant across steady states, and the effect of the structural transformation on GDP volatility is the same as in the version presented here. However, with exogenous labor supply the level of GDP volatility generated by the model is significantly lower.

residuals for the periods 1960-1983 and 1984-2005. These are  $\sigma_{m,60/83} = 0.0085$ ,  $\sigma_{m,84/05} = 0.0045$ ,  $\sigma_{s,60/83} = 0.0047$ ,  $\sigma_{s,84/05} = 0.0028$ . The data appendix provides details. Finally, the degree of capital adjustment costs  $\nu$  is set to 0.8, such that in the 1960 steady state the volatility of GDP in the model matches that in the data in that year.<sup>14</sup> Table 2 reports parameters values.

Table 2: Parameter Values

Parameter	Definition	Value	Source
$\alpha$	Share of capital in value added	0.34	Data
$\nu_m$	Share of $K_m$ and $N_m$ in $G_m$	0.40	Data
$\varepsilon_m$	Share of $M_m$ in manufacturing intermediates	0.71	Data
$\nu_s$	Share of $K_s$ and $N_s$ in $G_s$	0.62	Data
$\varepsilon_s$	Share of $S_s$ in services intermediates	0.72	Data
$\gamma_m$	Growth rate of sectoral manu. TFP 60/05	0.30	Data
$\gamma_s$	Growth rate of sectoral serv. TFP 60/05	0.27	Data
$\beta$	Subjective discount rate	0.985	Literature
$\delta$	Depreciation rate	0.012	Literature
$\rho$	Elasticity parameter in preferences	-1.5	Literature
$\bar{B}_{s1}$	TFP level in services in 1960 ss	1	Normaliz.
$\bar{B}_{m1}$	TFP level in manufacturing in 1960 ss	1	Normaliz.
$\rho_{z,m}$	Autoregressive parameter in manufacturing	0.95	Calibrated
$\rho_{z,s}$	Autoregressive parameter in services	0.92	Calibrated
$\nu$	Capital adjustment costs parameter	0.8	Calibrated
$\omega$	Efficiency parameter in cap. accumulation	2.0260	Calibrated
$\varphi_1$	Weight of leisure in 1960 ss	0.0822	Calibrated
$\varphi_2$	Weight of leisure in 2005 ss	0.1590	Calibrated
$\bar{s}$	Home production of services	1.2730	Calibrated
$b$	Weight of manufacturing in preferences	0.000023	Calibrated
$\sigma_{m,60/83}$	SD of shocks in manuf. 1960-1983	0.0085	Calibrated
$\sigma_{m,84/05}$	SD of shocks in manuf. 1984-2005	0.0045	Calibrated
$\sigma_{s,60/83}$	SD of shocks in services 1960-1983	0.0047	Calibrated
$\sigma_{s,84/05}$	SD of shocks in services 1984-2005	0.0028	Calibrated

<sup>14</sup>A value of 0.8 for  $\nu$  is in line with previous literature. See for instance Bernanke et al. (1999) for a brief discussion.

Table 3: Volatility across Steady States

Steady State	$\sigma_m$	$\sigma_s$	Services Share		% SD of GDP		Difference (Early - Late)	
			Model	Data	Model	Data	Model	Data
1960	0.85%	0.47%	0.53	0.53	1.92%	1.95%		
2005	0.45%	0.28%	0.71	0.71	0.93%	0.94%	0.99%	1.01%
							Proportion Explained	
2005	0.85%	0.47%	0.71	0.71	1.64%	0.94%	0.28	1.00
1960-1983	0.85%	0.47%	0.55	0.55	1.75%	1.90%		
1984-2005	0.45%	0.28%	0.67	0.67	0.82%	0.95%	0.93%	0.95%
							Proportion Explained	
1984-2005	0.85%	0.47%	0.67	0.67	1.49%	0.95%	0.28	1.00

