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# Anatomizing the Mechanics of Structural Change*

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**Abstract**

We identify the economic fundamentals governing the process of structural change in a non-parameterized growth model. These fundamentals are: the income elasticities of the consumption demand; the Allen-Uzawa elasticities of substitution between consumption goods; the capital income shares in sectoral outputs; the sectoral elasticities of substitution between capital and labor; and the degree of factor-bias in the technical change. These fundamentals determine the effect of aggregate income, relative prices, rental rates and technological progress on structural change. Finally, we estimate the aforementioned fundamentals from the Rotterdam model of demand and the translog cost functions to account for the contribution of each mechanism to the U.S. structural change. These econometric models provide the necessary flexibility to estimate the fundamentals, which allows for obtaining some new findings. In particular, we find that the main mechanism explaining the evolution of the employment share in services is income growth, whereas technological progress is the main mechanism in agriculture.

*JEL classification codes:* O11, O41, O47.

*Keywords:* structural change; non-homothetic preferences; sectoral productivity.

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## 1. Introduction

The process of economic growth and development exhibits structural change as one of the most robust features. Developed countries have experimented a secular shift in their allocation of employment, output and expenditure across the sectors of agriculture, manufactures and services. Figure 1 shows evidence of this long run trend in the U.S. economy. We observe that the production valued added, employment and expenditure on consumption valued added have continuously shifted from agriculture and manufactures to services from 1947 to 2010. Figure 2 shows the dynamic path followed by the capital income shares, the total factor productivity (henceforth, TFP) indexes, the prices of the three sectoral outputs and the ratio between the rental rate of labor and the rental rate of capital in these three sectors. We easily observe that the relative price of agriculture in terms of manufactures has decreased substantially, whereas the relative price of services has instead grown up during the sample period. Furthermore, the dynamic behavior of the other three magnitudes also clearly differs across the three sectors. Especially, we must emphasize that the accumulated growth rate of TFP has been much larger in agriculture than in manufactures and services. The changes in the variables displayed in Figure 2 together with economic growth are the mechanisms that, according to the literature, drive the patterns of structural change shown in Figure 1.[1] Our aim is to identify and estimate the deep fundamentals that measure the contribution that each of these economic mechanisms has on structural change.

[Insert Figures 1 and 2]

Recently, there is a renewed and growing interest in analyzing what are the possible economic factors driving the sustained process of structural transformation observed in the data. This literature has distinguished between demand-based and supply-based mechanisms of structural change. On the one hand, structural change in a growing economy is driven by income effects due to sectoral differences in income elasticities of the consumption demand, which occur when preferences are non-homothetic. This demand mechanism has been studied by, among others, Echevarria (1997), Laitner (2000), Kongsamunt et al. (2001), Caselli and Coleman (2001) or Foellmi and Zweimüller (2008). On the other hand, the literature also finds some supply factors that cause structural change through a substitution effect. A seminal contribution within this branch of literature is in Ngai and Pissarides (2007), who formalize the original idea of Baumol (1967) to explain structural change as a consequence of a sectoral-biased process of technological change. Alternatively, Acemoglu and Guerrieri (2008) explain this substitution effect behind structural change as the consequence of then capital deepening when the sectoral production functions exhibit different capital intensities. Finally, Alvarez-Cuadrado et al. (2017) point out that differences in the capital-labor substitution across sectors are also a supply factor of structural transformation.

The literature on structural change is inconclusive on the relative importance of the aforementioned mechanisms in explaining the observed structural transformation.

[1] See, for example, Herrendorf et al. (2014) for an extensive review of the literature on structural transformation.

There are some applied studies that analyze the accuracy of some mechanisms to explain the observed structural change. In particular, Dennis and Iscan (2009) quantitatively decompose the mechanisms explaining the U.S. reallocation of labor out of the agricultural sector into a demand-side effect, an effect from sectorally biased technological change and an effect from differential sectoral capital deepening. Herrendorf et al. (2013) analyze the ability of income and substitution effects to explain U.S. structural change by estimating the preferences parameters from the expression of expenditure shares obtained when preferences are characterized by a non-homothetic CES function. Herrendorf et al. (2015) assess how the properties of technology affect the reallocation of production factors across sectors by estimating a CES production function. Moro et al. (2017) study how a model with non-homothetic preferences and home production fit the observed patterns of structural change. Finally, Swiecki (2017) goes further in studying the importance of several mechanisms. He simulates a parametrized general equilibrium model to quantify in a large set of countries the contribution to structural change of four mechanisms: sector-biased technological change, non-homothetic preferences, international trade, and intersectoral wedges between sectoral rental rates. However, the analysis in all these papers is based on particular assumptions on the functional forms of both technologies and preferences. Obviously, these assumptions may bias the measure of the contribution of the different mechanisms of structural change. Therefore, a unified framework of analysis that combines several mechanisms of structural change in a general model seems necessary to obtain correct measures of the contribution of each mechanism.

