DEVELOPMENT, GROWTH AND VOLATILITY

2010

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Documentos de Trabajo
N.º 1023

BANCO DE ESPAÑA
Eurosistema

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(*) I would like to thank Michele Boldrin, Nezih Guner and Javier Díaz Giménez for their advice and Cristiano Cantore, Juan Carlos Conesa, Antonia Díaz, Huberto Ennis, Riccardo Fiorito, Esteban Jaimovich, Matthias Kredler, Joel López-Real, Vincenzo Merella, Galo Nuño, Josep Pijoan-Mas, Luis Puch and seminar participants at the Banco de España, Carlos III, City University London, the 50th Meeting of the SIE at the Bank of Italy and LUISS, 2009, and the XXXIV SAEe at the University of Valencia, 2009, for the useful comments. This paper is based on Chapter 3 of my PhD dissertation at Carlos III and was written while I was a Research Fellow at the Banco de España, whose financial support is kindly acknowledged. The views expressed are those of the author and do not represent the views of the Banco de España or the Eurosystem. The usual disclaimers apply.

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Documentos de Trabajo. N.º 1023

2010

ISSN: 0213-2710 (print)
ISSN: 1579-8666 (on line)
Depósito legal: M. 31298-2010
Unidad de Publicaciones, Banco de España

Abstract

Does GDP composition affect GDP growth and volatility? Typically, economies at advanced stages of development grow slower, are less volatile and have a larger share of services in GDP with respect to economies at middle stages. I propose a theory of development consistent with these three facts. I show that even when total factor productivity (TFP) growth and volatility are the same in manufacturing and services at the gross output level, the larger intensity of intermediate goods in gross output production in manufacturing implies a larger growth and volatility of TFP at the value added level in manufacturing than in services. As GDP is a weighted average of value added of the sectors in the economy, a larger share of services in the economy implies both a smaller GDP growth and a smaller GDP volatility. Numerical results suggest that along a transition path in which the share of services increases from 0.41 to 0.73, the same gross output TFP process in manufacturing and services implies a per-capita GDP growth and volatility 21% and 18% larger in the first part of the transition with respect to the second. These numbers represent 95% of the difference in per-capita GDP growth and 95% of the difference in per-capita GDP volatility between middle and high income economies during the 1970-2006 period. Also, the model can account for 58% of the per-capita GDP growth and 32% of the per-capita GDP volatility differences measured in the U.S. between the 1950-1978 and 1979-2007 periods.

Keywords: Structural Change, Growth, Volatility Decline, Total Factor Productivity.

JEL classification: C67, C68, E25, E32.

1 Introduction

Does GDP composition affect GDP growth and volatility? Typically, i) economies at advanced stages of development grow slower than economies at middle stages; ii) richer economies display lower GDP volatility than poorer ones; iii) richer economies display a larger share of services in GDP; and iv) across countries, the manufacturing sector displays a larger total factor productivity (TFP) growth and volatility with respect to the services sector. Together, these facts suggest that the growth and the volatility performance of an economy can be related to its sectoral composition. In particular, it is reasonable to expect that, as the services share in GDP increases with development, aggregate TFP growth and volatility decline. This, in turn, is expected to imply a reduction in GDP growth and volatility. In this paper, I quantitatively address this issue in the context of a two sector general equilibrium model.

The basic mechanism exploited in the paper is the relationship between gross output and value added TFP. For a sector with a given gross output TFP, value added TFP is an increasing function of the intensity of intermediate goods in gross output production in that sector. This is because, other conditions equal, an increase in productivity embodied in intermediate goods also increases the productivity of capital and labor. When the intensity of intermediate goods in production is larger, this effect is stronger, as the same increase in productivity embodied in intermediates increases gross output, and consequently capital and labor productivity, more. Value added TFP is defined as capital and labor productivity in real value added. In turn, real value added growth is defined as the proportion of gross output growth not explained by growth in intermediate goods. Thus, productivity increases due to intermediate goods raise value added TFP through an increasing function of the intensity of intermediate goods in gross output production. It follows that, the more intensive the production process in intermediates, the larger the impact of productivity changes embodied in intermediates on value added TFP.

This mechanism implies that, for a given growth and volatility of gross output TFP, the intensity of intermediate goods in gross output production provides a multiplier on value added TFP growth and volatility. In this paper, I show that the multiplier associated to intermediate goods is larger in manufacturing than in services for 25 developing and developed countries over the 1970-2005 period. Across countries, the same growth rate and volatility of TFP at the gross output level in manufacturing and services deliver, on average, a TFP growth and volatility at the value added level 71% larger in manufacturing.

Roughly speaking, aggregate GDP is a weighted average of value added of the sectors in the economy, not of gross output of those sectors. Thus, what matters for aggregate TFP determination is value added TFP in the sectors of the economy and the size of each sector in GDP. It follows that, even if manufacturing and services display the same process of sectoral (gross output) TFP, the sectoral composition of the economy has an impact on aggregate TFP growth and volatility. In this view, the decline in GDP growth and volatility, observed as an economy develops, can be the result of a change in the transmission mechanism of TFP from the sectoral (gross output) to the aggregate level rather than of a change in sectoral TFP processes. This reasoning also implies that even when two countries have a common production technology for manufacturing and for services, and the same process for gross output TFP in the two sectors, the country with the largest share of services should display both smaller aggregate TFP growth and volatility with respect to the other.

The production side of the model presented is composed of two sectors producing, respectively, manufacturing and services. In each sector, output is produced by means of a gross output production function in labor services and intermediate goods purchased from the sector itself and from the other sector. This production structure implies a well defined production possibility frontier, that determines all the feasible combinations of manufacturing and services that can be consumed given the aggregate amount of labor used in production in the economy. The size of the services sector is then determined by Stone-Geary type non-homothetic preferences, that imply an income elasticity of services consumption larger than one. When TFP in the economy increases, the model endogenously generates an increase in the share of services in GDP.

I use the model to quantify the effect of the size of the services sector on per-capita GDP growth and volatility. To do this, I compare middle and high income economies.[1] The share of services in middle income economies increases from 0.41 to 0.53 during the 1970-2006 period while that of high income economies increases from 0.55 to 0.73 during the same period. Also, middle income economies display an average growth rate and a volatility of per-capita GDP respectively 22% and 19% larger than high income economies during the

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[1] In this paper I abstract from explicitly modelling the agricultural sector. The aim here is to compare per-capita GDP growth and volatility of economies that already moved away from being mainly agricultural.

1970-2006 period. To compare the model with the data, I first calibrate the parameters of the production functions in the two sectors using U.S. data. Next, I perform the following experiment. I let gross output TFP in the two sectors follow an arbitrarily set common process. This means that in manufacturing and in services, gross output TFP grows at the same rate and receives the same shock each period. The remaining parameters of the model are calibrated such that, given the growth rate of TFP in the two sectors, the model generates a transition path in which the share of services increases from 0.41 to 0.73 in 74 years. These correspond to the double of the years in the period 1970-2006. Thus, to compare the model with the data, I study a single calibrated model economy along a transition path in which the share of services increases from the level displayed by middle income economies in 1970 to that displayed by high income economies in 2006. Along the transition path, per-capita GDP growth is 21% larger and 18% more volatile in the first 37 years with respect to the last 37. These numbers represent 95% of the difference in both per-capita GDP growth and per-capita GDP volatility between middle income and high income economies during the 1970-2006 period.

The same exercise is then repeated using, instead of a common process in the two sectors, gross output TFP processes calibrated to U.S. manufacturing and services data during the 1960-2005 period. In this case, the difference between the first and the second part of the transition is 20% in terms of growth and 24% in terms of volatility. This implies that the model accounts for 91% of the difference in growth rates and 100% of the difference in volatility between middle and high income economies.

Finally, I use the model to study the U.S. transition path from manufacturing to services. During the period 1950-1978 the U.S. per-capita GDP grows at an average yearly rate of 2.39% and its volatility is 2.52%. During the 1979-2007 period the average yearly growth rate of per-capita GDP is 1.89% and the volatility 1.75%. Thus, the U.S. displays both a growth rate 26% larger and a volatility 44% larger in the former period with respect to the latter. During the same period, the share of services in GDP increases from 0.59 to 0.81. Simulations of a 58 years calibrated model economy deliver a growth rate 15% larger and a volatility 14% larger in the first subperiod with respect to the second. Thus, the model accounts for around 58% of the difference in growth and 32% of the difference in volatility observed in the U.S. between the 1950-1978 and the 1979-2007 periods.

The remaining of the paper is as follows: section 2 describes the related literature; section

3 describes the relationship between gross output and value added measures of TFP growth and volatility; section 4 presents the model and the quantitative results; section 5 presents the U.S. case; finally, section 6 concludes.