Table 3 compares model and data. In the data, GDP volatility is 1.95% in 1960 and 0.94% in 2005.<sup>15</sup> The volatility difference between the two years is 1.01%. The first two lines of table 3 report theoretical standard deviations of GDP in the 1960 and 2005 steady states, where standard deviations of shocks are those calibrated for the 1960-1983 and 1984-2005 periods, respectively.<sup>16</sup> The model displays a GDP volatility of 1.92% in the 1960 steady state and of 0.93% in the 2005 steady state. With a difference in volatility of 0.99% between the two steady states, the model accounts for the entire decline of GDP volatility in the data between 1960 and 2005. This result derives from two effects. One effect is due to the reduction in sectoral TFP volatility in manufacturing and services between the two steady states, while the other is due to the increase in the share of services in GDP. To quantify the effect of the structural transformation alone, the third line of table 3 presents theoretical standard deviations of GDP in the 2005 steady state where standard deviations of shocks are  $\sigma_{m,60/83}$  and  $\sigma_{s,60/83}$  instead of  $\sigma_{m,84/05}$  and  $\sigma_{s,84/05}$ . In this case, GDP volatility is 1.64% so that the structural transformation accounts for 28% of the decline in GDP volatility between the two years.<sup>17</sup>

The last three lines of table 3 display theoretical standard deviations of GDP when the model is calibrated such that the two steady states match the average share of services during

<sup>15</sup>GDP volatility for 1960 and 2005 reported in table 3 is computed as follows. I log and detrend the quarterly real GDP series for the 1950-2010 period. Then, I compute the standard deviations of the detrended series for the subsamples 1950:q1-1960:q4 and 1995:q1-2005:q4.

<sup>16</sup>Series in the data and in the model are detrended using the Hodrick-Prescott with parameter  $\lambda = 1600$ . GDP statistics are computed using the quarterly real GDP series from St. Louis FED. Note also that for computation purposes, the values of calibrated parameters  $\bar{s}$ ,  $b$ ,  $\varphi_1$  and  $\varphi_2$  have to be set at a higher level of accuracy than those reported in table 2.

<sup>17</sup> $(1.92\% - 1.64\%)/(1.92\% - 0.93\%) = 0.28$

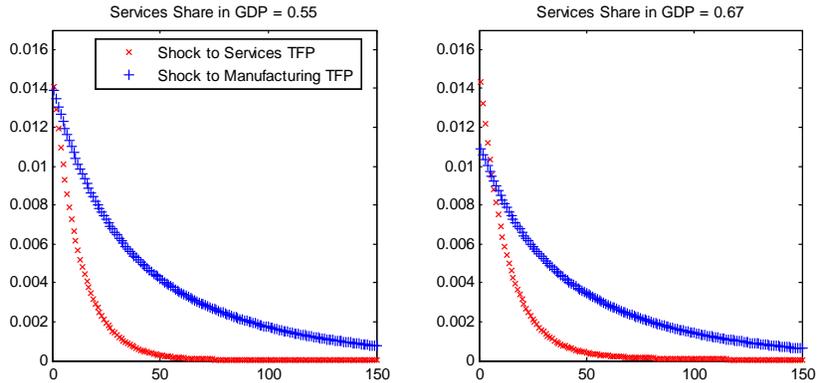


Figure 2: Percentage impulse response functions of GDP to a 1% sectoral TFP shock in services and manufacturing. The left panel shows responses in the 1960-1983 steady state, the right one those in the 1984-2005 steady state.

the periods 1960-1983 and 1984-2005. These are 0.55 and 0.67, respectively. With respect to the benchmark calibration in table 2, the following parameters have to be re-calibrated:  $\bar{s} = 0.1218$ ;  $b = 0.003430$ ;  $\varphi_1 = 0.5686$ ;  $\varphi_2 = 0.8356$ . In the data, GDP volatility is 1.90% in the first subperiod and 0.95% in the second one. The fourth and the fifth lines of table 3 report theoretical standard deviations of GDP in the 1960-1983 and 1984-2005 steady states, where the standard deviations of shocks are those calibrated for the corresponding periods. The model displays a volatility of GDP of 1.75% in the 1960-1983 steady state and of 0.82% in the 1984-2005 one. Instead, when standard deviations of shocks are  $\sigma_{m,60/83}$  and  $\sigma_{s,60/83}$ , GDP in the 1984-2005 displays a volatility of 1.49%. Thus, in this case also, the structural transformation accounts for 28% of the decline in volatility between subperiods. This confirms a substantial contribution of structural change to the decline in GDP volatility in the US.