The goal of this paper is to construct the aforementioned unified framework of analysis. In particular, we first identify the fundamentals that determine the contribution of each mechanism to structural change in a closed economy by using a generic framework, i.e., a model with the minimum set of assumptions and where preferences and technologies are not parametrized. More precisely, by deriving the growth rates of the sectoral employment shares, we find that these economic fundamentals are: (i) the income elasticities of the demand for consumption goods; (ii) the Allen-Uzawa elasticities of substitution between consumption goods; (iii) the capital income shares in sectoral outputs; (iv) the elasticity of substitution between capital and labor in each sector; and (v) the degree of factor-bias in the technical change. These fundamentals determine the contribution to structural change of the growth rates of aggregate income, relative prices, rental rates and technological progress. Obviously, our general expression of the employment growth rate can be particularized to the growth rates resulting from using the different functional forms of preferences and technologies considered by the existing literature.

We also develop an accounting exercise to quantify the contribution of each mechanism to the U.S. structural change. To this end, we first estimate the aforementioned fundamentals. The novelty of our approach rests on the fact that we estimate these fundamentals out of the model, i.e., without using the derived expresion for the time evolution of sectoral employment shares. The related literature considers a particular parametrization of preferences and technologies, and then it either calibrates or directely estimates the parameter values by using the expression of structural change derived in the proposed model.[2] By the contrary, we separately estimate the fundamentals associated to preferences from a flexible demand system and the fundamentals associated to technologies from a systems of translog cost functions. Both systems provide a much more flexible framework to estimate our fundamentals, which allows to obtain some new findings.

We show that the following mechanisms have contributed to the dynamics of sectoral employment shares in the US economy: (a) the income effects caused by both the growth of income and the changes in relative prices; and (b) the demand substitution and technological substitution effects caused by the variation of prices derived from sectoral-biased technological progress, capital deepening and sectoral differences in capital-labor substitution. However, they have worked in different directions, that is, in each sector, some mechanisms had an attractive effect on employment and others contribute to driving away employment. Obviously, the observed structural change in employment is finally the result of the balance between these opposite effects. We conclude that the dynamics of employment out of agriculture are mainly driven by the technological substitution effects, whereas the push on of employment to the service sector is mainly caused by the income effects. Moreover, our estimation procedure allows for showing that the fundamentals have changed a long time. As a consequence, all of these effects have varied along time because of the time-varying nature of the fundamentals. We also show that the variation in the fundamentals explains a significative fraction of the observed structural change.

The paper offers a general framework to study structural change and to isolate the economic fundamentals that we should take into account in characterizing this process. Our analysis then contributes to introduce discipline in building multisector growth models. To consider all of the mechanisms with a significant contribution to the observed structural change, as well as to identify the fundamentals that determine this contribution, seems a necessary requirement to derive unbiased conclusions on the macroeconomic effects of structural shocks like, for instance, fiscal policy reforms. These shocks may change the sectoral composition of the economy through different mechanisms of structural change and, in addition, they may even alter substantially the contribution of these mechanisms. Therefore, it is only possible to derive the entire effect of the shocks by considering all of the mechanisms in the same unified model. Our accounting exercise offers one of the first serious intent in this direction, although some other mechanisms may be still omitted.[3]

The rest of the paper is organized as follows. Section 2 presents the theoretical framework used by the analysis. Section 3 derives the growth rates of the sectoral shares of employment at the equilibrium and characterizes the mechanisms driving structural change in this general setting. Section 4 performs an empirical analysis to disentangle the relative importance of the derived mechanisms for the structural change observed in US data. Section 5 includes some concluding remarks.

