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Industrial Transformation, Heterogeneity in Price Stickiness, and the Great Moderation

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Abstract

Since the '80s the volatility of output growth and inflation experienced by several industrialized countries has remarkably declined, what has been dubbed the "Great Moderation". Various explanations have been proposed and likely all play some role. This paper shows that when an industrial transformation reduces the weight of the manufacturing sector relative to the services sector, the presence of sectoral heterogeneity in price stickiness leads to a significant decline in the volatility of inflation and output growth.

JEL Classification: E31, E32, E37, E52.

Key Words: Great Moderation, sectoral asymmetries, price stickiness, New Keynesian model, persistence, volatility.

1

1 Introduction

In the last three decades several industrialized countries experienced an unexpected and remarkable decline in the volatility of output growth and inflation, what has been dubbed the Great Moderation. Understanding this phenomenon has challenged the economic research, and the relative role of the candidate determinants is still unclear. These determinants can be classified in three types: structural changes, improved monetary policy and good luck. We suggest a new explanation which is structural and self-contained. Nevertheless, its presence bears important implications on the role played by the other two explanations, i.e. the good luck and the improved monetary policy.

The current explanation is based on two factors: the *industrial transformations* occurred in numerous economies concomitant with the Great Moderation, and the existence of *sectoral heterogeneity in price stickiness,* in particular services being stickier than manufacturing (Blinder et al. 1998, Bils and Klenov, 2004, Dhyne et al. 2006, ECB 2006). Adopting a New Keynesian model, the analysis shows that when sectoral price stickiness is considered along with a continuous expansion of the services sector and a contraction of the manufacturing sector, the volatility in output growth and inflation falls.

The intuition for this finding is that with services stickier than manufacturing, the industrial transformation activates/magnifies two buffering devices for supply shocks. The first is a *shock filtering mechanism* increasing with the overall stickiness in the economy (Ascari, Flamini, Rossi 2012). When the manufacturing sector contracts relatively to the services sector, stickiness increases and thus this mechanism is activated. The second is a *switching demand mechanism* activated by sectoral stickiness asymmetry (Flamini 2011) and increasing in the size of the stickier sector. When the manufacturing sector contracts relatively to the services sector, the size of the stickier sector increases and thus this mechanism is magnified.

Relating the industrial transformation to the Great Moderation has important precedents in the literature. Empirically, Black and Dowd (2009) found a positive and significant relationship between the manufacturing-to-services ratio and output

2

variability in US. Their interpretation of this relation is that services are less cyclical than manufacturing. This is in line with Burren and Neusser (2012) whose main finding is that the shift into the service sector allow explaining about 30% of the decline in GDP's volatility. Theoretically, Moro (2012) found that the reduction in output volatility can be associated to the industrial transformation via the volatility in aggregate factor productivity since this depends on the relative size of the two sectors.

With respect to this previous litterature, the current paper share with Moro's the theoretical standpoint, yet differs in terms of framework (New-Keynesian vs RBC) and in terms of the type of sectoral heterogeneity considered (price stickiness vs factor productivity). Hence, the mechanisms through which industrial transformation leads to a fall in the volatility of output and inflation are different.

The plan of the paper is as follows. Section 2 presents the model, derives the non-linear optimal conditions, shows the existence and uniqueness of the steady state, the log-linearized relations used in the following analysis, and the calibration of the structural parameters. Section 3 explains the relation between sectoral price stickiness, the industrial transformation of the type occurred in numerous developed economies and the Great Moderation. Section 4 focuses on the US and UK experiences. It considers the impact of the transition from manufacturing to services on output, inflation and interest rate volatility for the actual degree of sectoral price stickiness of these countries. It also discusses the implications on the good luck and the improved policymaking explanations of the structural explanation put forward in this paper. Concluding remarks are in section 5.

2   The model

The economy is populated by a continuum of unit mass of identical infinite-lived households each seeking to maximize

$$U_t = E_t \sum_{T=t}^{\infty} \beta^{T-t} \left\{ \widetilde{u} \left(C_T - \eta C_{T-1} \right) - \int_0^1 \widetilde{v} \left[H_T \left(j \right) \right] dj \right\}$$

where β is the intertemporal discount factor, C_t represents all interest-rate-sensitive expenditure including investments and is defined as a CES aggregate

$$C_t \equiv \left[(n_s)^{1/\rho} \left(C_t^s \right)^{(\rho-1)/\rho} + (n_m)^{1/\rho} \left(C_t^m \right)^{(\rho-1)/\rho} \right]^{\rho/(\rho-1)} \tag{1}$$

of the goods C_t^s and C_t^m which are produced, respectively, by the s and m-sector, with ρ defining their elasticity of substitution and n_s and n_m ($n_s \equiv 1 - n_m$) denoting the number of goods of sector s and m in C_t, respectively. Each sectoral good is, in turn, a Dixit-Stiglitz aggregate of the continuum of differentiated goods produced in the sector:

$$C_t^s \equiv \left[n^{s^{-\frac{1}{\theta}}} \int_0^{n_s} \left(C_t^s(i) \right)^{1-\frac{1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \qquad C_t^m \equiv \left[n^{m^{-\frac{1}{\theta}}} \int_{n_s}^1 \left(C_t^m(i) \right)^{1-\frac{1}{\theta}} di \right]^{\frac{\theta}{\theta-1}} \tag{2}$$