As discussed in the previous sections, the structural transformation in the model implies a change in the transmission of sectoral TFP shocks to GDP. This change can be observed in figure 2, which plots the percentage impulse response functions of GDP to a 1% sectoral TFP shock in services and manufacturing. In the 1960-1983 steady state the shock to services implies an increase in GDP on impact of 1.41%, while the same shock in the 1984-2005 steady state implies an increase of 1.43%. Instead, the same shock to manufacturing induces an increase of GDP of 1.39% in the first steady state and only of 1.09% in the second one.

Thus, figure 2 suggests that the effect of structural change on GDP volatility in the model occurs mainly through a milder impact of manufacturing TFP shocks on aggregate GDP.

Consider now the volatility of the remaining endogenous variables of the model. The first two columns of Table 4 report percentage standard deviations and correlations with GDP of individual components of GDP, labor, and aggregate TFP in the 1960-1983 steady state. The third and fourth columns report the corresponding statistics for the 1984-2005 steady state, both for the 1960-1983 shocks (model with steady state invariant TFP volatility) and for the 1984-2005 shocks (model with steady state specific TFP volatility). Each component of GDP is expressed in real value added units of the relevant sector before computing statistics. To compare model with data, table 4 also reports statistics for non-durables, durables, services, and investment from NIPA and labor and aggregate TFP from Jorgenson dataset for the two subperiods.

In the model with steady state specific volatility, both the effect of the structural transformation and the reduction in sectoral TFP volatilities are at work. As for GDP, the model performs reasonably well in replicating business cycles of the two periods. In the 1960-1983 steady state, investment displays a volatility of 8.23% versus 8.36% in the data. The volatility of manufacturing consumption in the model (1.53%) is close to the volatility of non-durables in the data (1.37%). The volatility of services (1.66%) is similar to that of manufacturing consumption, and larger than in the data (0.83%). Consider now the 1984-2005 steady state. The model accounts well for the volatility of investment (4.22% versus 5.14% in the data), manufacturing consumption (0.81% compared to a 0.82% of non-durables in the data), and services consumption (0.57% versus 0.65% in the data). As in the standard one-sector RBC model, the volatility of labor is significantly lower than in the data in both steady states.

Table 4: Business Cycles across Steady States

	1960-1983		1984-2005		Ratio
	$\sigma_{x,1}$	$\rho(x_1, y_1)$	$\sigma_{x,2}$	$\rho(x_2, y_2)$	$\sigma_{x,1}/\sigma_{x,2}$
Model (SS invariant TFP volatility)					
Manuf. Cons.	1.51%	0.84	1.49%	0.83	1.01
Services Cons.	1.66%	0.46	1.28%	0.45	1.30
Investment	8.23%	0.86	7.93%	0.82	1.04
Labor	0.65%	0.95	0.55%	0.99	1.18
Agg. TFP	1.36%	0.99	1.13%	0.99	1.20
Model (SS specific TFP volatility)					
Manuf. Cons.	1.51%	0.84	0.79%	0.80	1.91
Services Cons.	1.66%	0.46	0.76%	0.52	2.18
Investment	8.23%	0.86	4.20%	0.79	1.96
Labor	0.65%	0.95	0.30%	0.99	2.17
Agg. TFP	1.36%	0.99	0.62%	0.99	2.19
Data (NIPA)					
Non-Durables	1.37%	0.78	0.82%	0.82	1.67
Durables	5.25%	0.82	2.88%	0.66	1.82
Services	0.83%	0.79	0.65%	0.70	1.28
Investment	8.36%	0.92	5.14%	0.86	1.63
Data (Jorgenson)					
Labor	2.17%	0.92	1.33%	0.87	1.64
Agg. TFP	1.06%	0.70	0.49%	0.12	2.16

Notes:  $\sigma_x$  is the standard deviation of percentage deviations from HP filter of variable  $x$ ,  $y$  is GDP,  $\rho(x, y)$  is the correlation of variable  $x$  with GDP. In the model with SS invariant TFP volatility  $\sigma_m = 0.85\%$  and  $\sigma_s = 0.47\%$  in both steady states. In the model with SS specific TFP volatility  $\sigma_m = 0.85\%$  and  $\sigma_s = 0.47\%$  in the first SS and  $\sigma_m = 0.45\%$  and  $\sigma_s = 0.28\%$  in the second.