[2] See, for instance, Dennis and Iscan (2009) or Swiecki (2017) for contributions that follow a calibration procedure, and Herrendorf et al. (2013, 2015), Comin et al. (2015) or Moro et al. (2017) for contributions that estimate the growth rate of sectoral shares.

[3] For instance, we do not consider the effect of international trade in the process of structural change. Uy et al. (2013), Swiecki (2017) and Teignier (2017) show that this may be an important channel to explain the observed structural change.

## 2. Theoretical framework

We consider a continuous time, close economy composed of $m$ productive sectors. We interpret sector $m$ as the one producing manufactures that can be devoted to either consumption or investment, whereas the other $m-1$ sectors produce pure consumption goods. Firms in each sector $i$ operate under perfect competition by using the following sector-dependent production function:[4]

$$Y_i = F^i \left( s_i K, u_i L, A_i \right), \tag{2.1}$$

where $Y_i$ is the output produced in sector $i$; $s_i$ is the share of total capital, $K$, employed in sector $i$; $u_i$ is the share of total employment, $L$, in sector $i$; and $A_i$ is an index of technological knowledge in sector $i$. We assume that

$$\frac{\dot{A}_i}{A_i} = \gamma_i, \tag{2.2}$$

that is, the technological knowledge grows at the rate $\gamma_i$, which can be time-varing and different across sectors. Hence, technological progress can be either sectorally biased or unbiased.

We assume that the sectoral production functions are increasing in both capital and labor, they exhibit decreasing returns in each of these two arguments, and they are linearly homogenous in both private inputs. We can then express sectoral production in units of labor as

$$y_i = f^i \left( k_i, A_i \right), \tag{2.3}$$

where $y_i = Y_i/u_i L$ is the output per units of labor in sector $i$, and $k_i = s_i K/u_i L$ measures capital intensity in sector $i$. Given the properties of the sectoral production functions, we know that $f_k^i = \partial f_i/\partial k_i > 0$ and $f_{kk}^i = \partial^2 f_i / \left(\partial k_i\right)^2 < 0$.

Finally, the assumptions of competitive factor markets and full input utilization imply that each production factor is paid according to its marginal productivity. Hence, the following conditions hold:

$$r_i = p_i f_k^i \left( k_i, A_i \right), \tag{2.4}$$

and

$$w_i = p_i \left[ f^i \left( k_i, A_i \right) - f_k^i \left( k_i, A_i \right) k_i \right], \tag{2.5}$$

where $r_i$ and $w_i$ are the rental rates of capital and labor, respectively, in sector $i$. These rental rates can differ across sectors. This may be the case, for instance, if there exist some costs of moving production factors across sectors or intersectoral distortions and frictions (see, e.g., Caselli and Colleman, 2001; Buera and Kaboski, 2009; Sweicki, 2013; or Alonso-Carrera and Raurich, 2018). We denote by $p_i$ and $\omega_i = w_i/r_i$ the price of commodity $Y_i$ and the rental rate ratio in sector $i$, respectively. By combining (2.4) and (2.5), we conclude that the capital-labor ratio $k_i$ is an implicit function of the rental rate ratio $\omega_i$ and of the technological knowledge $A_i$. Hence, we can write $k_i = \Phi_i \left( \omega_i, A_i \right)$, with

$$\frac{\partial k_i}{\partial \omega_i} = -\frac{\left[ f_k^i \left( k_i, A_i \right) \right]^2}{f^i \left( k_i, A_i \right) f_{kk}^i \left( k_i, A_i \right)} > 0,$$

[4] For the sake of simplicity, time subindexes are not introduced.

and

$$\frac{\partial k_i}{\partial A_i} = \frac{f_k^i(k_i, A_i) f_A^i(k_i, A_i) - f^i(k_i, A_i) f_{kA}^i(k_i, A_i)}{f^i(k_i, A_i) f_{kk}^i(k_i, A_i)},$$

which follows from the properties of sectoral production functions. Note that the relation between the capital-labor ratio and the rental rate ratio is sectoral dependent because so are the production functions.