where $\theta > 1$ is the sectoral elasticity of substitution between any two differentiated goods. Period preferences on consumption and labour are modeled as CRRA functions

$$\widetilde{u} \left(C_t - \eta C_{t-1} \right) = \frac{\left(C_t - \eta C_{t-1} \right)^{1-\frac{1}{\widetilde{\sigma}}} - 1}{1 - \frac{1}{\widetilde{\sigma}}}, \tag{3}$$

$$\widetilde{v} \left[H_t(j) \right] \equiv \frac{H_t^{1+\nu}(j)}{1+\nu}, \tag{4}$$

where $H_t(j)$ is the quantity supplied of labour of type j, $\widetilde{\sigma} > 0$ captures the intertemporal elasticity of substitution in consumption, $0 \le \eta < 1$ measures the degree of habit persistence, and $\nu > 0$ is the inverse of the elasticity of goods production. The price index for the minimum cost of a unit of C_t is given by

$$P_t \equiv \left[n_s \left(P_t^s \right)^{1-\rho} + (n_m) \left(P_t^m \right)^{1-\rho} \right]^{1/(1-\rho)}, \tag{5}$$

with P^s, P^m denoting, respectively, the Dixit-Stiglitz price index for goods produced in the s and m sector

$$P_t^s \equiv \left[(n_s)^{-1} \int_0^{n_s} p^s(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}, \qquad P_t^m \equiv \left[(n_m)^{-1} \int_{n_s}^1 p^m(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}}.$$

Preferences captured by equation (1) imply that the optimal sectoral consumption levels are given by

$$C_t^s = n_s C_t \left(\frac{P_t^s}{P_t} \right)^{-\rho}, \tag{6}$$

$$C_t^m = n_m C_t \left(\frac{P_t^m}{P_t} \right)^{-\rho}. \tag{7}$$

Financial markets are assumed to be complete so that at any date all households face the same budget constraint and consume the same amount. Then, utility maximization subject to the budget constraint and the no-Ponzi scheme requirement yields the condition for optimal consumption

$$\lambda_t = \beta E_t \left\{ \frac{[\widetilde{u}_c (C_{t+1} - \eta C_t) - \beta \eta E_t \widetilde{u}_c (C_{t+2} - \eta C_{t+1})]}{\widetilde{u}_c (C_t - \eta C_{t-1}) - \beta \eta E_t \widetilde{u}_c (C_{t+1} - \eta C_t)} \frac{P_t}{P_{t+1}} \right\}, \tag{8}$$

where $\lambda_t \equiv \frac{1}{1+i_t}$ is the price of a one-period nominal bond. Finally, utility maximization requires that the optimal supply of labour of type j is given by

$$\Omega_t (j) = \Psi_t \frac{\widetilde{v}_h [H_t (j)]}{[\widetilde{u}_c (C_t - \eta C_{t-1}) - \eta \beta E_t \widetilde{u}_c (C_{t+1} - \eta C_t)]}, \tag{9}$$

where $\Omega_t (j)$ is the real wage demanded for labour of type j and $\Psi_t \geq 1$ is an exogenous markup factor in the labor market assuming that firms are wage-takers. Given (2), sectoral aggregate outputs are

$$Y_t^s \equiv \left[\frac{1}{n_s} \int_0^{n_s} [y_t^s (j)]^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}, \qquad\qquad Y_t^m \equiv \left[\frac{1}{n_m} \int_n^1 [y_t^m (j)]^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}.$$

Turning to production, each household i is assumed to supply all type of labour and is a monopolistically competitive producer of one differentiated good, either $y^m (i)$ or $y^s (i)$. In this economy any firm i belongs to an industry j which, in turn, belongs either to sector s or m. Furthermore, there is a unit interval continuum of industries indexed by j and in each industry there is a unit interval continuum of good indexed by i so that the total number of goods is one. Since in equilibrium all the firms belonging to an industry will supply the same amount, they will also demand the same amount of labour. As a result the total demand of labour in an industry is

equal to demand of labor of any differentiated firm in the industry. Next, we assume industry-specific labor as the only variable input and a sector-specific technology

$$y_t^s(i) = A_t [H_t^s(i)]^{\frac{1}{\phi}},$$
$$y_t^m(i) = A_t [H_t^m(i)]^{\frac{1}{\phi}},$$

where A_t is a technology shock, $H_t^s(i)$, $H_t^m(i)$ are the quantities of labour used by the representative firm i in the s and m-sector to produce good i respectively, and $\phi > 1$, is the elasticity of sectoral output with respect to hours worked. Thus the input requirement functions are

$$H_t^s = \left[\frac{y_t^s(i)}{A_t} \right]^{\phi}, \tag{10}$$

$$H_t^m = \left[\frac{y_t^m(i)}{A_t} \right]^{\phi}, \tag{11}$$

then, accounting for the preferences (1-2) the quantity demanded for each individual good in the manufacturing and services sector are, respectively,

$$y_t^s(i) = C_t^s(i)$$
$$= C_t \left(\frac{p_t^s(i)}{P_t^s} \right)^{-\theta} \left(\frac{P_t^s}{P_t} \right)^{-\rho}, \tag{12}$$

and

$$y_t^m(i) = C_t^m(i)$$
$$= C_t \left(\frac{p_t^m(i)}{P_t^m} \right)^{-\theta} \left(\frac{P_t^m}{P_t} \right)^{-\rho}. \tag{13}$$

