Growth, Structural Transformation, and Volatility

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PRELIMINARY AND INCOMPLETE

Abstract

I study how growth, via structural transformation, affects volatility. Growth in the United States has led to a shift in resources from agriculture and manufacturing to services. Since the service sector is the least volatile, this shift can potentially reduce aggregate volatility. Existing studies have explored this idea by aggregating sectoral volatilities to the economy-wide volatility when the sector shares are independent of sectoral shocks. But theories of structural transformation highlight the strong links between these: sectoral shocks are the source of changes in sectoral shares. I incorporate this relationship by developing a fully specified dynamic model of structural transformation with real business cycles, and use it to derive the equilibrium relationship between sectoral and aggregate volatilities. I then feed into my model the measured sectoral volatilities and growth trends. I find that growth, via structural transformation, can account for one third of the reduction in the volatility of US GDP in 1984-2007 compared to 1947-1983. This contrasts existing work that suggests that aggregate volatility is largely influenced by sectoral composition.

1 Introduction

One of the most studied business cycle facts in the United States is that the volatility of macroeconomic variables has fallen in the second half of the post war period, into what has

*Financial support from the Spanish Ministry of Science and Innovation (ECO2008-01300 and ECO2011-27014) is gratefully acknowledged. E-mail: lrubini@uc.cl.
been commonly termed the “Great Moderation”. Another well studied fact is that during this period the service sector has grown at the expense of agriculture and manufacturing. Kuznets (1973) called this reallocation structural transformation. Since the service sector is much less volatile than the other two sectors, it is reasonable to believe that structural transformation has been in part responsible for the Great Moderation. I study to what extent structural transformation can account for the reduction in aggregate volatility.

I start by introducing business cycles into a structural transformation model. The model is based on Herrendorf, Rogerson and Valentinyi (2009). There are three sectors: agriculture, manufacturing and services. Each sector has its own productivity process, with its own growth rate. These productivity processes, paired with the preference specification, determine the growth of each sector and its volatility. A low elasticity of substitution between sectors, in addition to a higher growth in agriculture and manufacturing than in services produces a shift in resources into the service sector as the economy grows. When the service sector is relatively larger, the volatility within services has a larger effect on the aggregate volatility. Since the volatility in services is lower than the volatility in agriculture and manufacturing, this shift reduces aggregate volatility.

A departure from Herrendorf et al. is the explicit modeling of the supply side. Growth and volatility comes from shocks to the production function of each type of good. Also, the dynamic nature of the model requires an explicit modeling of an investment good. I assume this is an aggregate of each type of consumption good, and the technology is designed to match shares in input output tables. Finally, I introduce a role for intermediate goods. I do this since, following Moro (2009), intermediate goods experienced significant structural transformation. Also, I find that data from the BEA are consistent Moro’s observation.
The calibration has two key components. The first component is sectoral shares. In 1947, services accounted for roughly 45 percent of consumption. By 2007, this share increased to more than 70 percent. The numbers are similar for intermediate good shares. The second component is the relative volatility of each sector. The theoretical construct predicts that sectoral shocks are closely related to sectoral prices, so I identify these shocks by observing data on prices. I find the service sector is about a third as volatile as the other two sectors.

Finally, given my calibration, I simulate the economy and measure the volatility of the main aggregate components of GDP dividing these into two periods: 1947-1983 and 1984-2007. I then measure the drop in volatility in the second period compared to the first period.

Computing the model is not trivial. Standard techniques used to compute business cycle models do not apply. These techniques often involve computing the steady state of an economy and log-linearizing around the steady state to compute the business cycle. The problem in this case is that there is no steady state, since a feature of these models is that as the economy grows, resources keep shifting from manufacturing and agriculture into services. To work around this issue, I use a technique developed by den Haan and Marcet (1990), the Parameterized Expectations Approximation method. The advantage of this method is that it does not rely on steady state assumptions.

The results show that structural transformation can account for a drop in the volatility of GDP, consumption, investment, and hours worked of 13 percent, 9 percent, 15 percent, and 17 percent, respectively. Compared to the data in Arias, Hansen and Ohanian (2007), these drops represent 28 percent of the drop in volatility of GDP, 21 percent for consumption, 36 percent for investment, and 59 percent for hours worked.

From these findings I conclude that while changes in sectoral shares led to drops in aggregate
volatility, the contribution of this channel to the overall drop in volatility is mild, and some other factors have played more important roles. Many studies have explored the effect of other factors. Arias et al. (2007) explore the behavior of standard real business cycles to account for the reduction in volatility. They find that these models can account for the reduction in volatility only when the shocks fed to the model becomes less volatile. In other words, they argue that standard models cannot account for these changes. Irvine and Schuh (2005) explore the role of better inventory management, and Clarida et al. (2000) focus on better monetary policy. Both of these changes are likely to contribute to the reduction in volatility.