2 Related Literature

In the literature on economic development and economic growth, several papers point out the importance of the sectoral composition for GDP growth. Most of these papers focus on differences in value added total factor productivity (TFP) or in labor productivity across sectors. Baumol (1967) is a pioneering work in the structural change literature. His conclusion is that in an economy with two sectors, one with productivity growth and one with constant productivity, the production cost of the stagnant productivity sector grows unbounded and that sector attracts the entire labor force as time passes. In the limit, the economy converges to the zero growth rate of the stagnant sector. Echevarria (1997) provides evidence that middle income countries display the largest GDP per-capita growth rates while low income countries the smallest. High income countries display growth rates that lie in between.[2] She also shows that, across countries, TFP growth at the value added level is larger in manufacturing than in services which, in turn, exhibit higher TFP growth than agriculture. Based on non-homotheticity of preferences, she constructs a model in which, as the economy becomes richer, the manufacturing sector expands with respect to agriculture and services. Eventually, when income in the economy is sufficiently high, the services sector expands with respect to agriculture and manufacturing. During this transition, when manufacturing is the largest sector in the economy, GDP growth is larger than when services is the largest sector. More recently, Duarte and Restuccia (2008) find that sectoral differences in labor productivity play a key role in the process of structural transformation and aggregate productivity differences across countries. Other recent paper relating the sectoral composition of an economy to economic growth are Kongsamut, Rebelo and Xie (2001), Ngai and Pissarides (2007) and Acemoglu and Guerrieri (2008).

In the literature on economic development and output volatility, Lucas (1988) notes that growth rates of advanced countries tend to be more stable than growth rates of poorer coun-

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[2] Echevarria (1997) plots the average annual growth of per-capita GDP during the 1950-1980 period against GDP per-capita in 1950.

tries. This is true not only when comparing rich countries with poor ones, but also when comparing high and middle income economies.[3] Acemoglu and Zilibotti (1997) provide evidence of a negative correlation between GDP levels and GDP volatility. They propose a theory in which volatility is high at early stages of development because of a lack of diversification in investment projects. Koren and Tenreyro (2008) report that GDP volatility declines with development, both in the cross section of countries and for each country over time. Furthermore, Koren and Tenreyro (2007) find that, as countries develop, they switch production from more volatile to less volatile sectors. This fact implies a reduction in aggregate GDP volatility. They estimate that the sectoral composition can account for up to 60% of the difference in aggregate volatility between poor and rich countries. They also find that a large part of this difference is due to a reduction in volatility within sectors. Koren and Tenreyro (2008) propose a theory based on inputs diversification to explain the decline in volatility within sectors during the development process.[4]

Another strand of the literature on economic development focuses on the role of intermediate goods for TFP levels. Jorgenson et al. (1987) argue that gross output based measures of TFP should be preferred to value added measures. This is because gross output TFP is the "pure" part of output growth that cannot be explained by changes in capital, labor and intermediate goods in the sector considered. Hulten (1978), Ciccone (2002) and Jones (2007) show that intermediate goods utilization in the production process can provide a multiplier effect on the aggregate TFP level. This multiplier effect is absent in standard models in capital and labor only and, according to Jones (2007) is able to explain up to 32-fold differences in TFP levels across countries. Ngai and Samaniego (2009) show that the multiplier associated with intermediate goods raises the contribution of investment specific technical change to post-war U.S. growth from 60% to 96%. In Moro (2009), I show that in the U.S. the multiplier effect due to intermediate goods is larger in manufacturing than in services. This implies that the same TFP volatility at the gross output level in manufacturing and services implies a 55% larger value added TFP volatility in manufacturing with respect to services.[5] Using this mechanism it is possible to show that the increase in the services sector

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[3] Ramey and Ramey (1995) find a negative relationship between growth and volatility. However, Martin and Rogers (2000) find that this relationship is robust only for developed countries.

[4] See also Jaimovich (2008) for a theory of development with similar predictions.

[5] See also Carvalho (2009), for the theoretical relationship between the share of intermediate goods and output volatility.

in the U.S. can account for 32% of the decline in GDP volatility over time.[6]

This paper presents a theory, based on sectoral composition, consistent with the evidence from the growth, the volatility and the development literature described above. In particular, I show that, other conditions equal, an economy with a larger share of services in GDP (high income economies) grows less and is less volatile than an economy with a smaller share (middle income economies). This implies that per-capita GDP growth and volatility decline along a transition path in which the share of services in GDP increases at the expenses of the share of manufacturing. As the transition from manufacturing to services appears to be a feature of each country at a certain level of income, the theory is also consistent with the reduction in GDP growth and volatility observed for a single country over time.[7]

3 From Gross Output to Value Added in Manufacturing and Services

Most macroeconomic models build on production functions in which capital and labor are the only inputs. This is the case both when the production function is an aggregate one and when it is sectoral. In general, at the sectoral level, intermediate goods contribute, together with capital and labor, to produce gross output of that sector. Value added is then measured as the contribution of capital, labor and technical change to gross output growth.[8] This procedure implies that what is measured as total factor productivity (TFP) growth at the value added level depends on two factors: one is TFP growth at the gross output level, defined as the part of gross output growth that cannot be explained by changes in capital, labor and intermediate goods; the other is the intensity of intermediate goods in gross output production.

To see this, consider a firm that produces gross output using capital, labor and intermedi-

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[6] The decline in output volatility has been extensively studied for the U.S. See, for instance McConnell and Perez-Quiros (2000), Blanchard and Simon (2001) and Stock and Watson (2002). However, these papers disregard the sectoral composition explanation for the GDP volatility decline. In Alcalá and Sancho (2003), Moro (2009) and Carvalho and Gabaix (2010) it is showed that the composition of the economy represents an important factor in the determination of GDP volatility in the U.S.

[7] The transition from agriculture to manufacturing is not studied in this paper. Echevarria (1997) shows that this transition implies an increase in the GDP growth rate, while Da-Rocha and Restuccia (2006) show that a decline in the share of agriculture in GDP implies a reduction in GDP volatility.

[8] See Sato (1976). Equivalently, value added can be defined as the part of gross output growth that cannot be explained by growth in intermediate goods.

ate goods. Consider now an increase in productivity embodied in intermediate goods. Fixed the amount of all inputs, the firm can now produce more gross output. This also implies an increase in capital and labor productivity in gross output. Furthermore, the more intensive intermediate goods are in the production process, the larger the increase in gross output. Thus, the increase in capital and labor productivity due to productivity embodied in intermediates increases with the intensity of intermediates in gross output. Value added TFP is defined as the part of real value added growth not explained by the growth in capital and labor inputs while real value added itself is defined as the contribution of capital, labor and productivity to gross output growth.[9] It follows that any change in productivity embodied in intermediate goods impacts value added TFP through an increasing function of the intensity of intermediate goods in gross output. The bottomline is that value added TFP becomes a linear function of productivity embodied in capital and labor and a non-linear function of productivity embodied in intermediate goods.

More formally, consider a generic sector in which the representative firm produces gross output using a Cobb-Douglas production function in intermediate goods M and a function of capital and labor $f(K,N)$.[10] With competitive markets the firm takes the price of labor w, of capital r, of gross output p_g and of intermediate goods p_m as given. The profit maximization problem of the firm is

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

where $Bf(K,N)^{\omega}M^{1-\omega}$ is the gross output production function, B is gross output TFP and $0 < \omega < 1$.

By taking the first order condition of (1) with respect to intermediate goods and using it to substitute for intermediate goods again in (1), the following reduced form problem is obtained

$$\max_{K,N} \left\{ p_v B^{\frac{1}{\omega}} f(K,N) - rK - wN \right\}. \tag{2}$$

In (2), $B^{\frac{1}{\omega}} f(K,N)$ is the value added production function of the sector considered and $p_v = \omega(1-\omega)^{\frac{1-\omega}{\omega}} p_g^{\frac{1}{\omega}} p_m^{-\frac{1-\omega}{\omega}}$ represents its price. It follows that TFP at the value added level,

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[9] See Sato (1976). More precisely, he writes, pag. 441: “Real value added is the contribution of primary inputs, economies of scale, and technical change in the production process”. Technical change here is represented by changes of productivity embodied in inputs. In the formal example later in the text, the technology is constant returs so economies of scale do not have any effect on gross output growth (see again Sato (1976), pag. 440).

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

defined as the part of value added growth not explained by the growth in capital and labor inputs, is given by $B^{\frac{1}{\omega}}$.[11]

The growth rate of a variable B_t at time t is given by $b_t = \log(B_t) - \log(B_{t-1})$ while that of a variable $B_t^{\frac{1}{\omega}}$ is given by $\bar{b}_t = (1/\omega)[\log(B_t) - \log(B_{t-1})] = (1/\omega)b_t$. As a result, the value of ω affects value added TFP growth through its effect on the sector's gross output TFP, B. In the Cobb-Douglas case, $1 - \omega$ is equal to the share of intermediate goods in gross output in equilibrium. Thus, the larger the share of intermediate goods in one sector, the larger TFP growth at the value added level for a given TFP growth at the gross output level.