In equilibrium, market clearing in the goods market requires

$$Y_t^m = C_t^m, \tag{14}$$
$$Y_t^s = C_t^s, \tag{15}$$
$$Y_t = C_t, \tag{16}$$

Then, combining (3), (8), and (16) we obtain the nonlinear version of the aggregate demand. Turning to the producers' pricing behaviour, firms in both sectors fix their

prices at random intervals following the Calvo (1983) staggered price model and have the opportunity to change their prices with probability $(1-\alpha)$. Thus, a producer i in the $h = m, s$ sector that is allowed to set its price in period t chooses its new price for the random period starting in t, $\widetilde{p}_t^h$, to maximize the flow of expected profits:

$$\max_{\widetilde{p}_t^h} E_t \sum_{T=t}^{\infty} \alpha^{T-t} \lambda_{t,T} \left\{ \widetilde{p}_t^h y_T^h(i) - \left[\frac{y_T^h(i)}{A_T}\right]^{\phi} \Psi_T \frac{\left[y_T^h(j)/A_T\right]^{\nu\phi}}{(C_t - \eta C_{t-1})^{-\frac{1}{\sigma}} - \eta\beta(C_{t+1} - \eta C_t)^{-\frac{1}{\sigma}}} P_T \right\},$$

where $\lambda_{t,T}$ is the stochastic discount factor by which financial markets discount random nominal income in period T. Accounting for firm i demand function in sector h, and considering that the firm's pricing decision cannot change the real wage, the f.o.c. is

$$0 = E_t \sum_{T=t}^{\infty} \alpha^{T-t} \lambda_{t,T} \left\{ C_T \left(\frac{\widetilde{p}_t^h}{P_T^h}\right)^{-\theta} \left(\frac{P_T^h}{P_T}\right)^{-\rho} - \theta C_T \left(\frac{\widetilde{p}_t^h}{P_T^h}\right)^{-\theta-1} \frac{\widetilde{p}_t^h}{P_T^h} \left(\frac{P_T^h}{P_T}\right)^{-\rho} - \quad (17) \right.$$

$$\left[-\phi\theta \left(\frac{C_T}{A_T}\right)^{\phi} \left(\frac{\widetilde{p}_t^h}{P_T^h}\right)^{-\phi\theta-1} \frac{1}{P_T^h} \left(\frac{P_T^h}{P_T}\right)^{-\phi\rho} \right] \frac{\Psi_T \left[C_t \left(\frac{p_t^h(j)}{P_t^h}\right)^{-\theta} \left(\frac{P_t^h}{P_t}\right)^{-\rho} \frac{1}{A_T} \right]^{\nu\phi}}{(C_T - \eta C_{T-1})^{-\frac{1}{\sigma}} - \eta\beta(C_{T+1} - \eta C_T)^{-\frac{1}{\sigma}}} P_T \left. \right\}.$$

2.1 Log-linearized equilibrium conditions

We now log-linearize the equilibrium conditions around the steady state where the variables $\left(Y_t^m, Y_t^s, Y_t, Q_t, \frac{P_{t+1}}{P_t}, \frac{P_{t+1}^s}{P_t^s}, \frac{P_{t+1}^m}{P_t^m}\right)$ are equal to $(Y^m, Y^s, Y, Q, 1, 1, 1)$ and all the shocks are equal to one[1]. Loglinearizing the Euler equation account being taken of the market clearing condition leads to the aggregate demand

$$y_t = \frac{\eta}{1 + \eta(1 + \beta\eta)} y_{t-1} + \frac{1 + \eta\beta(1 + \eta)}{1 + \eta(1 + \beta\eta)} y_{t+1|t} - \frac{\eta\beta}{1 + \eta(1 + \beta\eta)} y_{t+2|t}$$

$$(18)$$

$$- \frac{\widetilde{\sigma}(1 - \eta)(1 - \eta\beta)}{(1 + \eta + \beta\eta^2)} \left(\widehat{i}_t - \pi_{t+1|t}\right)$$

Defining $q_t \equiv \log \frac{Q_t}{Q}$, the law of motion for the log deviation of the relative price from its steady state value is given by

$$q_t = q_{t-1} + \pi_t^s - \pi_t^m. \qquad (19)$$

---

[1]The proof of the existence and uniqueness of the steady state equilibrium is reported in the appendix.