Two papers are closely related to mine, both of which explore the changes in the composition of output on volatility. Carvalho and Gabaix (2010) find evidence that aggregate volatility and a weighted sum of sectoral volatilities are correlated. That is, sectoral volatilities affect aggregate volatility. Their findings support the findings in this paper. Relative to their work, I propose a mechanism that specifies a causal relation between sectoral and aggregate volatility. A key difference is that by proposing a mechanism linking changes in sectoral composition to aggregate volatility, I can measure the contribution of this channel. I find that this contribution is low, while the strong correlations found in Carvalho and Gabaix suggest that the contribution should be somewhat stronger.

Their analysis is carried out in a framework in which changes in sectoral shares do not depend on sectoral shocks either because these are too small (infinitesimal), or because the sectoral composition does not respond to sectoral shocks (as in the case of preferences with unitary elasticity of substitution between sectors). Their theory does not extend to cases in which sectoral shocks affect sectoral composition.

This is a problem in the light of models of structural transformation. These models predict
that it is precisely asymmetric sectoral shocks, paired with preferences with low elasticity of substitution, the cause for structural transformation. Carvalho and Gabaix’s theory relies heavily on the use of the envelope theorem and all its assumptions: mainly, that changes are infinitesimal, and therefore cannot affect sectoral shares, although the results would extend to cases in which shocks do not affect sectoral shares. But a key assumption in most theories of structural transformation such as Ngai and Pissarides (2007), Kongsamut, Rebelo and Xie (2001) and Bah (2007) is that sectoral shocks are the driving forces behind changes in sectoral composition. These changes must be large enough to produce sizable sectoral changes.

To overcome this issue and understand the effects of sizable shocks that can generate changes in sector shares endogenously, we need a full-fledge dynamic stochastic general equilibrium model, in which aggregate variables are constructed from sectoral variables, and standard deviations are measured as in the national accounts. This is what this paper does. In this way, I provide a bridge between Carvalho and Gabaix’s findings and the literature on structural transformation.

A second closely related paper is Moro (2009), who develops a model consistent with structural transformation with two sectors and finds that structural transformation can account for about 30% of the reduction in GDP volatility. This is somewhat larger than with my findings. The main contribution of my model relative to Moro’s is that I measure volatilities during the process of structural transformation, in the same way as the national accounts measure this volatility. Moro, on the other hand, measures the volatility in two steady states: one with a low share of services, and one with a high share of services.

Other papers have focused on the cross section effects of sectoral composition on volatility. Da Rocha and Restuccia (2006) study whether different agricultural shares across countries
can account for the different volatilities observed across countries. Their results show that larger agricultural shares increase the volatility of the economy.

My results can be seen as first hand evidence of the effect of growth, via structural transformation, on volatility. As countries grow, their resources shift from the agricultural and manufacturing sectors to the service sector. The evidence shows that this feature is common to many countries, independent of their level of development. Ohanian et al. (2008) find evidence of structural transformation for many developed economies, while Bah (2010) finds evidence among developing economies. My findings suggest that growth itself, via structural transformation, will help developing countries reduce their volatility.

This paper is organized as follows. Section 3 develops a model of structural transformation and business cycles and defines the equilibrium. Section 4 calibrates the model. Section 5 discusses the results and section 6 concludes.

\section{Data}

This section describes the data that motivates the main question in the paper: that resources have shifted from the agricultural and manufacturing sectors to the service sector, and the service sector is much less volatile than the other two sectors. Thus, this shift in resources reduces aggregate volatility.

Figure 1 shows the evolution of sectoral shares in the United States from 1947 through 2007. The data is Value Added by Industry in the BEA website. Agriculture includes agriculture, forestry, fishing, and hunting. Manufacturing includes mining and manufacturing. Services comprises the sectors utilities; construction; wholesale trade; retail trade; transportation and
warehousing; information; finance, insurance, real estate, rental, and leasing; educational services, health care, and social assistance; arts, entertainment, recreation, accommodation, and food services; other services, except government; and government. This picture shows

Figure 1: Sectoral Shares on GDP

the evidence Kuznets focused on when depicting the structural transformation feature of growth. While in 1947 services represented about 60 percent of total value added, by 2007 this share grew to about 85 percent.

Theories of structural transformation focus more on the consumption aspect of structural transformation. To show this evolution for consumption, I proceed as follows. Private current
consumption expenditures comes from NIPA Table 2.3.5. Government current consumption expenditure comes from NIPA Table 3.9.5. I use quarterly data from 1947.1 through 2007.4.

As in Herrendorf et al. (2009), I define the following:

- Agriculture is “Food and beverages purchased for off-premises consumption”
- Manufactures are “manufacturing” except “Food and beverages purchased for off-premises consumption”
- Services are “Services” plus government consumption

Consumption divided into these three sectors is shown in Figure 2.