In the real business cycle literature, before computing volatility statistics, each variable is logged and detrended using the Hodrick-Prescott (HP) filter. For a variable $\log(B_t)$ and its HP filter $\log(\bar{B}_t)$, the deviation $\hat{b}_t$ at time t is given by $\hat{b}_t = \log(B_t) - \log(\bar{B}_t)$. Instead, for the variable $\log(B_t^{\frac{1}{\omega}})$ the deviation $\tilde{b}_t$ at t is given by $\tilde{b}_t = (1/\omega)[\log(B_t) - \log(\bar{B}_t)]$. As a result, the value of ω affects value added TFP volatility through its effect on sectoral TFP B. The result also extends to the case in which volatility is computed as the standard deviation of the variable's growth rate, as the above formula for $\bar{b}_t$ makes clear. It follows that a larger share of intermediate goods in gross output implies both a larger growth and a larger volatility of TFP at the value added level. Aggregate GDP growth can be computed as a weighted average of value added growth of the various sectors in the economy. Thus, what matters for aggregate TFP determination is value added TFP in the sectors of the economy and the size of each sector in GDP. It follows that for a common growth and volatility of B across the sectors in the economy, the larger the share of sectors with a smaller ω, the larger aggregate TFP growth and volatility.

Figure 1 reports the average share of intermediate goods in gross output in the manufacturing and in the services sectors across countries for the 1970-2005 period. The average share in the services sector across countries is 0.40 while that of manufacturing is 0.65. Figure 1 highlights the different production technology used in the two sectors, which implies that in manufacturing the incidence of intermediate goods in gross output is on average 63% larger than in services. When B displays the same growth and volatility level in the two sectors, that is the same b_t and the same $\hat{b}_t$, the difference in ω between the two sectors

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[11] An interpretation of the term B in the production function $Bf(K,N)^{\omega}M^{1-\omega}$ is that productivity is embodied in the three inputs, $[f(BK,BN)]^{\omega}\,[BM]^{1-\omega}$. Thus, as described in the text, value added TFP depends linearly on capital and labor productivity (through B) and non-linearly on intermediate goods productivity (through $B^{\frac{1-\omega}{\omega}}$), such that the two effects jointly deliver $B\ B^{\frac{1-\omega}{\omega}} = B^{\frac{1}{\omega}}$.

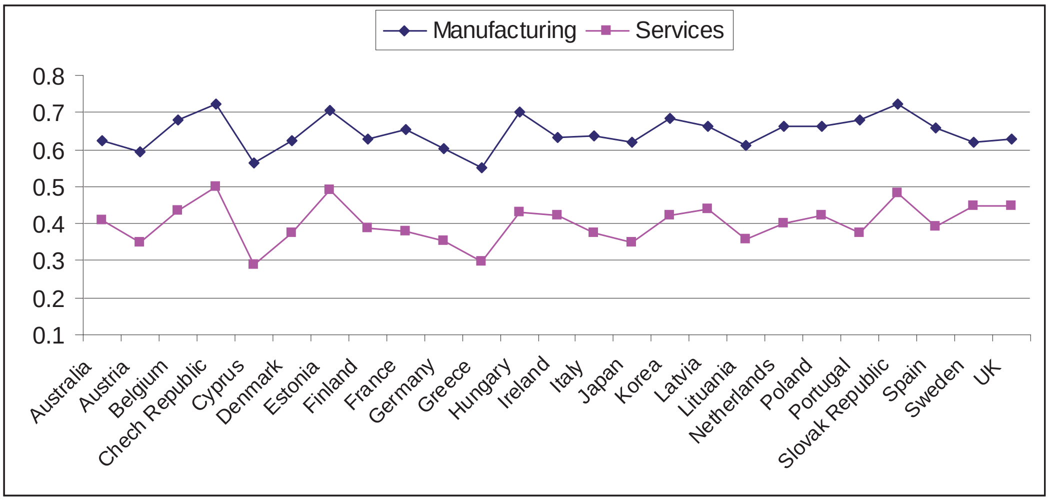

Figure 1: Average share of intermediate goods in manufacturing and in services across countries in the 1970-2005 period (Japan, 1973-2005; Hungary, 1991-2005; Cyprus, Chech Republic, Estonia, Lithuania, Latvia, Poland and Slovak Republic, 1995-2005; West Germany until 1990). Source: KLEMS dataset, 2008 and own calculation.

implies a value added TFP growth and volatility in manufacturing 71% larger than in services. This result suggests that, even if manufacturing and services had the same growth and volatility of B in each country and across countries, those economies with a larger share of services would display a smaller growth rate and a smaller volatility of aggregate TFP and, consequently, of GDP.

Figure 2, already reported in Moro (2009), displays the share of intermediate goods in manufacturing and services in the U.S. over the period 1960-2005. The U.S. average share of intermediate goods in the two sectors over the period is in line with the other countries, 0.38 in services and 0.6 in manufacturing. Furthermore, the shares are roughly constant over time, suggesting that the Cobb-Douglas assumption represents a reasonable approximation of the production technology in the two sectors.

A larger share of services in GDP implies a smaller aggregate TFP growth and volatility as long as manufacturing and services gross output TFP is similar. If B grows at a sufficiently larger pace in services than in manufacturing, it is possible that an increase in the services sector provide an increase in aggregate TFP instead of a decline. The same reasoning holds for volatility. Figure 3 reports B and $B^{\frac{1}{\omega}}$ for manufacturing and services during the 1960-2005 period in the U.S. As showed in the left panel, the growth rate of B is larger in manufacturing

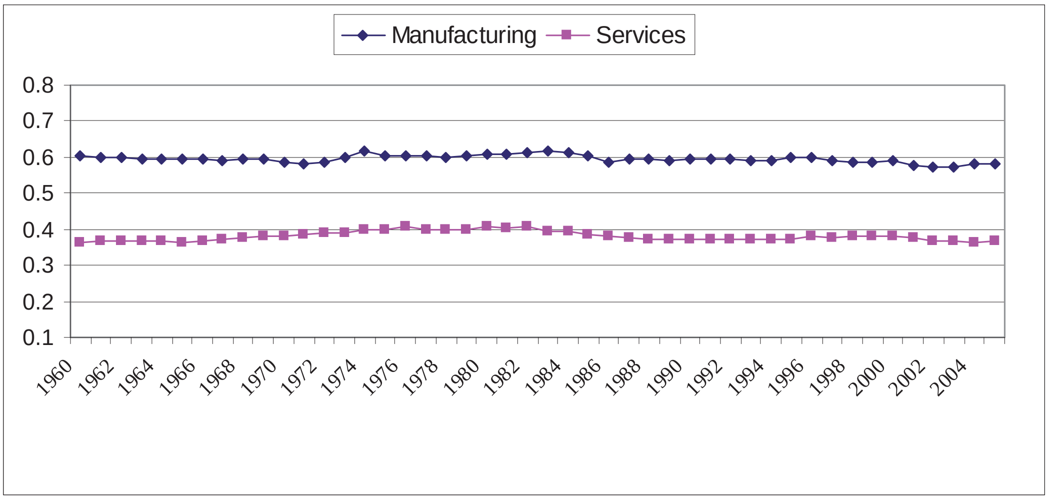

Figure 2: Share of intermediate goods in manufacturing and in services in the U.S. Source: Jorgenson dataset, 2007 and own calculation.

than in services, with a 28% larger average growth rate in manufacturing. When measuring value added TFP growth instead, $B^{\frac{1}{\omega}}$, the difference between the two sectors enlarges, with an average TFP growth rate 93% larger in manufacturing. The same argument holds for volatility.[12] It follows that an increase in the services sector is expected to provide a decline in aggregate TFP growth and volatility.

The multiplier effect that affects value added TFP through the share of intermediate goods is consistent with the growth/development facts observed: i) economies that are more intensive in manufacturing than in services (typically economies at middle stages of development) are expected to grow faster and display higher volatility of GDP, as the manufacturing sector displays a larger share of intermediate goods in gross output; ii) economies that are more intensive in services (typically developed economies) should instead display a smaller growth rate and volatility level of GDP, as the services sector displays a smaller share of intermediate goods in gross output. The question becomes quantitative: how much of the difference in growth rates and volatility across countries can be explained by the different composition of GDP alone? In the next section I construct a general equilibrium model to perform this analysis.

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[12] See Moro (2009) for a detailed quantitative analysis of U.S. TFP volatility.