For our analysis, it will be also useful to introduce the following fundamentals of sectoral structure of production: (i) the share of capital income in output from sector $i$, that we denote by $\alpha_i$; (ii) the elasticity of substitution between capital and labor in sector $i$, that we denote by $\pi_i$; and (iii) the elasticities of output and capital-labor ratio with respect to the technical knowledge in sector $i$, that we denote by $\zeta_i$ and $\lambda_i$, respectively. By using (2.3), (2.4) and (2.5), together with the definition of the rental rate ratio $\omega_i$, we obtain, after some simple algebra, that

$$\alpha_i \equiv \frac{r_i k_i}{p_i y_i} = \frac{f_k^i(k_i, A_i) k_i}{f^i(k_i, A_i)}, \tag{2.6}$$

$$\zeta_i \equiv \left(\frac{\partial Y_i}{\partial A_i}\right)\left(\frac{A_i}{Y_i}\right) = \frac{f_A^i(k_i, A_i) A_i}{f^i(k_i, A_i)}, \tag{2.7}$$

$$\pi_i \equiv \left(\frac{\partial k_i}{\partial \omega_i}\right)\left(\frac{\omega_i}{k_i}\right) = -\frac{(1-\alpha_i) f_k^i(k_i, A_i)}{f_{kk}^i(k_i, A_i) k_i}, \tag{2.8}$$

and

$$\lambda_i \equiv \left(\frac{\partial k_i}{\partial A_i}\right)\left(\frac{A_i}{k_i}\right) = \frac{f_k^i(k_i, A_i) A_i}{f_{kk}^i(k_i, A_i) k_i}\left[\frac{f_A^i(k_i, A_i)}{f^i(k_i, A_i)} - \frac{f_{kA}^i(k_i, A_i)}{f_k^i(k_i, A_i)}\right]. \tag{2.9}$$

Observe that the elasticity $\lambda_i$ measures the capital-bias of the technological change in sector $i$, i.e., it informs about the effects of this change on the capital deepening. If the technological change is Hicks neutral then $\lambda_i = 0$, whereas $\lambda_i = 1 - \pi_i$ under Harrow neutral (i.e., labor-augmenting) and $\lambda_i = \pi_i - 1$ under Solow neutral (i.e., capital-augmenting) technical changes. Finally, note that the fundamentals $\alpha_i$ and $\pi_i$ can be different across sectors. In this case, the prices $p_i$ depend not only on the exogenous technical change, but they are also endogenously determined by capital accumulation.

This economy is populated by a unique infinitely-lived representative household composed of $N$ members. Population grows at the (possibly time-varing) rate $n$. In each period, each member is endowed with $l$ hours of time that inelastically supplies in the labor market, so that the total household's labor supply is $L = lN$.[5] This household obtains income from renting capital and labor to firms. This income is devoted to either consumption or investment. Therefore, his budget constraint is

$$\sum_{i=1}^{m}(r_i s_i K + w_i u_i L) = \dot{K} + (1-\delta) K + N \sum_{i=1}^{m} p_i c_i, \tag{2.10}$$

[5]In the present analysis we consider that labor supply is exogenous and the goods can only be adquired through markets. However, our analysis is easily extended to incorporate both endogenous labor supply and home production. Once again, our choice is motivated by the search for clarity in the presentation.

where $c_i$ is the per capita consumption demand of the commodity produced by the sector $i$, and $\delta \in [0,1]$ is the depreciation rate of capital. Each individual derives utility from the consumption of $m$ goods. We consider an utility function $v(c_1, ..., c_m)$ that is increasing in each of its arguments and quasiconcave. The household maximizes

$$V = \int_{t=0}^{\infty} e^{-\rho t} N_t v(c_{1t}, ..., c_{mt})\, dt, \tag{2.11}$$

subject to the budget constraint (2.10) and the non-negativity constraint in the choice variables, and where $\rho > 0$ is the subjective discount rate. In solving this problem, we might follow a two-step procedure. In the first step, we would solve the following intratemporal problem: given per capita expenditure in consumption $c_t$, consumers choose the sectoral composition of consumption by maximizing $v(c_{1t}, ..., c_{mt})$ subject to

$$c_t = \sum\nolimits_{i=1}^{m} p_{it} c_{it}. \tag{2.12}$$

The solution of this problem characterizes the demands of consumption goods as a function of per capita expenditure $c$ and the vector of prices $p = (p_1, ..., p_m)$. We denote by $c_i = C^i(p,c)$ the Marshallian consumption demand for good produced in sector $i$. Given these demand functions, we would face the problem of deciding the intertermporal allocation of total expenditure. More precisely, we would secondly solve the problem that consists in maximizing (2.11) subject to (2.10), (2.12) and $c_i = C^i(p,c)$.