The share of services in consumption grew from about 45 percent to about 75 percent.
Interestingly, I do not find evidence of changes in the composition of investment. Analyzing data from input output tables from 1947 through 2007, the shares are fairly constant and definitively do not show a clear trend. Investment is formed by about 40 percent manufacturing goods and 60 percent services.

There is a clear pattern of structural transformation in the composition of intermediate goods. The BEA publishes intermediate goods by sector, and the trend toward a more intensive use of services in intermediate goods is evident. Figure 3 displays these shares. The weight of services on intermediate goods increases from 65 percent in 1947 to 85 percent in 2007. Models of structural transformation have accounted for the shift of resources toward services by combining preferences for agriculture, manufactures and services that have low elasticities of substitution with a disproportionate sectoral growth rate, where manufacture
grows fastest, followed by agriculture and services lags behind. Examples of these theories include Ngai and Pissarides (2007), ........ These differential growth rates can be easily seen by observing the evolution of relative prices across sectors. In time, services become relatively more expensive and manufactures relatively cheaper compared to agricultural goods.

I obtain prices from data on current and real private and public consumption expenditures. Private real consumption expenditures comes from NIPA Table 2.3.3 and government real consumption expenditure comes from NIPA Table 3.9.3. To obtain the price series for each category, I divide current expenditures by real expenditures. Real expenditures in the data are in quantity indexes (2005 = 100), so for the division to make sense, I multiply these quantity indexes by current expenditures in 2005. After obtaining all three price sequences, I normalize these prices by dividing each price by the trend in the price of agriculture. This trend is obtained via an HP filter with parameter 1600.

Figure 4 shows that compared to agricultural prices, prices in the service sector doubled, while manufacturing prices halved. These prices come from BEA data on current price expenditure for consumption in each sector and volume indices consumption in each sector.

The reason why the increasing share of resources in the service sector contributes to a reduction in aggregate volatility is that services is less volatile than the other sectors. THis can be seen by studying the volatility of the detrended prices in each sector. To detrend, I use a Hodrick Prescott with a smoothing parameter equal to 1600. Figure 5 shows the cyclical component of each price. Clearly, services is much less volatile than the other two prices. The standard deviation of the cyclical component of services is 0.0067, manufacturing is 0.0177, and agriculture is 0.0178. Thus, services is one third as volatile as manufacturing
and agriculture. Given the theory developed in section 3, this implies that the volatility of TFP in services is about one third as volatile as the volatility in the other two sectors.

Thus, given that services are less volatile than agriculture and manufacturing, and as the economy grows the share of services increases, the question is whether growth can account for a reduction in aggregate volatility. To answer this question, I build the model that I present next.
3 Model

Time is discrete and runs $t = 0, 1, \ldots, \infty$. There is a measure one of identical households with preferences given by the following utility function,

$$U = E \sum_{t=0}^{\infty} \beta^{t} \left[ \frac{\sum_{j=a,m,s} \omega_j^{1/\mu} (C_{jt} + \bar{c}_j) \mu^{-1} \mu^{\mu}(1-\tau)}{1 - \tau} + \kappa(1 - h_t) \right]$$

This utility function adds disutility of labor to Herrendorf et al. (2009). Labor is indivisible (the agent works $h_t = \bar{h}$ or not at all), and the labor market allows trade in employment lotteries, which are contracts that specify a probability of working $\bar{h}$ hours, as in Rogerson (1988) and Hansen (1985). Herrendorf et al. (2009) show that this function can capture fairly
well the rise in the share of services over manufacturing and agriculture on consumption given
\( \mu < 1 \) and \( \bar{c}_a < \bar{c}_m < \bar{c}_s \). I plot these shares in figure 2.

The production of the different goods requires capital, labor, and intermediate goods. The
technology for producing these goods is

\[
Y_{jt} = e^{z_{jt}} \left( K_{jt}^{\alpha} H_{jt}^{1-\alpha} \right)^{\nu} M_{jt}^{1-\nu}
\]

for \( j = a, m, s \), where \( M \) is the intermediate good.

The investment good inputs the three type of consumption goods. The investment good
technology is

\[
X_t = X_{at}^{\theta_a} X_{mt}^{\theta_m} X_{st}^{\theta_s}
\]

where \( \theta_j \in [0, 1] \), \( \sum_{j=a,m,s} \theta_j = 1 \) and \( X_{jt} \) is units of good \( j = a, m, s \). A consequence of
assuming this functional form is that the agriculture, manufacturing and service shares in
the investment good remain constant. This is consistent with evidence from Input Output
tables, as I explain in section 4.