Next, loglinearizing the f.o.c. for the firm's problem (17) with respect to sector m and s we obtain

$$\pi_t^m = \kappa^m \left[\omega + \varphi \left(1 + \eta^2 \beta \right) \right] y_t - \kappa^m \varphi \eta y_{t-1} - \kappa^m \varphi \eta \beta y_{t+1|t} + \kappa^m \overline{Q}^s \left(\rho \omega + 1 \right) q_t$$

(20)

$$- \kappa^m \left[\left(1 + \omega \right) a_t - \psi_t \right] + \beta \pi_{t+1|t}^m$$

and

$$\pi_t^s = \kappa^s \left[\omega + \varphi \left(1 + \eta^2 \beta \right) \right] y_t - \kappa^s \varphi \eta y_{t-1} - \kappa^s \varphi \eta \beta y_{t+1|t} - \kappa^s \overline{Q}^m \left(\rho \omega + 1 \right) q_t$$

(21)

$$- \kappa^s \left[\left(1 + \omega \right) a_t - \psi_t \right] + \beta \pi_{t+1|t}^s$$

where $a_t \equiv \log A_t$, $\psi_t \equiv \Psi_t$ and

$$\overline{Q}^s \equiv \frac{n_s Q^{1-\rho}}{n_s \left(Q^{1-\rho} - 1 \right) + 1}, \qquad \overline{Q}^m = 1 - \overline{Q}^s,$$

$$\omega \equiv \phi \left(v + 1 \right) - 1,$$

(22)

$$\kappa^h \equiv \frac{\left(1 - \alpha^h \right) \left(1 - \alpha^h \beta \right)}{\alpha^h \left(1 + \omega \theta \right)}, \qquad h = m, s,$$

(23)

$$\varphi \equiv \frac{1}{\left(1 - \eta \right) \widetilde{\sigma} \left(1 - \eta \beta \right)},$$

(24)

At this point three considerations are in order. First, accounting for (23), the shocks elasticity of sectoral inflation in (20-21) and of aggregate inflation in (27) below is decreasing in the degree of price stickiness. This implies a shock filtering device which is increasing with stickiness. Second, abstracting from the sectors' size, the elasticity of sectoral inflation to the relative price q_t is larger in the sector where price are more flexible. This matters for another shock buffering device that is based on demand swithcing across sectors. Third, $\overline{Q}^s$ and $\overline{Q}^m$ are the only (composite) parameters in (20-21) that depend on n^s. This implies that a first channel through which an industrial transformation affects the economy is the degree of impact of the

relative price on sectoral inflations which depends on $\overline{Q}^s$. These three points will be examined below in the analysis of the relation between the industrial transformation and the Great Moderation.

Turning to the exogenous shocks, they follow

$$a_{t+1} = \gamma_a a_t + \varepsilon^a_{t+1},$$

$$\psi_{t+1} = \gamma_\psi \psi_t + \varepsilon^\psi_{t+1},$$

where $E_t \left(\varepsilon^h_{t+1} \right) = 0$, $h = a$, ψ. Log-linearizing the price index (5) we obtain aggregate inflation

$$\pi_t = (1 - \widetilde{n}) \pi^s_t + \widetilde{n}\pi^m_t, \tag{25}$$

where

$$\widetilde{n} \equiv \frac{n_m}{n_s \left(Q^{1-\rho} - 1 \right) + 1}, \tag{26}$$

and substituting the sectoral inflations we obtain aggregate inflation in terms of lagged, current, and expected output gap, the relative price, expected inflation, and the exogenous shocks

$$
\begin{aligned}
\pi_t =\ & \left[(1 - \widetilde{n}) \kappa^s + \widetilde{n}\kappa^m \right] \left[\omega + \varphi \left(1 + \eta^2 \beta \right) \right] y_t \\
& - \varphi\eta \left[(1 - \widetilde{n}) \kappa^s + \widetilde{n}\kappa^m \right] y_{t-1} - \varphi\eta\beta \left[(1 - \widetilde{n}) \kappa^s + \widetilde{n}\kappa^m \right] y_{t+1|t} \\
& - (\rho\omega + 1) \left[(1 - \widetilde{n}) \kappa^s \overline{Q}^m - \widetilde{n}\kappa^m \overline{Q}^s \right] q_t + \beta\pi_{t+1|t} \\
& - \left[(1 - \widetilde{n}) \kappa^s + \widetilde{n}\kappa^m \right] \left[(1 + \omega) a_t - \psi_t \right]
\end{aligned} \tag{27}
$$

Here it is worth noting a second channel through which the industrial transformation affects the economy. Indeed, accounting for (26) and (23), when n^s increases the shock elasticity of aggregate inflation falls.

The model is closed with a Taylor rule describing the behaviour of the central bank

$$i_t = \delta_0 i_{t-1} + (1 - \delta_0) \delta_1 \pi_t + (1 - \delta_0) \delta_2 y_t.$$

2.2 Calibration

The calibration of the structural parameters that we have used in this model is quite standard in the previous litterature[2]. The degree of habits persistence is $\eta = 0.7$; the elasticity of intertemporal substitution in consumption is $\widetilde{\sigma} = 2/3$; the elasticity of substitution between C_t^s and C_t^m in the CES consumption aggregate is $\rho = 0.4$; the elasticity of sectoral output with respect to hours worked is $\phi = 1.333$; the inverse of the elasticity of goods production is $\nu = 1.17$; the sectoral elasticity of substitution between any two differentiated goods is $\theta = 7.88$; the intertemporal discount factor is $\beta = 0.9975$; the coefficients of the Taylor rule are $\delta_0 = 0.8$; $\delta_1 = 1.5$; $\delta_2 = 0.5/4$; the AR coefficients of the exogenous processes are $\gamma_a = \gamma_\psi = \gamma_c = 0.95$ and for any shock the variance is $\sigma_\varepsilon^2 = 0.009^2$.