The last column of table 4 reports the ratio of volatilities between subperiods and steady states. In the data, the volatility of each component of GDP and that of labor declines between the periods 1960-1983 and 1984-2005. The model with steady state invariant sectoral TFP volatility shows that a part of this decline can be attributed to the structural transformation. Structural change implies a decline in the volatility of manufacturing and services consumption, investment, labor and aggregate TFP between steady states. This is due to a general equilibrium effect that arises with structural change. When GDP volatility declines because of a larger share of services, the income of the representative consumer becomes less volatile, and this implies a less volatile demand for *all* (consumption and investment)

goods. The outcome of this mechanism is that, in equilibrium, the volatility of each GDP component and that of labor declines. Thus, structural change in the two sector model has the same effect of an exogenous reduction in aggregate TFP volatility in a standard one sector growth model.

Finally, with regard to comovements, the model generates a positive correlation of manufacturing and services consumption, investment, labor and aggregate TFP with GDP in both steady states. The magnitude of correlations is similar to the data for all variables except for services, which display a smaller correlation, 0.46 versus 0.79 in the first steady state and 0.52 versus 0.70 in the second. Note that this has to be attributed to the fact that aggregate TFP shocks are generated by two types of independent sectoral shocks. Assume for instance a positive TFP shock in manufacturing. This implies an increase in GDP, as shown in figure 2. However, it also implies that the relative price of services to manufacturing increases, so that the substitution effect leads the representative consumer to reduce services consumption and increase manufacturing. The relative price effect thus tends to reduce the correlation of services with GDP. Note that the same mechanism applies to manufacturing consumption, but the effect of a positive shock to services TFP on the relative price of the two goods is milder than in the case of a manufacturing shock, due to the different share of intermediate goods in the two sectors.<sup>18</sup> Thus, the correlation of manufacturing consumption with GDP is less affected by this channel.

## 5 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 common process across industrialized countries. This paper shows that the structural transformation can account for 28% of the difference observed in GDP volatility between the 1960-1983 and the 1984-2005 periods in the US in the context of a two-sector growth model.

It is due noticing here, that in the last years the volatility of GDP in the US showed a marked increase. This is commonly attributed to the recent financial turmoil. The model presented here shows that, given a certain volatility of sectoral TFP shocks, a structural

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<sup>18</sup>To see this, refer to the marginal rate of transformation between the two goods in the planner's problem in appendix B.

change towards services implies a reduction in GDP volatility. Thus, the model is consistent with the possibility that the volatility of sectoral shocks increases at some point in time, implying an increase in GDP volatility regardless of the structural change.

## Data Appendix

The series for GDP is the quarterly Real GDP series from the Federal Reserve Bank of St. Louis.<sup>19</sup> The series for non-durables, durables, services and investment used to obtain statistics in table 4 are from NIPA.<sup>20</sup> The remaining data are from Jorgenson Dataset, 2007.<sup>21</sup>

Jorgenson dataset, 2007, provides yearly data for 35 sectors from 1960 to 2005 that cover US GDP. 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,  $p^p$  = price of output that producers receive, and  $q$  = 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, 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 interme-

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<sup>19</sup>Downloadable at <http://research.stlouisfed.org/fred2/categories/106>

<sup>20</sup>Downloadable at <http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1>

<sup>21</sup>Downloadable at <http://www.economics.harvard.edu/faculty/jorgenson>.

intermediate goods for the two broad sectors, manufacturing and services. Gross output for each broad sector is constructed using chain-weighted Fisher indices.<sup>22</sup> The aggregate labor series in each broad sector, manufacturing and services, is computed as

$$\Delta \ln N_t = \sum_{j=1}^I \bar{\chi}_{jt}^n \Delta \ln N_{jt}, \quad (10)$$

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.<sup>23</sup>

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

$$\Delta \ln K_t = \sum_{j=1}^I \bar{\chi}_{jt}^k \Delta \ln K_{jt}, \quad (11)$$