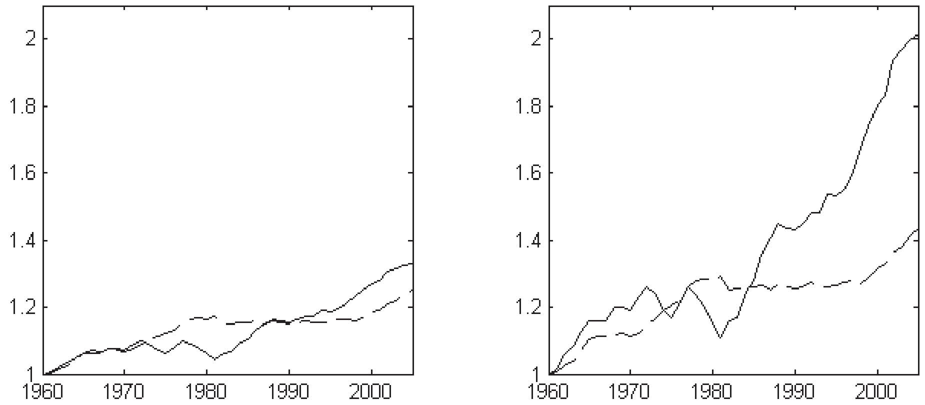

Figure 3: The left panel reports gross output TFP in manufacturing (continuous line) and services (dashed line). The right panel reports value added TFP in manufacturing (continuous line) and services (dashed line). Source: Jorgenson Dataset, 2007, and own calculations.

4 The Model

The model presented in this section is based on Moro (2009). In this version I abstract from capital accumulation decisions.

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 labor, manufactured intermediate goods and intermediate services. The gross output production function of the representative firm in the manufacturing sector is

$$G_m = B_m N_m^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m} \right)^{1-\nu_m}, \tag{3}$$

and that of the representative firm in the services sector is

$$G_s = B_s N_s^{\nu_s} \left(M_s^{1-\varepsilon_s} S_s^{\varepsilon_s} \right)^{1-\nu_s}, \tag{4}$$

where $0 < \nu_j < 1$, $0 < \varepsilon_j < 1$, N_j is labor, M_j is the manufactured intermediate good, S_j is intermediate services and B_j is gross output TFP, with $j = m, s$. Gross output TFP in each sector follows a stochastic process, unspecified for the time being.

The profit maximization problem of the representative firm in manufacturing is

$$\max_{N_m, M_m, S_m} \left[p_m G_m - wN_m - p_m M_m - p_s S_m\right] \tag{5}$$

$$\text{subject to (3),}$$

where w is the wage rate, p_m the price of the manufacturing good and p_s the price of services. The problem of the representative firm in services is

$$\max_{N_s, M_s, S_s} \left[p_s G_s - wN_s - p_m M_s - p_s S_s\right] \tag{6}$$

$$\text{subject to (4).}$$

Given the structure of the supply side of the economy, competitive markets imply that the relative price of services with respect to manufacturing, p_s/p_m, is independent of the quantities produced of the two goods. This is given by

$$\frac{p_s}{p_m} = \Omega(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) \left(\frac{B_m^{\nu_s}}{B_s^{\nu_m}}\right)^{\frac{1}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_s\nu_m}}. \tag{7}$$

Details of the derivation are given in appendix A. In (7), Ω is a function of the parameters ν_m, ν_s, ε_m and ε_s. The relative price of the two goods is technologically determined as it only depends on the parameters of the production functions and on sectoral TFP, B_m and B_s. This result follows from the non-substitution theorem (Samuelson, 1951).

The supply side of this economy allows the construction of an aggregate production function similar to the standard neoclassical aggregate production function. As there are two goods in the economy, the aggregate production function can be expressed either in manufacturing or in services units. Thus, I define an aggregate production function for the economy under study as a mapping from the total amount of labor available in the economy at a point in time into the maximum amount of manufacturing or services that can be produced for consumption purposes. To find the aggregate production function in manufacturing units at time t it is sufficient to solve the following problem

$$\max_{N_m, M_m, S_m, M_s} \left[B_m N_m^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}\right)^{1-\nu_m} - M_m - M_s\right] \tag{8}$$

subject to

$$B_s \left(N - N_m\right)^{\nu_s} \left(M_s^{1-\varepsilon_s} S_s^{\varepsilon_s}\right)^{1-\nu_s} = S_m + S_s,$$

where $B_m N_m^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m}\right)^{1-\nu_m}$ and $B_s \left(N - N_m\right)^{\nu_s} \left(M_s^{1-\varepsilon_s} S_s^{\varepsilon_s}\right)^{1-\nu_s}$ are the gross output production functions defined in (3) and (4) and N is the total amount of labor used in production in the economy in the period considered. The solution to problem (8) determines the maximum amount of manufacturing that can be consumed in the economy given the amount of labor services N used in production at the economy level. That is, it represents the point in which the production possibility frontier of this economy crosses the manufacturing axis. Note that the constraint in (8) implies that the services sector becomes an intermediate goods sector, as it produces only intermediate services used in the production of manufacturing and of services themselves. The solution to problem (8) at time t is

$$V_{m,t} = \Theta_m(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) B_{m,t}^{f_1(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} B_{s,t}^{f_2(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} N_t, \tag{9}$$

where Θ_m, f_1 and f_2 are functions of ν_m, ν_s, ε_m and ε_s. By dividing (9) by (7) it is possible to derive the maximum amount of services that can be consumed when the manufacturing sector produces only intermediate goods

$$V_{s,t} = \Theta_s(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) B_{m,t}^{f_3(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} B_{s,t}^{f_4(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} N_t, \tag{10}$$

where Θ_s, f_3 and f_4 are also functions of ν_m, ν_s, ε_m and ε_s.[13] Details of the derivation and the explicit functional form of Θ_m, Θ_s, f_1, f_2, f_3 and f_4 are given in appendix A. As a standard neoclassical aggregate production function, (9) and (10) represent the economy's resources in two extreme cases, one in which only manufacturing is consumed and services is only an intermediate sector, and another in which the opposite situation holds. The difference between the two cases lies in the TFP term that multiplies aggregate labor services. For given processes of $B_{m,t}$ and $B_{s,t}$, the pattern of the TFP term depends on the functions f_1 and f_2 when the economy produces only manufacturing, and on f_3 and f_4 when the economy produces only services. As already reported in Moro (2009), in the U.S. $f_1 + f_2 = 2.24$ while $f_3 + f_4 = 1.71$. This implies that if TFP in manufacturing and services follow the same process over time, $B_{m,t} = B_{s,t} = B_t \;\forall\; t$, the growth and the volatility of the TFP term in (9) are 31% larger than the same term in (10). Thus, other conditions equal, aggregate TFP growth and volatility decline along the production possibility frontier of the economy when decreasing manufacturing and increasing services.

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[13] Note that (7) implies that the production possibility frontier of this economy is linear. Thus, p_s/p_m gives the feasible amount of manufacturing that can be produced in the economy by reducing the production of services by one unit.

4.2 Households

The model economy is inhabited by a measure one of identical households, indexed in the interval $i \in [0,1]$. Households in this economy have preferences over manufacturing and services consumption and are endowed with one unit of labor services each period.

The utility function of the consumer at date t is given by

$$u = \log \left[b c_m^{\rho} + (1-b)\left(c_s + \bar{s}\right)^{\rho}\right]^{\frac{1}{\rho}} + \varphi \log(1-n), \tag{11}$$

where c_s and c_m are the per-capita consumption levels of manufacturing and services and n are per-capita labor services.[14] In (11), $\rho \leq 1$, $b \in [0,1]$, $\bar{s} > 0$ and $\varphi > 0$. As in Kongsamut, Rebelo and Xie (2001), $\bar{s}$ is interpreted as home production of services.[15]

Once the consumption index is defined as $c = \left[b c_m^{\rho} + (1-b)\left(c_s + \bar{s}\right)^{\rho}\right]^{\frac{1}{\rho}}$, the utility function in (11) coincides with the one often used in growth theory and in the real business cycle literature. In this paper, n is defined as labor services and not as hours worked. Average hours worked in the U.S. slightly fell from 1950 to 2000.[16] Instead, per-capita labor services increased by a factor of 1.21 between 1960 and 2005 as measured in Jorgenson Dataset, 2007. Growth in labor services is computed as a weighted average of growth in hours worked of several types of labor, where the weights are given by the share of each type of labor in total labor compensation.[17]

Each period, the household decides how much labor services to supply, earns a wage wn, and spends it in manufacturing and services consumption. The problem of each household at time t is

$$\max_{c_s, c_m, n} \left\{ \log \left[b c_m^{\rho} + (1-b)\left(c_s + \bar{s}\right)^{\rho}\right]^{\frac{1}{\rho}} + \varphi \log(1-n) \right\} \tag{12}$$

subject to

$$p_s c_s + p_m c_m = wn.$$

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[14] As households are identical I avoid the use of the index i for the time being.

[15] Herrendorf, Rogerson and Valentinyi (2009) show that Stone-Geary preferences in agriculture, manufacturing and services provide a good fit of post-war expenditure shares in these three types of goods in the U.S.

[16] See Duarte and Restuccia (2007), among others.

[17] See Jorgenson, Gollop and Fraumeni (1987) and O'Mahony and Timmer (2009) for a detailed description of the methodology to construct series of labor services. I use labor services instead of hours worked because the data on manufacturing and services that I use for the calibration come from Jorgenson Dataset, 2007. This dataset provides labor services data instead of hours worked. As TFP in manufacturing and services is computed using this dataset, the appropriate measure of labor in the model is labor services.