Finally, regarding sectoral price stickiness in the US and UK, we use the median price durations found by Nakamura and Steinsson (2008) and by Bunn and Ellis (2011), respectively. With these statistics, we compute for the US the median duration for services- and goods-producing industries, equal respectively to 13 and 3.3 months, which in turn, results in $\alpha^s = 0.77$ and $\alpha^m = 0.09$. For the UK mean durations computed by Bunn and Ellis are 4.16 and 11.1 months for goods and services respectively, which, in turn, results in $\alpha^m = 0.28$ and $\alpha^s = 0.73$.

3 Structural changes and buffering devices

The mechanics through which industrial transformation has decreased the volatility of output, inflation and the interest rate is based on two buffering devices for supply shocks accompanied by the fact that the services sector is stickier than the manufacturing sector.

Larger stickiness in services than in manufacturing is an amply documented fact (Blinder et al. 1998, Bils and Klenov, 2004, Dhyne et al. 2006). Turning to the shock buffering devices, the first consists of a *shock filtering mechanism* increasing with stickiness (Ascari, Flamini, Rossi 2012). When stickiness increases, the elasticity

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[2]See, for example, Smets and Wouters (2007).

of inflation to supply shocks falls. What happens here is that the less frequently firms optimally update the price, the less supply shocks can pass through to marginal costs and therefore to inflation. This holds for sectoral inflations and clearly also for aggregate inflation as shown by equations (20-21) and (27) account being taken of the definition of κ provided by (23).

The second buffering device is a *switching demand mechanism* activated by, and increasing in, sectoral stickiness asymmetry (Flamini 2011). When sectors differ in terms of stickiness, sectoral inflations differ after a shock and the stickier sector experiences a smaller change in inflation[3]. As a result the relative price between sectors kicks in as shown by equation (19) and tends to divert the demand from the sector whose goods are relatively more expensive to the sector whose goods are relatively cheaper. As expected, in the former sector inflation falls while in the latter increases as shown by the opposite signs of the relative price elasticities of sectoral inflation in equations (20-21). Yet, these sectoral inflation changes caused by q, beyond differing in direction, differ also size wise because the change in marginal costs caused by the demand change impacts less inflation in the stickier sector. This is captured by the elasticity of sectoral inflation to the relative price which is decreasing in sectoral stickiness as shown in equations (20-21). This difference in the impact of the relative price on sectoral inflations implies a fall in aggregate inflation and therefore a buffering role played by the switching demand mechanism.

Now both the filtering mechanism and the switching demand mechanism are amplified by the industrial transformation through *size effects*. To see why, let us recall the fact that the services sector is stickier than the manufacturing sector and consider the impact of an increase in the services sector size, n_s, on the mechanisms just described. Starting with the shock filtering mechanism, it is worth noting that the shock enters the economy more through the manufacturing sector than the services sector because the latter is stickier than the former. Clearly industrial transformation, by contracting the manufacturing sector and expanding the services sector, turns out

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[3]This holds no matter what the shock is: with a supply shock through the shock filtering mechanism and with a demand shock through a different slope of the Phillips curve.

to filter out the shock more. This size effect on the shock filtering mechanism is captured by the fact that the shock elasticity of aggregate inflation is decreasing in the share of services as shown in equation (27).As a result when the share of services increases, the volatility of inflation and then, via the monetary policy, the volatility of the interest rate and output fall.

Let us now turn to the impact of the industrial transformation on the switching demand mechanism. It is worth noting that when the relative price changes, the demand switches across sectors according to how important sectors are in the household consumption basket and how sostitutable the (composite) sectoral goods are. Thus if one sectoral price increases relative to the other, the demand will switch from the former to the latter proportionally to the size of the latter and to the elasticity of substitution between the two sectoral (composite) goods. This size effect on the switching demand mechanism is captured by the negative relation between the (absolute value of the) price level elasticity of sectoral inflation and the sectoral size as shown in equations (20-21)[4]. Hence, when n_s increases, the relative price elasticities

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[4]The relative price elasticity of the m-sector inflation is proportional to

$$\overline{Q}^s \equiv \frac{n_s Q^{1-\rho}}{n_s \left(Q^{1-\rho} - 1\right) + 1}.$$

It can be shown that $\frac{\partial \overline{Q}^s}{\partial n_s} > 0$ using the equations for the steady state and the Implicit Function Theorem. What follows is a shortcut proof based on $\frac{\partial Q}{\partial n_s} > 0$ (numerically) and $\frac{\partial \overline{Q}^s}{\partial Q} > 0$ for $\rho > 1$.