Capital is accumulated using investment in standard ways

\[
K_{t+1} = (1 - \delta)K_t + X_t
\]

The intermediate good is produced with a combination of each consumption good. The
functional form defers from a standard Cobb Douglas assumption so that, in equilibrium,
the share of each input changes as in the data. Figure 3 shows how these shares have
changed since 1947. In 1947, 64 percent of intermediate goods were services, and 28 percent of intermediates were manufacturing goods. In 2009 these shares changed to 86 percent and 13 percent, respectively.

The technology to produce the intermediate good is

\[ M_t = \left[ \sum_{j=a,m,s} \lambda_j^{1/\varphi} q_{jt}^{\varphi-1} \right]^{\varphi-1} \]

As in the case of the utility function, I choose this functional form to replicate the observed pattern of the composition of intermediate goods in the economy. The main difference is that this function features constant returns to scale, which is convenient for aggregation.

Feasibility implies

\[ Y_{jt} = C_{jt} + X_{jt} + M_{jt}, \quad \text{for } j = a, m, s \]
\[ M_t = \sum_{j=a,m,s} M_{jt} \]
\[ K_t = \sum_{j=a,m,s} K_{jt} \]
\[ H_t = \sum_{j=a,m,s} H_{jt} \]

where \( H_t = s_t \bar{h}, \) and \( s_t \) is the share of individuals working \( \bar{h} \) hours in period \( t. \)
3.1 Prices

I solve for a competitive equilibrium. To do so, I fix the price of the investment good in each period as the numeraire, and I introduce prices $p_{at}, p_{mt}, p_{st}, r_t, w_t$ and $P_{It}$, the latter being the price of the intermediate good. In addition, as in Dixit and Stiglitz (1977) it is convenient to introduce an aggregate consumption price index $P_t$, which represents the minimum cost in period $t$ to buy one unit of an aggregate consumption good $C_t$, defined as

$$C_t = \left[ \sum_{j=a,m,s} \omega_j^{1/\mu} (C_{jt} + \tilde{c}_j)^{\mu-1} \right]^{\mu/(\mu-1)}$$

The following proposition establishes what different prices are in equilibrium.

**Proposition 1** Equilibrium prices for the aggregate consumption good, the intermediate good, the agricultural good, the manufacturing good, and services are

$$P_t = \left[ \sum_{j=a,m,s} \omega_j^{1/\mu} p_{jt}^{1-\mu} \right]^{1/\mu} - \sum_{j=a,m,s} p_{jt} \tilde{c}_j$$  \hspace{1cm} (1)

$$P_{It} = \left[ \sum_{j=a,m,s} \lambda_j p_{jt}^{1-\nu} \right]^{1/\nu}$$  \hspace{1cm} (2)

$$p_{jt} = \tilde{\theta} e^{z_{xt}} e^{-z_{jt}} \quad j = a, m, s$$  \hspace{1cm} (3)

where $\tilde{\theta} = \theta_a^{\phi_a} \theta_m^{\phi_m} \theta_s^{\phi_s}$ and $z_{xt} = \sum_{j=a,m,s} \theta_j z_{jt}$.

**Proof** I omit the subindex $t$ for the proof. To show 1, let $\tilde{c}_j = c_j + \tilde{c}_j$. Then

$$C = \left[ \sum_{j=a,m,s} \omega_j^{1/\mu} \tilde{c}_j^{\mu-1} \right]^{\mu/(\mu-1)}$$
If the consumer pays for each unit of the good $\hat{c}_i$, the minimum cost to purchase one unit of the good $C_t$ is\(^1\)

$$
\hat{P} = \left[ \sum_{j=a,m,s} \omega_j p_j^{1-\mu} \right]^{\frac{1}{1-\mu}}
$$

However, the consumer pays for $\hat{c}_j - \bar{c}_j$, which gives equation (1). Equation (2) is the minimum cost to purchase one unit of the good $M$.

To see equation (3), rewrite the problem for the investment firm as the following

$$
\max \prod_{j=a,m,s} e^{-z_j} \left[ (k_j^\alpha h_j^{1-\alpha})^\nu m_j^{1-\nu} \right]^{\theta_j} - \\
w \sum_{j=a,m,s} h_j - r \sum_{j=a,m,s} k_j - P_t \sum_{j=a,m,s} m_j = \\
\max \prod_{j=a,m,s} e^{-z_j} \left[ (k_j^\alpha h_j^{1-\alpha})^\nu m_j^{1-\nu} \right]^{\theta_j} - \\
w \sum_{j=a,m,s} h_j - r \sum_{j=a,m,s} k_j - P_t \sum_{j=a,m,s} m_j
$$

Notice that $z_{xt} = \sum_{j=a,m,s} \theta_j z_{jt}$. The following equations are part of the solution

$$
\frac{h_a}{\theta_a} = \frac{h_m}{\theta_m} = \frac{h_s}{\theta_s}
$$

$$
w = e^{z_x (1 - \alpha) \nu m} \prod_{j=a,m,s} \left( \frac{X_j}{h_m} \right)^{\theta_j}
$$