4.3 The Competitive Equilibrium

A competitive equilibrium for this economy is a set of prices $\{p_s,\, p_m,\, w\}$, allocations for the households $\{c_s,\, c_m, n\}$, for the manufacturing firm $\{N_m,\, M_m,\, S_m\}$ and for the services firm $\{N_s,\, M_s,\, S_s\}$ such that: a) given prices, $\{c_s,\, c_m, n\}$ solve the household problem; b) given prices, $\{N_m,\, M_m,\, S_m\}$ solve the manufacturing firm problem; c) given prices, $\{N_s,\, M_s,\, S_s\}$ solve the services firm problem; and d) markets clear:

$$G_m = \int_0^1 c_m di + M_m + M_s = c_m + M_m + M_s,$$

$$G_s = \int_0^1 c_s di + S_m + S_s = c_s + S_m + S_s,$$

$$\int_0^1 n di = n = N_m + N_s.$$

The numeraire of the economy is the price of manufacturing, $p_m = 1$. Absent capital accumulation, the dynamic equilibrium of the economy is a sequence of static equilibria. Once the equilibrium $c_{m,t}$ and $c_{s,t}$ are found at each t, real value added in the two sectors, $y_{m,t}$ and $y_{s,t}$, is given by

$$y_{m,t} = \frac{c_{m,t}}{p_{ym,t}} \text{ and } y_{s,t} = \frac{p_{s,t} c_{s,t}}{p_{ys,t}}$$

where

$$p_{ym,t} = \nu_m (1-\nu_m)^{\frac{1-\nu_m}{\nu_m}} \left(\frac{p_{s,t}^{1-\varepsilon_m}}{\varepsilon_m^{\varepsilon_m} (1-\varepsilon_m)^{1-\varepsilon_m}} \right)^{-\frac{1-\nu_m}{\nu_m}},$$

and

$$p_{ys,t} = \nu_s (1-\nu_s)^{\frac{1-\nu_s}{\nu_s}} p_{s,t}^{\frac{1}{\nu_s}} \left(\frac{p_{s,t}^{\varepsilon_s}}{\varepsilon_s^{\varepsilon_s} (1-\varepsilon_s)^{1-\varepsilon_s}} \right)^{-\frac{1-\nu_s}{\nu_s}}.$$

Here $p_{ym,t}$ and $p_{ys,t}$ are the value added deflators in manufacturing and services.[18] Aggregate value added at t, which is the model's counterpart of real GDP in the data, is computed as a chain-weighted Fisher index of sectoral value added. This is the same concept suggested by NIPA and used to construct the U.S. real GDP series.

4.4 Strategy and Simulations

The main aim of the paper is to quantify the importance of the size of the services sector on the difference in GDP growth and volatility between high and middle income countries.

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[18] To interpret the formulas for $p_{ym,t}$ and $p_{ys,t}$ refer to problem (2).

However, as noted in Lucas (1988), the cross country variability in growth rates is high for middle income economies while it is low for high income economies. Thus, the comparison of per-capita GDP growth and volatility between a high income and a middle income economy crucially depends on the middle income country chosen, even when controlling for the share of services in GDP. To avoid this problem, I compare the two groups of countries defined High Income and Middle Income by the Word Bank in 2008.[19] As these two groups include a large number of countries, idiosyncratic conditions of single countries are netted out. Figure 4 reports the share of services in GDP in the two groups of countries. The share of services in middle income economies increases from 0.41 to 0.53 from 1970 to 2006 while that of high income economies increases from 0.55 to 0.73 during the same period. Although the two panels in figure 4 represent two groups of countries with a different share of services during the same time interval, they can also be interpreted as the development path of a unique economy over time. That is, middle income economies are in 2006 at a similar stage of development as high income economies were in 1970. Thus, the strategy I adopt to compare the model to the data is to calibrate a unique economy and study its GDP growth and volatility properties along a transition path in which the share of services increases over time.

To simulate the model it is necessary to calibrate eight parameters and the gross output TFP processes in the two sectors. A natural benchmark to start with is a situation in which technological change (gross output TFP change) is the same in manufacturing and services. Thus, I arbitrarily let gross output TFP in manufacturing and services, $B_{m,t}$ and $B_{s,t}$, grow at the same rate $\psi = 0.01$ over time and receive a common shock z_t each period, such that

$$B_{m,t} = B_{s,t} = B_t = B_{t-1}(1+\psi)e^{z_t},$$

with $B_0 = 1$, $z_t = \rho_z z_{t-1} + \epsilon_t$, $\rho_z = 0.63$, $\epsilon_t \sim N(0, \sigma^2)$ and i.i.d. over time with $\sigma = 0.01$. In this way, the gross output TFP process is exogenously set to be the same in the two sectors.

Once TFP processes are set, there are four technology and four preference parameters left. Calibration of the technology parameters ν_m, ν_s, ε_m and ε_s requires data on the value of gross output, labor and intermediate inputs for the manufacturing and the services sector.

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[19] This approach implies that all countries that belong to the High (Middle) Income group in 2008 are used to construct the time series of the share of services and GDP growth of the High (Middle) Income group from 1970 to 2006. Thus, although it is possible that a country defined High (Middle) Income in 2008 was not so in 1970, this methodology provides data for two homogenous groups of countries over time.

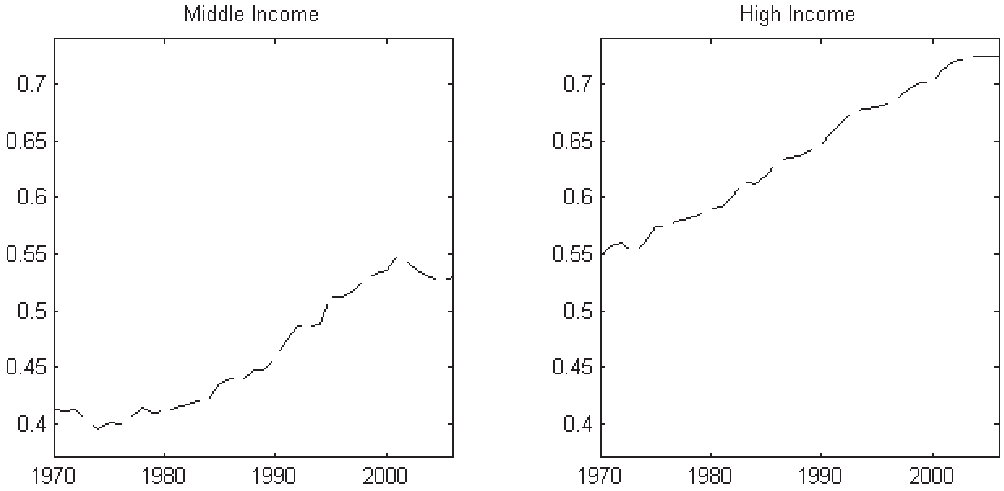

Figure 4: Share of Services in GDP in Middle Income and High Income countries from 1970 to 2006. Source: World Bank.

These data are not available for the two groups of high and middle income countries, so I calibrate the parameters using U.S. data from Jorgenson dataset, 2007. The Cobb-Douglas assumption implies that the elasticities of output with respect to inputs are equal to the inputs shares of gross output in equilibrium. Thus, parameters are set equal to the average shares during the 1960-2005 period.

On the demand side, I set ρ according to Rogerson (2008) and Duarte and Restuccia (forthcoming 2010), equal to -1.5. The remaining three parameters, $\bar{s}$, b and φ are set to match three targets in the data. Two targets are the share of services in GDP in the first period (0.41) and that in the last period (0.73). That is, given the growth rate and the initial level of $B_{m,t}$ and $B_{s,t}$, the model matches a share of services in GDP of 0.41 in period 1 and of 0.73 in period 74. The third target is the increase in the per-capita labor services over time. This target is not available for the two groups of high and middle income economies. Thus, I measure the total growth in per-capital labor services in the U.S. during the 1960-2005 period using Jorgenson dataset. The average yearly growth rate is 0.43%. This implies that the third target of the calibration is an increase in per-capita labor services of a factor $(1+0.0043)^{74} = 1.3678$ between periods 1 and 74. All parameter values are reported in table 2.

Table 2: Calibrated Parameters

Parameter	Description	Value
ν_m	Share of N_m in G_m	0.32
ε_m	Share of M in manufac. interm.	0.71
ν_s	Share of N_s in G_s	0.51
ε_s	Share of S in services interm.	0.72
ρ	Elasticity parameter in preferences	-1.5
b	Weight of manufacturing in preferences	0.037
$\bar{s}$	Home production of services	0.046
φ	Weight of labor services in preferences	0.835

I run 100,000 simulations of the model, each 74 periods long. Each model period corresponds to one year in the data. I then compare the difference between per-capita GDP growth and volatility between the first and the last 37 model periods with the difference between middle and high income countries in the 1970-2006 period. This implies that the pattern of middle and high income in the data is interpreted as the behavior of a single economy at different stages of development.