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 manufactured intermediate goods used in the broad manufacturing sector is constructed as a chain-weighted Fisher quantity index of inputs from the 27 manufacturing sectors going to the 27 manufacturing sectors. The index of intermediate services used in the broad manufacturing sector is constructed as a chain-weighted Fisher quantity index of inputs from the 8 services sectors going to the 27 manufacturing sectors. The index of manufactured intermediate goods used in the broad services sector is constructed as a chain-weighted Fisher quantity index of inputs from the 27 manufacturing sectors going to the 8 services sectors. The index of intermediate services used in the broad services sector is constructed as a chain-weighted Fisher quantity index of inputs from the 8 services sectors going to the 8 services sectors.

Consider the production functions (1) and (2). Sectoral TFP in manufacturing and

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<sup>22</sup>This type of index is suggested by the US National Product and Income Accounts (NIPA) to construct real value added. See Bureau of Economic Analysis (2006) for details.

<sup>23</sup>For a description of the methodology used to construct sectoral labor and capital series, see Jorgenson, Gollop, and Fraumeni (1987).

services is constructed in each period as

$$TFP_{GO}^i = \frac{G_i}{(K_i^\alpha N_i^{1-\alpha})^{\nu_i} (M_i^{\varepsilon_i} S_i^{1-\varepsilon_i})^{1-\nu_i}}, \quad (12)$$

where,  $i = manufacturing, services$ ,  $G_i$  is the gross output quantity index for sector  $i$ ,  $K_i$ ,  $N_i$ ,  $M_i$  and  $S_i$  are the capital, labor, intermediate manufactured goods and intermediate services indices,  $\alpha$  is the capital share in value added,  $\nu_i$  is the capital and labor share in gross output and  $\varepsilon_i$  is the share of manufactured intermediates in total intermediates of sector  $i$ . Values of  $\alpha$ ,  $\nu_i$  and  $\varepsilon_i$  are averages over the period 1960-2005. Note that  $\alpha$  is common across sectors and it is equal to the average share of capital in value added in the economy. This is done for consistency with the model. By computing (12) with the sectoral  $\alpha$  for each sector  $i$  provides the same figures reported in table 1. Thus, volatility is not affected by this choice. In terms of growth, considering a different  $\alpha$  across sectors would imply a growth factor of 1.33 instead of 1.30 for manufacturing and of 1.25 instead of 1.27 for services over the 1960-2005 period.

Value added TFP is constructed as

$$TFP_{VA}^i = (TFP_{GO}^i)^{\frac{1}{\nu_i}}, \quad (13)$$

where  $\nu_i$  is one minus the average share of intermediate goods in gross output in sector  $i$  over the period 1960-2005. The share of intermediate goods in gross output in manufacturing is given by the value of intermediates used in the 27 manufacturing sectors divided by the value of gross output produced in those sectors. The share of intermediate goods in gross output in services is accordingly computed. These are the series appearing in Figure 1.<sup>24</sup>

The calibration of stochastic processes is as follows. Jorgenson dataset, 2007 provides time series of data at an annual frequency. To obtain quarterly data I interpolate annual sectoral TFP series constructed as in (12) with cubic splines, and use these series to calibrate stochastic processes. To compute the standard deviation of  $z_{j,t}$  of sector  $j = m, s$ , recall that  $B_{j,t} = \bar{B}_j e^{z_{j,t}}$ , so by taking logarithms

$$\log(B_{j,t}) - \log(\bar{B}_j) = z_{j,t}. \quad (14)$$

The deviation  $\log(B_{j,t}) - \log(\bar{B}_j)$  can be computed at each quarter  $t$  in the data as the percentage deviation from an Hodrick-Prescott filter, and the series of these deviations can

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<sup>24</sup>Refer to appendix A for the complete derivation of value added TFP.

be used to compute the standard deviation of  $z_{j,t}$ ,  $\sigma_{zj}$ , for the subperiods 1960-1983 and 1984-2005. Next, consider that given the stochastic process  $z_{j,t+1} = \rho_j z_{j,t} + \epsilon_{j,t+1}$ , the standard deviation of shocks  $\epsilon_j$  is  $\sigma_{\epsilon j} = (1 - \rho_j^2)^{1/2} \sigma_{zj}$ . Thus, once  $\sigma_{zj}$  is known, it is sufficient to estimate  $\rho_j$  with OLS using the series in (14) to calibrate  $\sigma_{\epsilon j}$ . The estimated autoregressive parameters for the two sectors are  $\rho_m = 0.95$  and  $\rho_s = 0.92$ .