\(^1\)The price of the good $\hat{c}_j$ is $p_j$, since this is the marginal cost to a purchaser.
where \(X_j = (k_j^\alpha h_j^{1-\alpha})^{\nu} m_j^{1-\nu}\). Combining these two equations,

\[
w = e^{zs} (1 - \alpha) \nu \bar{\theta} \prod_{j=a,m,s} \left( \frac{X_j}{h_j} \right)^{\theta_j}
\]

Adding the first order conditions for the firms producing each consumption good, and noticing that the equilibrium capital labor and intermediate labor ratios are constant for each firm gives equation 3.

\[\blacksquare\]

### 3.2 Equilibrium

The following conditions define the equilibrium prices and allocations

- The consumer maximizes utility subject to the budget constraint
- Firms maximize profits: these include firms producing the agricultural good, the manufacturing good, services, the intermediate good, and the investment good.
- Markets clear

### 3.3 Solution

Solving the problem presents a computational challenge. Standard techniques commonly used in real business cycle models cannot be applied in this case, since there is no steady state. To work around this issue, I use the parameterized expectation approximation technique proposed by den Haan and Marcet (1990). This method consists of “guessing” a functional form for the expectation of next period’s utility function as a function of the state variables.
Based on this guess, run the model for many periods, and use regression analysis to update the initial guess. Repeat this procedure until the initial guess and the estimates are close enough. Appendix A details the procedure.

4 Calibration

One period is one quarter, and I use quarterly data for the United States from 1947 to 2007. The most relevant parameters, given the exercise, are the ones governing the random shocks to productivity $z_{at}$, $z_{mt}$, $z_{st}$. These processes are as follows. For $j = a, m, s$,

$$z_{j,t+1} = \gamma_j + \rho_j z_{j,t} + \epsilon_{j,t}, \epsilon \sim N(0, \sigma_j^2)$$

In equilibrium, we have that the price of each good is

$$p_{jt} = \tilde{\theta} e^{-z_{jt}} e^{z_{xt}}$$

Where $z_{xt} = \sum_{j=a,m,s} \theta_j z_{jt}$ Therefore, I use information on prices to identify $\gamma_j$, for $j = a, m, s, x$ and $\rho_j, \sigma_j$, for $j = a, m, s$. I next describe the prices that I use.

I calibrate, for $j = a, m, s$, the following

- $\rho_j$ is set to match the autocorrelation coefficient that comes from the following regression

$$\log p_{j,t+1} = \hat{\rho}_j \log p_{j,t} + error_{j,t}$$
• $\sigma_a, \sigma_m$ and $\sigma_s$ are set to match the relative volatility of the cyclical component of prices in the three sectors and the aggregate volatility of the cyclical component of real consumption. The cyclical component is obtained by filtering the series with an HP filter with parameter 1600.

• $\gamma_a$ is set to match the increase in consumption from 1947.1 through 2007.4

• $\gamma_m$ is set to match the ratio $p_{m, 1947.1}/p_{m, 2007.4}$

• $\gamma_s$ is set to match the ratio $p_{s, 1947.1}/p_{s, 2007.4}$

The parameters in the utility function are $\omega_a, \omega_m, \omega_s, \tilde{c}_a, \tilde{c}_m, \tilde{c}_s$, and $\mu$. Herrendorf et al. (2009) shows that normalizing one of the non homotheticity parameters does not affect the results, so I set $\tilde{c}_a = 0$. I also normalize $\omega_a = 1$. From Herrendorf et al. (2009), I set $\mu = 0.81$. The rest of the parameters are calibrated to match:

• The share of manufacturing to total consumption in 1947.1

• The share of services to total consumption in 1947.1

• The share of manufacturing to total consumption in 2007.4

• The share of services to total consumption in 2007.4

The parameters in the production function of the intermediate good are calibrated similarly. These parameters are $\varphi, \lambda_a, \lambda_m$, and $\lambda_s$. I normalize $\lambda_a = 1$. The rest of the parameters match\(^2\)

\(^2\)I do not match the share of manufacturing goods in total intermediates in 2007, but this is almost all that is not services since the share of agricultural goods in intermediates in 2007 is extremely small.
• The share of manufacturing in total intermediates in 1987

• The share of services in total intermediates in 1987

• The share of services in total intermediates in 2007

The remaining parameters are calibrated as follows. $\theta_a, \theta_m$ and $\theta_s$ are the shares of agricultural goods, manufacturing goods, and services in investment goods taken from the 2007 input output tables. As I mentioned in the data section, these shares have hardly changed since 1947. $\nu$ is set to match the share of intermediates on total output in the economy, from the 2007 input output tables. $\alpha$ is set so that the share of labor income is $2/3$ of total value added.