Results of simulations are reported in table 3. The first row of the table reports the average per-capita GDP growth rate and the standard deviations of per-capita GDP growth rates for the first 37 model periods and for middle income economies during the 1970-2006 period. The second row reports the same statistics for the last 37 model periods and for high income economies during the 1970-2006 period. Finally, the third row reports the ratio between the two cases. The absolute value of growth and volatility are not indicative here as the TFP process has been arbitrarily set. Instead, the relevant statistics are the differences in per-capita GDP growth and volatility between the two economies. The model delivers an average growth rate of per-capita GDP 21% larger in the middle income model economy with respect to the high income one. In the data the difference is 22%. Thus, the size of the services sector alone is able to explain around 95% of the difference in growth rates between middle and high income economies. The ratio of volatility is 18% in the model while it is 19% in the data. Thus, the different size of the services sector also explains 95% of the difference in volatility between middle and high income economies.[20,21]

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[20] In its non-stochastic version, that is when shocks are zero in both sectors in each period, the model generates a continuous decline in the per-capita GDP growth rate as the share of services in GDP increases. In this case, the growth of per-capita GDP declines from 3.67% in period 2 to 2.46% in period 74.

[21] Note that the results in table 3 are robust to changes in the technological parameters ν_m, ν_s, ε_m and ε_s. I run the same simulations reported in table 3 with these parameters calibrated using KLEMS data for Poland, which is a middle income economy in 2008. In this case, the quantitative results deliver a difference

Table 3: Counterfactual with common gross output TFP process

	Average per-capita GDP Growth rate		**Per-capita GDP Volatility (SD of growth rates)**		**Value Added Volatility in the Model (SD of growth rates)**	
	Model	**Data**	**Model**	**Data**	**Manuf.**	**Serv.**
Middle income (Model's first 37 years)	3.11%	2.69%	2.68%	1.70%	2.78%	3.76%
High Income (Model's last 37 years)	2.57%	2.20%	2.28%	1.42%	2.84%	2.68%
Ratio	**Model**	**Data**	**Model**	**Data**	**Manuf.**	**Serv.**
Middle income/High Income	1.21	1.22	1.18	1.19	0.98	1.40

An interesting feature of the model is the change in volatility *within sectors* along the transition path. This paper stresses the fact that, as services is the least volatile sector, an increase in the share of services in GDP implies a GDP volatility decline. Koren and Tenreyro (2007 and 2008) stress the fact that a large part of the volatility decline observed during the development process is due to a reduction of volatility within the firm. The last two columns of table 3 report the volatility of manufacturing and services real value added in the model in the two subperiods. While the volatility of manufacturing remains almost unchanged, the volatility of services is 40% larger in the first subperiod with respect to the second.[22]

The results in table 3 provide a quantitative assessment of the importance of the relative size of manufacturing and services for GDP growth and volatility when $B_{m,t}$ and $B_{s,t}$ follow a common process. However, not necessarily $B_{m,t}$ and $B_{s,t}$ follow a common process in the data. As pointed out in section 3, if gross output TFP grows faster and is more volatile in services than manufacturing, it is possible that a larger share of services in GDP imply a faster and more volatile GDP growth. Figure 5 plots $B_{m,t}$ and $B_{s,t}$ for the U.S. during the 1960-2005 period, computed using the model's production functions (3) and (4) and the corresponding Hodrick-Prescott filtered series.[23] Interestingly, gross output TFP growth is similar in the two sectors during the period considered, although the two series diverge remarkably in the seventies and the eighties. In particular, the productivity slowdown occurred during the

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between the first and the second part of the transition of 23% both in terms of growth and in terms of volatility.

[22] This effect follows from the non-homotheticity of preferences, which imply an income elasticity of services larger than one. As TFP grows, the income elasticity of services declines over time. Instead, the income elasticity of manufacturing is always equal to one along the transition path.

[23] This is different from figure 7 because $B_{m,t}$ and $B_{s,t}$ are computed using labor and intermediates only, while figure 6 is constructed using also capital.

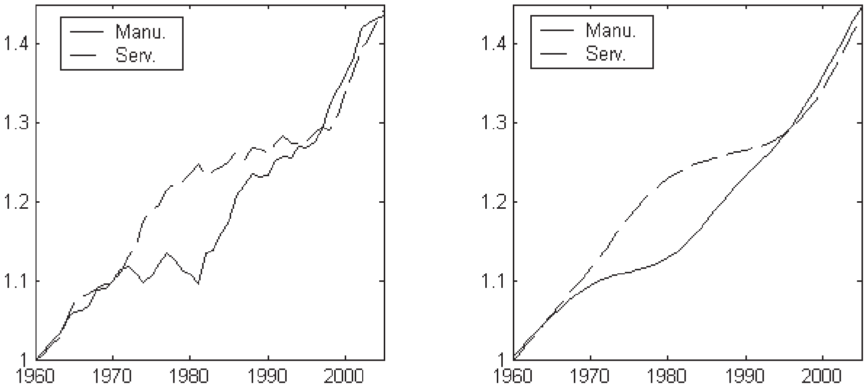

Figure 5: Left Panel: Gross output TFP in manufacturing (continuous line) and in services (dashed line). Right Panel: Hodrick-Prescott filtered series. Source: Jorgenson Dataset, 2007, and own calculations.

oil shocks appears to affect manufacturing and not services. On the other hand, services experience a slowdown in TFP growth after 1980, when manufacturing TFP growth starts recovering. By looking at the HP trends, the series appear to follow a common growth pattern that diverge between 1970 and 1995. The average yearly growth rate of gross output TFP is 0.0079 in manufacturing and 0.0081 in services over the 1960-2005 period. Instead, the standard deviation of gross output TFP growth rates is larger in manufacturing than in services during the 1960-2005 period, 0.0105 versus 0.0082.

I now turn to perform simulations of the model where the gross output TFP processes in manufacturing and services are calibrated using U.S. data for the 1960-2005 period from Jorgenson dataset, 2007.[24] Gross output TFP in manufacturing follows

$$B_{m,t} = B_{m,t-1}(1+\psi_m)e^{z_{mt}}, \tag{13}$$

with $B_{m,0} = 1$, $\psi_m = 0.0079$, $z_{mt} = \rho_z z_{mt-1} + \epsilon_{mt}$, $\epsilon_{mt} \sim N(0, \sigma_m^2)$ and i.i.d. over time with $\sigma_m = 0.0113$ and gross output TFP in services is

$$B_{s,t} = B_{s,t-1}(1+\psi_s)e^{z_{st}},$$

with $B_{s,0} = 1$, $\psi_s = 0.0081$, $z_{st} = \rho_z z_{st-1} + \epsilon_{st}$, $\epsilon_{st} \sim N(0, \sigma_s^2)$ and i.i.d. over time with $\sigma_s = 0.0082$. Finally, $\rho_z = 0.63$. With the new processes for B_m and B_s, the parameters $\bar{s}$,

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[24] See appendix B for details of the calibration.

Table 4: Counterfactual with U.S. gross output TFP processes

	Average per-capita GDP Growth rate		**Per-capita GDP Volatility (SD of growth rates)**		
	Model	**Data**	**Model**	**Data**	**Model Adjusted**
Middle income (Model's first 37 years)	2.55%	2.69%	2.74%	1.70%	1.92%
High Income (Model's last 37 years)	2.12%	2.20%	2.21%	1.42%	1.31%
Ratio	**Model**	**Data**	**Model**	**Data**	**Model Adjusted**
Middle income/High Income	1.20	1.22	1.24	1.19	1.47

b and φ have to be calibrated again to match the three targets in the data. The calibrated parameters are now $\bar{s} = 0.066$, $b = 0.022$ and $\varphi = 0.624$. Table 4 reports average statistics of 100,000 simulations. As in table 3, the first row of table 4 reports results for middle income and the second row results for high income economies, while the third row reports the ratios between the two economies. With respect to table 3, the absolute value of growth rates in the model is very close to that in the data. In terms of growth rates, the difference between the two economies, 20%, is similar to table 3 because gross output TFP grows almost at the same pace in the two sectors. Thus, the sectoral composition still accounts for 91% of the difference between the two types of economies. Instead, the ratio of the standard deviations of GDP growth rates in the two economies is now 24% in the model while it is 19% in the data. In this case, the different size of the services sector can account for more than the observed difference in volatility between middle and high income economies. This is due to the larger TFP volatility in manufacturing with respect to services. In table 4, a larger services share reduces GDP volatility because of the composition effect reported in table 3 and because the manufacturing sector displays larger gross output TFP volatility than services.