Proof $\frac{\partial \overline{Q}^s}{\partial Q} > 0$ for $\rho > 1$:

$$\frac{\partial \overline{Q}^s}{\partial Q} = \frac{n_s \left(1 - \rho\right) Q^{-\rho} \left[n_s \left(Q^{1-\rho} - 1\right) + 1\right] - n_s \left(1 - \rho\right) Q^{-\rho} n_s Q^{1-\rho}}{\left[n_s \left(Q^{1-\rho} - 1\right) + 1\right]^2}$$

$$= \frac{n_s^2 \left(1 - \rho\right) \left(Q^{1-2\rho} - Q^{-\rho}\right) + n_s \left(1 - \rho\right) Q^{-\rho} - n_s^2 \left(1 - \rho\right) Q^{1-2\rho}}{\left[n_s \left(Q^{1-\rho} - 1\right) + 1\right]^2}$$

$$= \frac{n_s^2 \left(1 - \rho\right) Q^{1-2\rho} - n_s^2 \left(1 - \rho\right) Q^{-\rho} + n_s \left(1 - \rho\right) Q^{-\rho} - n_s^2 \left(1 - \rho\right) Q^{1-2\rho}}{\left[n_s \left(Q^{1-\rho} - 1\right) + 1\right]^2}$$

$$= \frac{\left(1 - \rho\right) n_s Q^{-\rho} \left[-n_s + 1\right]}{\left[n_s \left(Q^{1-\rho} - 1\right) + 1\right]^2} > 0 \qquad \text{for } \rho > 1.$$

of manufacturing inflation and services inflation respectively increase and decrease. This is important as the manufacturing sector, being the less sticky sector, is also the one whose inflation departs more from its steady state value. Thus, when n_s increases, m-sector inflation will converge more and s-sector inflation will depart less from their steady state values. As a result the switching demand mechanism is magnified.

4   Sectoral heterogeneity in price stickiness, industrial transformation, and the Great Moderation

Since the '80s in several industrialized countries the volatility of the output gap and inflation has remarkably decreased. What has ultimately caused this change, called the Great Moderation, is still unclear and several factors can likely have played a role. Structural change in inventory management, better macro-economic policies and good luck are, so far, the most accredited explanations given to this phenomenon. Reasonably, all of them matter but there is no consensus on their relative importance[5]. Since the '80s another important change occurred in numerous developed economies: a massive industrial transformation consisting in a contraction of the manufacturing sector accompanied by an expansion of the services sector[6]. We have explained in the previous section why the industrial transformation and price stickiness in the service sector larger than in the manufacturing sector result in a fall in the volatility of output and inflation. Here we use the model at hand to investigate quantitatively the role played by this new explanation for the Great Moderation.

4.1   US case

During the last 50 years in the United States of America the composition of the value added by industry as a percentage of GDP has substantially changed. Figure

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[5]Other interesting explanations are better financial instruments and a decline in the volatility of aggregate total factor productivity.

[6]For some countries, this industrial transformation started before the '80s but what is interesting here is that the '80s witnessed an accelaration of this phenomenon.

1 disaggregate GDP in three components: value added by Private goods-producing industries, by Private services-producing industries and by Government[7].

1
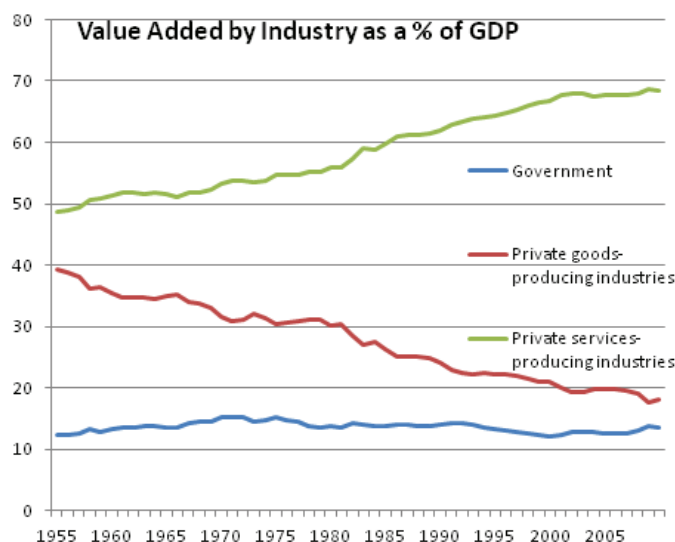
$_1$.pdf

While the Government component does not exhibit a remarkable trend, private services and goods do trends up and down respectively. Specifically, the private services industry increases its value added percentage of GDP of 34.6% while the private goods industry decreases it of 92.2%.Splitting the sample equally in two parts, denoting the second the Great moderation period and the first the period prior to the Great Moderation, we find that the average size of the services sector rises from 0.53 to 0.65. Using this information we compute the volatility of output, inflation and the interest rate in both periods and report in Table 1 the change in these variables

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[7]The source that we have used for data on the value added by industries as a percentage of GDP is the Beareau of Economic Analysis.

occurred moving from one period to the other along with the actual changes[8].

<div align="center">

Table 1. Variation in GDP, inflation, interest rate

volatility from ´58-83 to ´84- ´08

	Data	Model
GDP	-45.3%	-19%
GDP Deflator	-66.2%	16.4%
Interest rate	–	-21.5%

</div>

Table 1 shows that once price stickiness differences are taken into account, the industrial transformation plays a remarkable role in explaining the fall in the volatility of GDP and inflation occurred during the second period. Specifically, the model suggests that 41.9% of the fall in the GDP volatility and 24.7% of the fall in the inflation volatility contained in the data can be associated to this explanation.