Table 1 summarizes the targets and the results of the calibration.

5 Results

I perform 2,500 simulations of an economy with 1,000 periods. In each simulation, I retain only the last 244 periods for the analysis, to match the 244 quarters from 1947.1 through 2007.4. Before documenting the results, it is worth to explore a few outcomes of the model. I report what the estimated values for $\eta$’s are in Appendix A. The R squared of these regressions is very close to 1 in each case (0.99999), which means that the agents make very small mistakes in their predictions.

The model can replicate quite closely the patterns of structural transformation in consumption observed in the data. Figure 6 shows the result of one simulation compared to the data.
Table 1: Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>Wage income to value added is 70%</td>
<td>0.30</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Risk free interest rate of 1%</td>
<td>0.99</td>
</tr>
<tr>
<td>$\tau$</td>
<td>log preferences</td>
<td>1.00</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Match an investment to output ratio of 20%</td>
<td>0.01</td>
</tr>
<tr>
<td>$\theta_a$</td>
<td>Share of Ag on investment</td>
<td>0.00</td>
</tr>
<tr>
<td>$\theta_m$</td>
<td>Share of Ma on investment</td>
<td>0.40</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Share of value added on total output</td>
<td>0.60</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>Work one third of time available</td>
<td>5.00</td>
</tr>
<tr>
<td>$\bar{h}$</td>
<td>Normalization</td>
<td>0.50</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Herrendorf et al. (2009)</td>
<td>0.81</td>
</tr>
<tr>
<td>$\bar{c}_a$</td>
<td>Normalization</td>
<td>0.00</td>
</tr>
<tr>
<td>$\bar{c}_m$</td>
<td>Match increase in share of consumption in manufacturing</td>
<td>107.47</td>
</tr>
<tr>
<td>$\bar{c}_s$</td>
<td>Match increase in share of consumption in services</td>
<td>347.35</td>
</tr>
<tr>
<td>$\lambda_a$</td>
<td>Normalization</td>
<td>1.00</td>
</tr>
<tr>
<td>$\lambda_m$</td>
<td>Match share of manufacturing in intermediates</td>
<td>23.73</td>
</tr>
<tr>
<td>$\lambda_s$</td>
<td>Match share of services in intermediates</td>
<td>15.52</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Match increase in share of services in intermediates</td>
<td>0.50</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Price autocorrelation from data</td>
<td>0.87</td>
</tr>
<tr>
<td>$\rho_m$</td>
<td>Price autocorrelation from data</td>
<td>0.87</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>Price autocorrelation from data</td>
<td>0.87</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Match standard deviation of output</td>
<td>0.015</td>
</tr>
<tr>
<td>$\sigma_m$</td>
<td>Match ratio of agriculture to manufacturing st. dev.</td>
<td>0.0147</td>
</tr>
<tr>
<td>$\sigma_s$</td>
<td>Match ratio of agriculture to services st. dev.</td>
<td>0.0052</td>
</tr>
<tr>
<td>$\gamma_a$</td>
<td>No increase in agricultural prices</td>
<td>0.00</td>
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<tr>
<td>$\gamma_m$</td>
<td>Match increase in manufacturing prices</td>
<td>0.003</td>
</tr>
<tr>
<td>$\gamma_s$</td>
<td>Match increase in services prices</td>
<td>-0.003</td>
</tr>
</tbody>
</table>
All simulations feature similar results.

Before presenting the results, I briefly discuss the performance of the model along a couple of dimensions that were not targeted in the data. First, the correlations in the model are not far from the data, except for hours worked. These correlations are 0.67 for consumption, 0.92 for investment, and 0.05 for hours worked. In the data, these correlations are 0.76 for consumption, 0.84 for investment, and 0.80 for hours worked.

To measure how well the model can account for the reduction in volatility, I proceed as follows. I produce series for GDP, consumption, investment and hours worked in the model. I then detrend these series using an HP filter with smoothing parameter 1,600. Finally, I study the deviations from trend by diving these into two periods. The firms covers the quarters between 1947 and 1983, and the second covers the periods between 1984 and 2007.
Table 2: Results

<table>
<thead>
<tr>
<th>Relative St Dev</th>
<th>Data</th>
<th>Model</th>
<th>% Accounted</th>
<th>Model</th>
<th>% Accounted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Median)</td>
<td></td>
<td>(Mean)</td>
</tr>
<tr>
<td>Output</td>
<td>0.53</td>
<td>0.89</td>
<td>23%</td>
<td>0.90</td>
<td>21%</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.57</td>
<td>0.92</td>
<td>19%</td>
<td>0.95</td>
<td>12%</td>
</tr>
<tr>
<td>Investment</td>
<td>0.58</td>
<td>0.88</td>
<td>29%</td>
<td>0.89</td>
<td>26%</td>
</tr>
<tr>
<td>Hours Worked</td>
<td>0.71</td>
<td>0.86</td>
<td>48%</td>
<td>0.88</td>
<td>41%</td>
</tr>
</tbody>
</table>

Table 2 shows the averages and medians across simulations. When looking at the median, the volatility of output drops by 11 percent, consumption by 8 percent, investment by 12 percent and hours worked by 13 percent. Comparing with the data, this is 23 percent of the reduction in volatility in output, 19 percent for consumption, 29 percent for investment, and 45 percent for hours worked.