Finally, note that some care must be taken when interpreting the absolute value of the standard deviations generated by the model in table 4. These values are sensibly larger than the ones in the data. This is because the model is calibrated on the U.S. economy, which has a smaller size than the two groups of countries considered in the data. To see this, suppose that each aggregate of countries is composed by n economies of the size of the U.S. Thus, the GDP growth rate γ of the aggregate economy can be written as

$$\gamma = \sum_{i=1}^{n} \frac{\gamma_i}{n}$$

where γ_i is the growth rate of GDP of the i economy. Consider now two extreme cases, the one in which the γ_i's are perfectly correlated and that in which they are uncorrelated. If the standard deviation of each γ_i is σ, and the growth rates are perfectly correlated across i's, the standard deviation of γ is σ itself. Instead, when the growth rates are perfectly uncorrelated across i's, the standard deviation of γ is $\sigma/\sqrt{n}$. In this case, the absolute value of the volatility generated by the model is similar to that of an economy that receives U.S. shocks but also that is similar in size to the U.S.[25] The purchasing power parity GDP in international dollars in 2008 of the aggregate of middle income countries in 2008 is 2.04 times that of the U.S. while that of high income economies is 2.79 times that of the U.S. in the same year. Thus, under the assumption of perfectly uncorrelated γ_i's, the standard deviations generated by the model should be divided by $\sqrt{2.04} = 1.43$ for middle income economies and by $\sqrt{2.79} = 1.67$ for high income economies. The last column of table 4 reports the adjusted values. Volatility in the model is now closer to the data while the ratio of standard deviations becomes 47%.

The numerical results of this section point to a crucial role of the sectoral composition for the growth rate and the volatility of GDP. The analysis suggests that, other conditions equal, economies that differ in the size of the services sector relative to manufacturing display different patterns of GDP growth and volatility. That is, the transmission of sectoral TFP to aggregate TFP changes as an economy develops. Thus, the growth performance of aggregate TFP should be evaluated by taking into account the size of manufacturing and services in the economy. The same argument holds for aggregate TFP volatility.

5 The U.S. case

In the previous section, I compared the performance of per-capita GDP along a transition path of a calibrated model economy with that of middle and high income economies during the 1970-2007 period. In this section, I extend the analysis to study the growth and volatility properties of a single economy, taking the U.S. as a case study.

During the period 1950-1978 the U.S. per-capita GDP grows at an average yearly rate of 2.39% and its volatility is 2.52%. During the 1979-2007 period, the average yearly growth rate of per-capita GDP is 1.89% and the volatility 1.75%. Thus, the U.S. displays both a

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[25] See the next section for a comparison of the model with U.S. data.

Table 5: U.S.

Subperiod	Average per-capita GDP Growth rate		Per-capita GDP Volatility (SD of growth rates)	
	Model	**Data**	**Model**	**Data**
1950-1978	2.39%	2.39%	2.39%	2.52%
1979-2007	2.07%	1.89%	2.10%	1.75%
Ratio	**Model**	**Data**	**Model**	**Data**
1950-1978/1979-2007	1.15	1.26	1.14	1.44

growth rate 26% larger and a volatility 44% larger in the former with respect to the latter period. During the 1950-2007 period the share of services in GDP increases from 0.58 to 0.81 in the U.S. Buera and Kaboski (2007) document that the increase in the share of services in GDP in the U.S. started around the 1950, while it had been historically constant before that date. Thus, the decline in GDP growth and volatility is expected to have also started working around 1950.

The calibration of the model economy is the same as in the simulations reported in table 4 apart from the parameters b, $\bar{s}$ and φ. The three targets used to calibrate them are the share of services in GDP in 1950 (0.58) in the initial period of the simulation and that in 2007 (0.81) in the final period, and the growth factor in the per-capita labor services during the 1950-2007 period. Jorgenson dataset provides labor services only for the 1960-2005 period. Thus, as in the previous section, I use the average yearly growth rate in per-capita labor services during the 1960-2005 period (0.0043), and calibrate the model to match an increase in per-capita labor services of $(1+0.0043)^{58} = 1.28$ in 58 years. Calibrated parameter values are $b = 0.0044$, $\bar{s} = 0.11$ and $\varphi = 0.3303$. I perform 100,000 simulations of a 58 periods-long model economy, corresponding to the years 1950-2007.

Results of simulations are reported in table 5. The model delivers a difference of 15% in growth rates and of 14% in volatility between the former and the latter period. Thus, in terms of growth the model accounts for around 58% of the difference in growth rates between periods. In terms of volatility, the model account for 32% of the difference observed in the data during the corresponding periods for volatility.

6 Conclusion

In an influential contribution, Jorgenson et al. (1987) argue that gross output measures of TFP should be preferred to value added measures. This is because gross output measures take explicitly into account intermediate goods contribution to output growth. Instead, value added TFP is an increasing function of the share of intermediate goods in gross output. In this paper, I show that the share of intermediate goods in gross output is larger in manufacturing than in services for 26 developing and developed countries. This fact implies that, for the same growth and volatility of TFP at the gross output level in the two sectors, manufacturing displays a higher valued added TFP growth and volatility. Thus, an economy that is more intensive in services displays a lower GDP volatility and a lower GDP growth with respect to an economy more intensive in manufacturing.

In this paper, I exploit this intuition to quantify the importance of the sectoral composition for growth and volatility across countries. To do this, I construct an input-output general equilibrium model and compare per-capita GDP growth and volatility along a transition path in which the share of services increases. I find that the structure of the economy has a quantitatively important effect both on GDP growth and volatility. Results are confirmed, along the transition path in a version calibrated to the U.S. Thus, this paper represents an attempt to reconcile cross-country and single country times series evidence on GDP growth and volatility in a unique environment. The results obtained should be considered as a first step in this direction.

Data Appendix

KLEMS dataset, 2008. This dataset provides harmonized data for 30 countries. These are the countries reported in figure 1 plus Malta, Luxemburg and the U.S. The first two are excluded for their size. For the U.S. I use data from Jorgenson Dataset, 2007, that reports a longer time period. The share of intermediate goods in gross output in manufacturing is computed as the total value of intermediate goods used in manufacturing divided the total value of gross output produced in manufacturing. The share of intermediate goods in gross output in services is accordingly constructed. The sectors used in manufacturing computations are 1) Agriculture, hunting and forestry, 2) Fishing, mining and quarrying, 3) Total Manufacturing, 4) Electricity, gas and water supply, 5) Construction. The sectors used in services computations are 6) Wholesale and retail trade, 7) Hotels and restaurants, 8) Transport, storage and communication, 9) Financial intermediation, 10) Real estate, renting and business activities, 11) Public administration and defense, 12) Education, 13) Health and social work, 14) Other community, social and personal services, 15) Private households with employed persons, 16), Extra-territorial organizations and bodies.

Jorgenson Dataset, 2007. This dataset provides data for 35 sectors that cover the U.S. economy for the period 1960-2005. For each sector and for each year the dataset provides quantity and price indices for gross output, capital, labor and intermediate goods coming from the same 35 sectors. The share of intermediate goods in gross output in manufacturing is computed as the total value of intermediate goods used in manufacturing divided the total value of gross output produced in manufacturing. The share of intermediate goods in gross output in services is accordingly constructed.[26] 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,

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[26] See Moro (2009) for further details.

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.

World Bank Data (World Development Indicators). The World Bank reports time series of per capita-GDP levels for the group of countries defined High Income economies and the group defined Middle Income economies.[27] Also, it reports the share of services in GDP for these two groups of countries. The share of services in GDP for High Income countries is available only from 1970 to 2006, so I use this time period to compare the model with the data. I use the per-capita GDP series to compute the per-capita GDP growth rate and the standard deviation of per-capita GDP growth reported in tables 3 and in table 4. Finally, I use the purchasing power parity GDP in international dollars in 2008 to perform the adjustment of GDP volatility in the model in table 4.

U.S. Data. The data for the U.S. used in section 5 are from the Bureau of Economic Analysis (share of services in GDP), St. Louis FED (real GDP) and the Penn World Table (population). The real GDP and the population series are used to construct per-capita GDP. Using this series, I compute the average growth rate and the standard deviation of growth rates reported in table 5.