By using the values of  $\sigma_{\epsilon j}$  so computed for the two sectors, the model displays a low level of GDP volatility (0.61% in the 1960 steady state). This is due to the following reasons: i) standard RBC models display a low volatility of GDP compared to the data; ii) in the two-sector model presented here, aggregate TFP fluctuations are generated by two types of independent shocks. This implies a lower volatility with respect to the case in which shocks are perfectly correlated (which is equivalent to a single shock model as the one-sector RBC model); iii) quarterly volatilities are obtained from interpolated annual data, which display a smoother pattern with respect to actual quarterly data.<sup>25</sup> Thus, for the model to match in the 1960 steady state the level of GDP volatility observed in the data, the values of  $\sigma_{\epsilon j}$  in the two sectors have to be increased. Instead of multiplying the  $\sigma_{\epsilon j}$  by an arbitrary constant, to calibrate the standard deviation of shocks I use the values of  $\sigma_{zj}$  obtained for the two sectors instead of those of  $\sigma_{\epsilon j}$ . These are  $\sigma_{zm,60/83} = 0.0085$ ,  $\sigma_{zm,84/05} = 0.0045$ ,  $\sigma_{zs,60/83} = 0.0047$ ,  $\sigma_{zs,84/05} = 0.0028$ , which are the values reported in table 3 for  $\sigma_m$  and  $\sigma_s$ . Note that by using the values of  $\sigma_{\epsilon j}$  instead of those of  $\sigma_{zj}$  the structural transformation accounts for 0.33 of the GDP volatility decline between the 1960 and the 2005 steady states, compared to the 0.28 obtained in table 3.

## Appendix A: Real Value Added

Consider again the maximization problem (3)

$$\begin{aligned} & \max_{K_m, N_m, M_m, S_m} [p_m G_m - r K_m - w N_m - p_m M_m - p_s S_m] & (15) \\ & \text{subject to } G_m = B_m (K_m^\alpha N_m^{1-\alpha})^{\nu_m} (M_m^{\varepsilon_m} S_m^{1-\varepsilon_m})^{1-\nu_m}. \end{aligned}$$

Define

$$R_m = M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}, \quad (16)$$

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<sup>25</sup>This can be seen by comparing for instance the volatility of quarterly real GDP with the volatility of the series obtained by interpolating annual real GDP. In the first case, the volatility measured for the period 1950-2010 is 1.63% while in the second case it is 1.39%.

as the intermediate goods index in the manufacturing sector. Given the Cobb-Douglas form of this index, with competitive markets the price of  $R_m$  is

$$p_r = \frac{p_m^{\varepsilon_m} p_s^{1-\varepsilon_m}}{\varepsilon_m^{\varepsilon_m} (1-\varepsilon_m)^{1-\varepsilon_m}}. \quad (17)$$

Thus, problem (15) can be written as

$$\begin{aligned} & \max_{K_m, N_m, R_m} [p_m G_m - r K_m - w N_m - p_r R_m] \\ & \text{subject to } G_m = B_m (K_m^\alpha N_m^{1-\alpha})^{\nu_m} (R_m)^{1-\nu_m}. \end{aligned} \quad (18)$$

The first order condition of (18) with respect to  $R_m$  delivers the following condition

$$R_m = (1 - \nu_m)^{\frac{1}{\nu_m}} \left( \frac{p_m}{p_r} \right)^{\frac{1}{\nu_m}} B_m^{\frac{1}{\nu_m}} K_m^\alpha N_m^{1-\alpha}. \quad (19)$$