These results have been obtained assuming that prior and during the Great Moderation the sectoral degree of price stickiness are the same. This assumption is unrealistic in that trend inflation has changed over the two periods and thus it is reasonable to expect that with the Great Moderation price stickiness increased. We then ask to what extent if any a larger degree of price flexibility prior to the Great Moderation can impact on the previous results. Since statistics on sectoral price stickiness for the first period are not available we introduce the conservatory assumption that in the first period both sectors experienced a 10% decrease in price stickiness. Following the previous approach, we obtain the results reported in Table 4.

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[8]Blanchard and Simon (2001) report that the variability of real output growth (in terms of standard deviation) has declined by half since the mid-1980s, while the variability of quarterly inflation has declined by about two thirds.

Table 2. Variation in GDP, inflation, interest rate
volatility from ´58-83 to ´84-´08

	Data	Model
GDP	-45.3%	-29.2%
Inflation	-66.2%	16.%
Interest rate	–	-30%

4.2   UK case

We also consider the UK case where the average size of the service sector in terms of GDP rises from 0.53 to 0.71 from the first to the second period[9]. Using this information we compute the volatility of output, inflation and the interest rate in both periods and report in Table 1 the change in these variables occurred moving from one period to the other along with the actual changes.

Table 3. Variation in GDP, inflation, interest rate
volatility from ´58-83 to ´84-´08

	Data	Model
GDP	-46.2%	-19%
GDP Deflator	-61.7%	-16.1%
Interest rate	–	-18.3%

Table 3 shows that once price stickiness differences are taken into account, the industrial transformation plays a remarkable role in explaining the fall in the volatility of GDP and inflation occurred during the second period. Specifically, the model suggests that 41.1% of the fall in the GDP volatility and 26.1% of the fall in the inflation volatility contained in the data can be associated to this explanation. We next consider a 10% decrease in price stickiness in the first period due to the higher value of trend inflation. Results are reported in Table 4 and are in line with what has been shown before for the US.

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[9]Source: UK Office of National Statistics.

Table 4. Variation in GDP, inflation, interest rate
volatility from ´58-83 to ´83-´08

	Data	Model
GDP	-46.2%	-26.1%
GDP Deflator	-61.7%	-25.4%
Interest rate	–	-26.9%

4.3 Industrial transformation with price stickiness heterogeneity, improved monetary policy and good luck

It is interesting to note that this new determinant of the Great Moderation based on the industrial transformation and heterogeneity in sectoral price stickiness bears important implications on the role played by the other determinants, i.e. the good luck and the improved monetary policy explanations. Consider first the impact on the good luck determinant. According to this explanation, in the last 30 years the shocks hitting the economy have become smaller and less frequent leading to more economic stability. But account being taken of the industrial transformation in presence of price stickiness heterogeneity, supply shocks are now also more buffered. This suggests that the role played by the good luck explanation tends to be magnified by the determinant proposed in this work. Next, consider the impact on the improved policymaking determinant. Carvalho (2006) has shown that with sectoral heterogeneity in price stickiness, monetary policy shocks exert larger and more persistent real effects. Thus, an improved monetary policy in presence of the determinant proposed here would benefit from a further gain in terms of effectiveness.

5 Concluding remarks

This paper shows that when heterogeneity in sectoral price stickiness is considered along with an expansion of the sector with stickier prices, a possibility often occurred in the industrial transformations experienced since the '80s by several developed economies, heterogeneity in sectoral price stickiness offers a quantitatively relevant

argument to explain the Great Moderation.

Further analysis will investigate other changes in the composition of value added by industries as a percentage of GDP during the last 50 years which seem promising to explain the Great Moderation. In particular the pattern of Durables and Non-durables goods and Agricultural goods. We also intend to study the role of capital accumulation and take the model to the data to assess the relative role played by the various proposed explanations of the Great Moderation.

Appendix: Existence and uniqueness of the steady state equilibrium

In presence of flexible prices, the monopolistic competitive representative firm i in sector m sets the optimal price $\widetilde{p}_t^m$ in any period to maximize the period profit

$$
\max_{\widetilde{p}_t^m} \left\{ \widetilde{p}_t^m y_t^m(i) - \left[\frac{y_t^m(i)}{A_t^m} \right]^{\phi} \left[\Psi_t \frac{\widetilde{v}_h[H_t(j)]}{[\widetilde{u}_c(C_t - \eta C_{t-1}) - \eta \beta E_t \widetilde{u}_c(C_{t+1} - \eta C_t)]} P_t \right] \right\},
$$

and the f.o.c. consists of setting the price as a mark-up on marginal costs

$$
\widetilde{p}_t^m = \frac{\theta}{(\theta - 1)} \phi \left[\frac{y_t^m(i)}{A_t^m} \right]^{\phi - 1} \left[\Psi_t \frac{\widetilde{v}_h[H_t(j)]}{[\widetilde{u}_c(C_t - \eta C_{t-1}) - \eta \beta \widetilde{u}_c(C_{t+1} - \eta C_t)]} P_t \right].
$$