Appendix A: Relative Price and Aggregate Production Functions

The maximization problem of the representative firm in manufacturing is

$$\max_{N_m, M_m, S_m} \left[p_m G_m - w N_m - p_m M_m - p_s S_m\right] \tag{14}$$

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

where w is the wage rate, p_m the price of the manufacturing good and p_s the price of services. The problem of the firm in services is

$$\max_{N_s, M_s, S_s} \left[p_s G_s - w N_s - p_m M_s - p_s S_s\right] \tag{15}$$

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[27] High-income economies are those in which 2008 GNI per capita was \$11,906 or more. Middle-income economies are those in which 2008 GNI per capita was between \$976 and \$11,905.

$$\text{subject to } G_s = B_s N_s^{\nu_s} \left(M_s^{1-\varepsilon_s} S_s^{\varepsilon_s} \right)^{1-\nu_s}.$$

As the gross output production function in the two sectors is Cobb-Douglas, it is possible to derive a *net production function*, defined as the amount of gross output produced in one sector minus the amount of inputs produced and used in the same sector. The net production function in the manufacturing sector is obtained by solving

$$Y_m = \max_{M_m} \left\{ B_m N_m^{\nu_m} \left(M_m^{\varepsilon_m} S_m^{1-\varepsilon_m} \right)^{1-\nu_m} - M_m \right\}, \tag{16}$$

and it is equal to

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

where $\Phi_{m1} = [1 - \varepsilon_m (1 - \nu_m)] [\varepsilon_m (1 - \nu_m)]^{\frac{\varepsilon_m(1-\nu_m)}{1-\varepsilon_m(1-\nu_m)}}$. Equation (16) can be re-written as

$$Y_m = A_m N_m^{\theta} S^{1-\theta}, \tag{17}$$

where

$$A_m = \Phi_{m1} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}}, \tag{18}$$

$0 < \theta < 1$ 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

$$\max_{N_m, S} [p_m Y_m - w N_m - p_s S] \tag{19}$$

$$\text{subject to (17) and (18).}$$

By using the same derivation, the net production function in the services sector is given by

$$Y_s = A_s N_s^{\gamma} M^{1-\gamma}, \tag{20}$$

where $0 < \gamma < 1$ is equal $\frac{\nu_s}{1-\varepsilon_s(1-\nu_s)}$, N_s is the amount of labor and M is the amount of manufacturing used as intermediate good in the services sector, with

$$A_s = \Phi_{s1} B_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}}, \tag{21}$$

and $\Phi_{s1} = [1 - \varepsilon_s (1 - \nu_s)] [\varepsilon_s (1 - \nu_s)]^{\frac{\varepsilon_s(1-\nu_s)}{1-\varepsilon_s(1-\nu_s)}}$.

The problem of the representative firm in services becomes

$$\max_{N_s, M} [p_s Y_s - w N_s - p_m M] \tag{22}$$

$$\text{subject to (20) and (21).}$$

The production functions (17) and (20) and competitive markets imply that the representative firms in the two sectors set prices as

$$p_m = \frac{w^\theta p_s^{1-\theta}}{\Phi_{m2} A_m}, \tag{23}$$

and

$$p_s = \frac{w^\gamma p_m^{1-\gamma}}{\Phi_{s2} A_s}, \tag{24}$$

where $\Phi_{m2} = \theta^\theta (1-\theta)^{1-\theta}$ and $\Phi_{s2} = \gamma^\gamma (1-\gamma)^{1-\gamma}$. The relative price of the two goods is

$$\frac{p_s}{p_m} = \frac{(\Phi_{m2} A_m)^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{(\Phi_{s2} A_s)^{\frac{\theta}{\gamma+\theta-\theta\gamma}}}. \tag{25}$$

By substituting (18) and (21), (25) can be rewritten as

$$\frac{p_s}{p_m} = \frac{\left(\Phi_{m1}\Phi_{m2} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}}\right)^{\frac{\gamma}{\gamma+\theta-\theta\gamma}}}{\left(\Phi_{s1}\Phi_{s2} B_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}}\right)^{\frac{\theta}{\gamma+\theta-\theta\gamma}}}.$$

Finally, using $\theta = \frac{\nu_m}{1-\varepsilon_m(1-\nu_m)}$ and $\gamma = \frac{\nu_s}{1-\varepsilon_s(1-\nu_s)}$,

$$\frac{p_s}{p_m} = \Omega(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) \left(\frac{B_m^{\nu_s}}{B_s^{\nu_m}}\right)^{\frac{1}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_s\nu_m}}, \tag{26}$$

where

$$\Omega(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) = \frac{(\Phi_{m1}\Phi_{m2})^{\frac{\nu_s[1-\varepsilon_m(1-\nu_m)]}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_s\nu_m}}}{(\Phi_{s1}\Phi_{s2})^{\frac{\nu_m[1-\varepsilon_s(1-\nu_s)]}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_s\nu_m}}}.$$

To find the aggregate production function in manufacturing units at time t it useful to rely again on the *net production functions*, and solve

$$\max_{N_m, M, S} \left[A_m N_m^\theta S^{1-\theta} - M\right] \tag{27}$$

subject to

$$A_s (N - N_m)^\gamma M^{1-\gamma} = S,$$

where N is the total amount of labor available in the economy. Note that (27) corresponds to a reduced form of problem (8) in the main text, in which the first order conditions with respect to M_m and S_s already hold. The solution to problem (27) determines the maximum amount of manufacturing that can be produced for consumption purposes when the services sector produces only the intermediate goods needed in the manufacturing sector, S_t, that is, when services is only an intermediate goods sector. This is given by

$$V_m = \Phi_{m3} A_m^{\frac{1}{\gamma+\theta-\theta\gamma}} A_s^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}} N, \tag{28}$$

with $\Phi_{m3} = [1-(1-\theta)(1-\gamma)][(1-\theta)(1-\gamma)]^{\frac{1-\theta-\gamma+\theta\gamma}{\theta+\gamma-\theta\gamma}} \left(\frac{\theta}{\gamma+\theta-\gamma\theta}\right)^{\frac{\theta}{\theta+\gamma-\theta\gamma}} \left(\frac{\gamma.(1-\theta)}{\gamma+\theta-\gamma\theta}\right)^{\frac{\gamma(1-\theta)}{\theta+\gamma-\theta\gamma}}$. By substituting the definitions of A_m and A_s, (28) becomes

$$V_m = \Phi_{m3} \Phi_{m1}^{\frac{1}{\gamma+\theta-\theta\gamma}} \Phi_{s1}^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}} B_m^{\frac{1}{1-\varepsilon_m(1-\nu_m)}\frac{1}{\gamma+\theta-\theta\gamma}} B_s^{\frac{1}{1-\varepsilon_s(1-\nu_s)}\frac{1-\theta}{\gamma+\theta-\theta\gamma}} N,$$

and by defining $\Theta_m = \Phi_{m1}^{\frac{1}{\gamma+\theta-\theta\gamma}} \Phi_{m3} \Phi_{s1}^{\frac{1-\theta}{\gamma+\theta-\theta\gamma}}$ and using the definitions of θ and γ it is possible to write (28) as

$$V_m = \Theta_m(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) B_m^{f_1(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} B_s^{f_2(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} N, \tag{29}$$

which is equation (9) in the main text. In (29) $f_1 = \frac{1-\varepsilon_s(1-\nu_s)}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_m\nu_s}$ and $f_2 = \frac{(1-\varepsilon_m)(1-\nu_m)}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_m\nu_s}$. Finally, by dividing (29) by (26) it is possible to obtain

$$V_s = \Theta_s(\nu_m, \nu_s, \varepsilon_m, \varepsilon_s) B_m^{f_3(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} B_s^{f_4(\nu_m,\nu_s,\varepsilon_m,\varepsilon_s)} N,$$

$\Theta_s = \Theta_m/\Omega$, $f_3 = \frac{(1-\varepsilon_s)(1-\nu_s)}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_m\nu_s}$ and $f_4 = \frac{1-\varepsilon_m(1-\nu_m)}{\nu_m[1-\varepsilon_s(1-\nu_s)]+\nu_s[1-\varepsilon_m(1-\nu_m)]-\nu_m\nu_s}$, which is equation (10) in the paper.

Appendix B: Calibration

From (3), the series for $B_{m,t}$ is given by

$$B_{m,t} = \frac{G_{m,t}}{N_{m,t}^{\nu_m}\left(M_{m,t}^{\varepsilon_m} S_{m,t}^{1-\varepsilon_m}\right)^{1-\nu_m}},$$

where ν_m and ε_m are given in Table 2 and G_m, N_m, M_m and S_m are indices of gross output, labor services, manufactured intermediates and intermediate services in the manufacturing sector calculated using Jorgenson Dataset, 2007.[28] This and the corresponding series for services are reported in figure 9.

Equation (13) implies that the shock z_{mt} is the difference of two components

$$z_{mt} = \underbrace{\log(B_{m,t}) - \log(B_{m,t-1})}_{\text{Growth rate at } t} - \underbrace{\log(1+\psi_m)}_{\text{Trend growth rate}}, \tag{30}$$

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[28] See Moro (2009) for details of the calculations of the series in the data.

the realized growth rate of B_m at t and the trend growth rate. I use the series z_{mt}, generated by (30) using the series $B_{m,t}$ and the average growth rate ψ_m measured in the data, to generate a series of shocks

$$\epsilon_{mt} = z_{mt} - \rho_z z_{mt-1},$$

where ρ_z is set to 0.63. The standard deviation of these shocks is $\sigma_m = 0.0113$. I apply the same methodology to the services sector and find that the standard deviation of shocks is $\sigma_m = 0.0082$. This is the same procedure applied in Cooley and Prescott (1995) who use $\rho_z = 0.95$ instead of 0.63. To calibrate this parameter, I first log and detrend the series $B_{m,t}$ and then estimate an AR(1) process for the percentage deviations from trend. The autocorrelation coefficient so estimated is equal to 0.63 both for manufacturing and for services and statistically significant.[29]

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[29] An alternative way to calibrate ρ_z would be to directly use z_{mt}, as generated in (14), to estimate

$$z_{mt} = \rho_z z_{mt-1} + \epsilon_{mt}.$$

However, the estimated coefficient ρ_z is not statistically significant for manufacturing.

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