By plugging (19) into (18) it is possible to obtain the reduced form problem

$$\begin{aligned} & \max_{K_m, N_m} [p_{vm} V A_m - r K_m - w N_m] \\ & \text{subject to } p_{vm} V A_m = \nu_m (1 - \nu_m)^{\frac{1-\nu_m}{\nu_m}} \left( \frac{p_m}{p_r^{1-\nu_m}} \right)^{\frac{1}{\nu_m}} B_m^{\frac{1}{\nu_m}} K_m^\alpha N_m^{1-\alpha}. \end{aligned}$$

Here  $p_{vm} V A_m$  represents nominal value added. Real value added  $V A_m$  is defined, as in Sato (1976), as the contribution to gross output growth of primary inputs (capital and labor) and technical change. It follows that the real value added production function is given by

$$V A_m = B_m^{\frac{1}{\nu_m}} K_m^\alpha N_m^{1-\alpha},$$

and the price of value added 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  $p_r$  is given by (17). Value added TFP is then given by

$$TFP_{VA}^m = B_m^{\frac{1}{\nu_m}},$$

which corresponds to (13).  $V A_s$ ,  $p_{vs}$  and  $TFP_{VA}^s$  are accordingly constructed.

To obtain real value added in the two sectors I first express the allocations of the competitive equilibrium in gross output units. These are  $p_m [c_{m,t} + I_t]$  in manufacturing and  $p_s c_{s,t}$  in services. It follows that real value added is  $V A_m = (p_m / p_{vm}) [c_{m,t} + I_t]$  in manufacturing and  $V A_s = (p_s / p_{vs}) c_{s,t}$  in services.

## Appendix B: Non-Stochastic Steady State

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

$$\max_{c_{m,t}, c_{s,t}, n_t} \sum_{t=0}^{\infty} \beta^t \left\{ \log [bc_{m,t}^\rho + (1-b)(c_{s,t} + \bar{s})^\rho]^{\frac{1}{\rho}} + \varphi \log(1 - n_t) \right\} \quad (20)$$

subject to

$$\phi c_{s,t} + c_{m,t} + I_t = V_{m,t}, \quad (21)$$

$$V_{m,t} = \Theta k_t^\alpha n_t^{1-\alpha},$$

$$k_{t+1} - (1 - \delta)k_t = \frac{1}{\omega} \left( \frac{I_t}{k_t} \right)^\nu k_t, \quad (22)$$

and

$$\phi = \Omega \left( \frac{\bar{B}_m^{\nu_s}}{\bar{B}_s^{\nu_m}} \right)^{\frac{1}{\nu_m[1-\varepsilon_s(1-\nu_s)] + \nu_s[1-\varepsilon_m(1-\nu_m)] - \nu_s\nu_m}}.$$

Here  $\phi$  is the marginal rate of transformation between manufacturing and services, and  $\Omega$  is a constant term depending on  $\nu_m$ ,  $\nu_s$ ,  $\varepsilon_m$ , and  $\varepsilon_s$ .  $V_{m,t}$  is the aggregate production function in manufacturing units defined in (5), where  $\Theta = \Theta_m \bar{B}_m^{f_1} \bar{B}_s^{f_2}$ . As for  $V_{m,t}$  and  $\Theta_m$ , details of the calculations of  $\phi$  and the explicit functional form of  $\Omega$  are provided in the online appendix.

Define  $\lambda_{1t}$  and  $\lambda_{2t}$  as the Lagrange multipliers attached to constraints (21) and (22) respectively. Then, the first order conditions with respect to  $c_{s,t}$ ,  $c_{m,t}$ ,  $n_t$ ,  $I_t$  and  $k_{t+1}$  deliver the following four conditions

$$c_{s,t} = \frac{c_{m,t}}{\phi^{1/(1-\rho)}} \left( \frac{1-b}{b} \right)^{1/(1-\rho)} - \bar{s}, \quad (23)$$

$$\varphi \frac{n_t}{1 - n_t} = \frac{(1 - \alpha)V_{m,t}}{V_{m,t} - I_t + \phi \bar{s}}, \quad (24)$$