Let s^m be the *real* marginal cost in the $m-$sector

$$
s^m\left(y_t^m(i), C_t, \frac{P_t^s}{P_t^m}; \xi_t\right) \equiv \phi \left[\frac{y_t^m(i)}{A_t^m} \right]^{\phi - 1} \left[\frac{\Psi_t \widetilde{v}_h[y_t^m(i)]}{[\widetilde{u}_c(C_t - \eta C_{t-1}) - \eta \beta \widetilde{u}_c(C_{t+1} - \eta C_t)]} \frac{P_t}{P_t^m} \right],
\tag{28}
$$

where "real" is with respect to the price of the composite good in the m sector. Notice that accounting for (5) we obtain

$$
\frac{P_t}{P_t^m} = \left[n_s \left(Q_t^{1-\rho} - 1 \right) + 1 \right]^{\frac{1}{1-\rho}},
\tag{29}
$$

and

$$
\frac{P_t}{P_t^s} = \left[n_m \left(Q_t^{\rho-1} - 1 \right) + 1 \right]^{\frac{1}{1-\rho}},
\tag{30}
$$

where $Q_t \equiv \frac{P_t^s}{P_t^m}$, so that s^m turns out to be a function only of $(y_t^m(i), C_t, Q_t; \xi_t^m)$ where $\xi_t^m \equiv \left(A_t^m, \Psi_t^m, \overline{C}_t \right)'$ is a vector of shocks. Then the f.o.c. can be rewritten as

$$
\frac{\widetilde{p}_t^m}{P_t^m} = \frac{\theta}{(\theta - 1)} s^m\left(y_t^m(i), C_t, Q_t; \xi_t^m\right).
\tag{31}
$$

Now, rearranging the demand for good i in sector m given by (13) we obtain

$$
\frac{p_t^m(i)}{P_t^m} = \frac{[y_t^m(i)]^{-\frac{1}{\theta}}}{C_t^{-\frac{1}{\theta}}} \left(\frac{P_t^m}{P_t} \right)^{-\frac{\rho}{\theta}}.
$$

19

Then, accounting for (31) the supply of good i must satisfy

$$\frac{[y_t^m(i)]^{-\frac{1}{\theta}}}{C_t^{-\frac{1}{\theta}}}\left(\frac{P_t^m}{P_t}\right)^{-\frac{\rho}{\theta}}=\frac{\theta}{(\theta-1)}s^m\left(y_t^m(i),C_t,Q_t;\xi_t^m\right).$$

Now notice that the LHS and the RHS are, respectively, decreasing and increasing in $y_t^m(i)$. Thus there is only one value of $y_t^m(i)$ that satisfies the previous equation given (C_t,Y_t^s,Q_t). In equilibrium all the firms in the m-sector produce the same quantity so that it must be that $y_t^m(i)=Y_t^m$. Hence

$$\frac{[Y_t^m]^{-\frac{1}{\theta}}}{C_t^{-\frac{1}{\theta}}}\left(\frac{P_t^m}{P_t}\right)^{-\frac{\rho}{\theta}}=\frac{\theta}{(\theta-1)}s^m\left(Y_t^m,C_t,Q_t;\xi_t^m\right),$$

and accounting for (28) and (29) we obtain

$$\frac{[Y_t^m]^{-\frac{1}{\theta}}}{C_t^{-\frac{1}{\theta}}}\left(\frac{P_t^m}{P_t}\right)^{-\frac{\rho}{\theta}}=\frac{\theta}{(\theta-1)}\phi\left[\frac{Y_t^m}{A_t^m}\right]^{\phi-1}\frac{[y_t^m(j)/A_t^m]^{\nu\phi}\left[n_s\left(Q^{1-\rho}-1\right)+1\right]^{\frac{1}{1-\rho}}}{\left[(C_t-\eta C_{t-1})^{-\frac{1}{\sigma}}-\eta\beta\left(C_{t+1|t}-\eta C_t\right)^{-\frac{1}{\sigma}}\right]},$$

which, assuming no shocks and accounting for (7) and (14-16) boils down to

$$\frac{(\theta-1)}{\theta\phi}=\frac{[Y^m]^{\nu\phi+\phi-1}}{(1-\eta\beta)\left[(1-\eta)Y\right]^{-\frac{1}{\sigma}}}\left[n_sQ^{1-\rho}+n_m\right]^{\frac{1}{1-\rho}}.\qquad(32)$$

Similarly for the other sector

$$\frac{(\theta-1)}{\theta\phi}=\frac{[Y^s]^{\nu\phi+\phi-1}}{(1-\eta\beta)\left[(1-\eta)Y\right]^{-\frac{1}{\sigma}}}\left[n_s+n_m\left(Q\right)^{\rho-1}\right]^{\frac{1}{1-\rho}}.\qquad(33)$$

Now accounting for (6-7) and the sectoral market clearing conditions (14-16) and (29-30) we obtain

$$Y^m=n_mY\left[n_s\left(Q\right)^{1-\rho}+n_m\right]^{\frac{\rho}{1-\rho}},\qquad(34)$$

$$Y^s=n_sY\left[n_s+n_m\left(Q\right)^{\rho-1}\right]^{\frac{\rho}{1-\rho}},\qquad(35)$$

thus we have to solve a system of four equations (32-35) in four unknowns (Y^m,Y^s,Y,Q).

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