I also compute the model when all sectors are equally volatile. In theory, there should be no change in volatilities across periods. In practice, the volatilities change very little across periods. The medians across simulations show that GDP in the second half is equally volatile, consumption 3 percent more volatile, investment is 1 percent more volatile, and hours worked equally volatile. Comparing these numbers with the ones in table 2 I conclude that the reductions I obtain when I allow volatilities to differ across sectors are due to the larger weight of services on the economy.

6 Conclusion

This paper contributes to our understanding of structural transformation on volatility. As an economy grows, its resources move from more volatile sectors such as agriculture and man-
ufacturing to services, which is less volatile. The consequence of this shift is that aggregate volatility drops. This effect can account for one third of the reduction in volatility in output that we observe in the data.

My results link the findings of Carvalho and Gabaix (2010) to the literature on growth and structural transformation. While Carvalho and Gabaix find a strong relationship between aggregate volatility and sectoral composition, the assumptions used to derive this relationship are at odds with the existing literature. Essentially, these authors derive their results by assuming that sectoral shocks do not affect sectoral composition, either because they are too small (infinitesimal) or because sectoral shares do not respond to sectoral shocks (as would be the case when using Cobb Douglas preferences). Thus, while the authors shed light on a relationship between sectoral composition and aggregate volatility, they do not provide a mechanism that establishes causation. By uniting their findings with structural transformation theories such as Ngai and Pissarides (2007) and Kongsamut et al. (2001), I propose such a mechanism.

An implication of my findings is that as countries grow, they will experience a drop in volatility. This insight should be important in the light of developing economies. It is widely known that the volatility in developing economies is larger than the volatility in developed economies. My results suggest that one cause is the level of development itself. As these countries develop, they experience a shift in sectoral composition similar to developed economies, as pointed out by Bah (2010). Thus, development should contribute to a reduction in aggregate volatility.
References


Appendix A  The Parameterized Expectations Approximation

The model is solved using an algorithm developed by den Haan and Marcet (1990). Since we do not know how the expectation of future utility looks like (the right hand side of the Euler equation (4)), we need to approximate it. Standard techniques approximate it by loglinearizing the first order conditions and using a Taylor expansion around the steady state. This is not possible in this case since there is no steady state.

The Parameterized Expectations Approximation Method approximates the unknown expectation as a function of the state variables. These are the aggregate capital stock $K$, and the shocks $z_a, z_m, z_s$. However, the Euler condition shows that a particular function of these states is what matters:

$$
\frac{c_t^{\gamma}}{P_t} = \beta E_t \left( \frac{c_{t+1}^{\gamma}}{P_{t+1}} (r_{t+1} + 1 - \delta) \right)
$$

The relevant state variables are $K, z_x = \sum_{i=a,m,s} \theta_i z_i$ and $P$. A crucial assumption is which function to use to approximate this expectation. I follow den Haan and Marcet (1990)'s suggestion and use the following functional form$^3$

$$
E_t \left( \frac{c_{t+1}^{\gamma}}{P_{t+1}} (r_{t+1} + 1 - \delta) \right) = \Psi(K_t, z_{xt}, P_t)
$$

$^3$I have tried with other functions as well and obtain similar results.
where

\[
\log \Psi(K_t, z_{xt}, P_t) = \eta_1 + \eta_2 \log(K_t) + \eta_3 z_{xt} + \eta_4 \log(P_t) + \eta_5 \log(P_t) + \eta_6 \log(K_t)^2 + \eta_7 \log(z_{xt})^2 + \eta_8 \log(P_t)^2 \\
+ \eta_9 \log(K_t)z_{xt} + \eta_{10} \log(K_t) \log(P_t) + \eta_{11} z_{xt} \log(P_t) \\
+ \eta_{12} z_{xt} \log(P_t) \log(K_t)
\]

Given this function, I proceed as follows:

1. Pick some initial \( \eta_i, i = 1, \ldots, 10 \).

2. Given states \( K_t, z_{jt} \) and \( \eta \)'s, compute \( \Psi_t = \Psi(K_t, P_t) \) get \( c_t^{-\gamma}/P_t \)

3. Get \( P_{Mt} \):

   From the first order conditions of the investment firm, when maximizing with respect to \( k_{mx,t} \)

   \[
   r_t = e^{z_{xt}} \nu \alpha \tilde{\theta} \frac{H_t}{K_t} (1-\alpha)^\nu \left( \frac{M_t}{K_t} \right)^{1-\nu}
   \]

   From the first order conditions of firm \( i = a, m, s \), when maximizing with respect to \( k_{jt} \)

   \[
   r_t = p_{jt} e^{z_{jt}} \nu \alpha \frac{H_t}{K_t} (1-\alpha)^\nu \left( \frac{M_t}{K_t} \right)^{1-\nu}
   \]

   This implies that for \( i = a, m, s \),

   \[
   p_{jt} = \tilde{\theta} e^{-z_{jt}} e^{z_{xt}}
   \]
Given these prices, \( P_{It} \) solves equation (2).

4. Get \( H_t = h_t\bar{h} \) and \( M_t \)

\[
P_{Mt} = e^{\varepsilon \gamma_t (1 - \nu) \hat{\theta}} \left[ \left( \frac{K_t}{M_t} \right)^{\alpha} \left( \frac{H_t}{M_t} \right)^{1-\alpha} \right]^{\nu}
\]

\[
\Phi_t = \frac{\kappa(1 - \bar{h})}{e^{\varepsilon \gamma_t (1 - \alpha) \nu} \left( \frac{K_t}{H_t} \right)^{\alpha(1-\nu)} \left( \frac{M_t}{H_t} \right)^{1-\nu} \hat{\theta}}
\]

\[
M_t/H_t = \frac{K_t/H_t}{K_t/M_t}
\]

This implies

\[
\frac{H_t}{M_t} = \frac{P_{Mt} \Phi_t}{(1 - \alpha) \nu} \frac{1-\nu}{1-\nu} \kappa(1 - \bar{h})
\]

\[
\frac{K_t}{M_t} = \left( \frac{K_t}{H_t} \right)^{\alpha(1-\nu)} \left( \frac{M_t}{H_t} \right)^{1-\nu} \frac{1}{\psi}
\]

\[
M_t = \frac{K_t}{K_t/M_t}
\]

\[
H_t = \frac{H_t}{M_t} M_t
\]

5. Get \( r_t \) from

\[
r_t = e^{\varepsilon \gamma_t \nu \alpha \hat{\theta}} \left( \frac{H_t}{K_t} \right)^{(1-\alpha) \nu} \left( \frac{M_t}{K_t} \right)^{1-\nu}
\]

6. Get \( K_{t+1} \)

\[
P_tC_t + X_t = Y_t = w_t H_t + r_t K_t = \frac{r_t K_t}{\alpha}
\]
\[ K_{t+1} = (1 - \delta)K_t + \frac{r_t K_t}{\alpha} - P_t C_t \]

7. Use the equilibrium allocation to compute

\[ E_t \left( \frac{c_{t+1}^\tau}{P_{t+1}} (r_{t+1} + 1 - \delta) \right) \]

8. Obtain new \( \eta \)'s via a non linear regression (call these \( \tilde{\eta} \))

\[
\log E_t \left( \frac{c_{t+1}^\tau}{P_{t+1}} (r_{t+1} + 1 - \delta) \right) = \log \tilde{\eta}_1 + \tilde{\eta}_2 \log K_t + \tilde{\eta}_3 z_{xt} + \tilde{\eta}_4 \log P_t + \tilde{\eta}_5 z_{xt} \log K_t + \text{error}
\]

9. Compare \( \eta \) with \( \tilde{\eta} \)

- If \( \sum_{i=1}^5 (\eta_i - \tilde{\eta}_i)^2 > 1e^{-10} \), set \( \eta_i = \Gamma \eta_i + (1 - \Gamma) \tilde{\eta}_i \), \( \Gamma \in (0, 1] \) and go to step 2
- Otherwise stop iteration

The estimates obtained vary across simulations, but they stay very close to each other. Table 3 shows the point estimates in the first simulation.

<table>
<thead>
<tr>
<th>( \eta_1 )</th>
<th>( \eta_2 )</th>
<th>( \eta_3 )</th>
<th>( \eta_4 )</th>
<th>( \eta_5 )</th>
<th>( \eta_6 )</th>
<th>( \eta_7 )</th>
<th>( \eta_8 )</th>
<th>( \eta_9 )</th>
<th>( \eta_{10} )</th>
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</thead>
<tbody>
<tr>
<td>Estimate</td>
<td>4.21</td>
<td>-0.60</td>
<td>-0.02</td>
<td>-0.29</td>
<td>-0.34</td>
<td>-0.02</td>
<td>0.01</td>
<td>-0.02</td>
<td>-0.18</td>
</tr>
</tbody>
</table>