$$q_t = \beta \frac{c_{m,t+1}^{\rho-1}}{c_{m,t}^{\rho-1}} \frac{bc_{m,t}^\rho + (1-b)(c_{s,t} + \bar{s})^\rho}{bc_{m,t+1}^\rho + (1-b)(c_{s,t+1} + \bar{s})^\rho} \left\{ \alpha \Theta k_{t+1}^{\alpha-1} n_{t+1}^{1-\alpha} + \left[ (1 - \delta) + \frac{1 - \nu}{\omega} \left( \frac{I_{t+1}}{k_{t+1}} \right)^\nu \right] q_{t+1} \right\}, \quad (25)$$

and

$$q_t = \frac{\omega}{\nu} \left( \frac{I_t}{k_t} \right)^{1-\nu}, \quad (26)$$

where  $q_t = -\frac{\lambda_{2t}}{\lambda_{1t}}$ . Variable  $q_t$  represents the marginal rate of transformation between manufacturing goods and new capital.

In the calibration, the steady state value of  $q$  is required to be one. For given  $\nu$  and  $\delta$ , to have  $q = 1$  in steady state, it is sufficient to set the appropriate value of the efficiency parameter  $\omega$ . By imposing steady state conditions  $I_t = I$ , and  $k_t = k$ , together with  $q = 1$ , (26) can be solved to obtain

$$\frac{I}{k} = \left(\frac{\nu}{\omega}\right)^{\frac{1}{1-\nu}}, \quad (27)$$

while from (22)

$$\frac{I}{k} = (\omega\delta)^{\frac{1}{\nu}}. \quad (28)$$

By combining (27) and (28), it obtains that, for given  $\nu$  and  $\delta$ , the unique value of  $\omega$  that makes  $q = 1$  in steady state is

$$\omega = \frac{\nu^\nu}{\delta^{1-\nu}}.$$

Next, by using the remaining steady state conditions  $c_{m,t} = c_m$ ,  $c_{s,t} = c_s$  and  $n_t = n$ , (25) can be solved to obtain

$$k = \left( \frac{\alpha\Theta}{1/\beta - (1-\delta) - \frac{1-\nu}{\omega} \left(\frac{\nu}{\omega}\right)^{\frac{\nu}{1-\nu}}} \right)^{\frac{1}{1-\alpha}} n, \quad (29)$$

and plugging (29) in the production function  $V_{m,t}$ , it is possible to derive

$$V_m = \Theta \left( \frac{\alpha\Theta}{1/\beta - (1-\delta) - \frac{1-\nu}{\omega} \left(\frac{\nu}{\omega}\right)^{\frac{\nu}{1-\nu}}} \right)^{\frac{\alpha}{1-\alpha}} n. \quad (30)$$

Define  $\Gamma = \Theta \left( \frac{\alpha\Theta}{1/\beta - (1-\delta) - \frac{1-\nu}{\omega} \left(\frac{\nu}{\omega}\right)^{\frac{\nu}{1-\nu}}} \right)^{\frac{\alpha}{1-\alpha}}$ . By using (24), (27), (29) and (30), steady state labor is given by

$$n = \frac{1 - \alpha - \varphi\bar{s}\phi\Gamma^{-1}}{1 - \alpha + \varphi \left\{ 1 - \alpha \left(\frac{\nu}{\omega}\right)^{\frac{1}{1-\nu}} [1/\beta - (1-\delta) - \frac{1-\nu}{\omega} \left(\frac{\nu}{\omega}\right)^{\frac{\nu}{1-\nu}}]^{-1} \right\}}. \quad (31)$$

Next, by using (31) in (29) and (30) steady state capital and output are found, and using (27) or (28) steady state investment is obtained. Note that steady state labor is an increasing function of sectoral TFP  $\bar{B}_m$  and  $\bar{B}_s$ .<sup>26</sup>

Finally, the constraint (20) becomes, in steady state,

$$\phi c_s + c_m + I = V_m. \quad (32)$$

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<sup>26</sup>This is because the term  $\Gamma/\phi$  is an increasing function of  $\bar{B}_m$  and  $\bar{B}_s$ .

By using (23) in (32) the steady state value of  $c_m$  is

$$c_m = \frac{V_m - I + \phi \bar{s}}{\phi^{-\frac{\rho}{1-\rho}} \left(\frac{1-b}{b}\right)^{\frac{1}{1-\rho}} + 1}, \quad (33)$$

and using (33) in (23) the steady state level of  $c_s$  is obtained.

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