However, for our analysis, we only need to characterize the properties of the temporal functions of consumption demand $c_i = C^i(p,c)$. The relevant properties are summarized by the price and income elasticities of those demand functions. In particular, the price elasticity of the Marshallian demand for good $i$ with respect to the price of good $j$ is given by

$$\eta_{ij} = \left[\frac{\partial C^i(p,c)}{\partial p_j}\right]\left[\frac{p_j}{C^i(p,c)}\right], \tag{2.13}$$

whereas the income elasticity of this demand is

$$\mu_i = \left[\frac{\partial C^i(p,c)}{\partial c}\right]\left[\frac{c}{C^i(p,c)}\right]. \tag{2.14}$$

Since the demand system satisfies the budget constraint (2.12), we obtain the following properties of this system, which will be relevant for the empirical analysis. First, we obtain from derivating (2.12) with respect to expenditure, and after some algebra, that

$$\sum_{i=1}^{m} \mu_i x_i = 1, \tag{2.15}$$

which is the *Engel Aggregation Condition*, and where $x_i$ is the expenditure share of the good produced in sector $i$, i.e., $x_i = p_i c_i / c$. In addition, we also obtain from derivating (2.12) with respect to price $p_j$, and after some algebra, that

$$x_j + \sum_{i=1}^{m} \eta_{ij} x_i = 0, \tag{2.16}$$

which is the *Cournot Aggregation Condition*. Finally, the demand theory states that demand functions are linearly homegeneous in prices and expenditure, so that the demand system must also satisfy the following *Homogeneity Condition*:

$$\mu_i + \sum_{j=1}^{m} \eta_{ij} = 0, \tag{2.17}$$

for all $i = 1, 2, ..., m$. The price elasticities (2.13) and the income elasticities (2.14) of the demand, together with the conditions (2.15), (2.16) and (2.17), fully characterize the optimal response of consumers to changes in the economic conditions.

## 3. Sources of structural change

In this section, we characterize the equilibrium dynamics of sectoral employment shares $u_i$. To this end, we use the clearing condition in the markets of the pure consumption goods, which is given by

$$c_i \equiv C^i(p, c) = \frac{u_i L f^i(k_i, A_i)}{N},$$

for $i \neq m$. Log-differentiating with respect to time this condition, and by noting that capital-labor ratio $k_i$ is a function of rental rate ratio $\omega_i$ and of technical efficiency $A_i$, we obtain for $i \neq m$:

$$\frac{\dot{u}_i}{u_i} = \frac{\sum_{j=1}^{m} \left(\frac{\partial c_i}{\partial p_j}\right) \dot{p}_j + \left(\frac{\partial c_i}{\partial c}\right) \dot{c}}{c_i} - \frac{\dot{l}}{l} - \frac{f_k^i(k_i, A_i) \left[ \left(\frac{\partial k_i}{\partial \omega_i}\right) \dot{\omega}_i + \left(\frac{\partial k_i}{\partial A_i}\right) \dot{A}_i \right] - f_A^i(k_i, A_i) \dot{A}_i}{f^i(k_i, A_i)}.$$

By using the definitions of $\eta_{ij}$, $\mu_i$, $\alpha_i$, $\zeta_i$, $\lambda_i$ and $\pi_i$ given respectively by (2.13), (2.14), (2.6), (2.7), (2.9) and (2.8), and after some algebra, we derive that

$$\frac{\dot{u}_i}{u_i} = \mu_i \left(\frac{\dot{c}}{c}\right) + \sum_{j=1}^{m} \eta_{ij} \left(\frac{\dot{p}_j}{p_j}\right) - \alpha_i \pi_i \left(\frac{\dot{\omega}_i}{\omega_i}\right) - (\alpha_i \lambda_i + \zeta_i) \gamma_i - \frac{\dot{l}}{l}. \tag{3.1}$$

We observe that the dynamics of sectoral employment share in a sector $i \neq m$ are driven by the following economic mechanisms: (a) the growth rate of total expenditure on consumption (or, equivalently, of income), whose contribution to structural change is given by the income elasticity of the demand of consumption good $i$; (b) the growth rate of prices of all consumption goods, where the contribution is measured by the price-elasticities of the demand of good $i$; (c) the growth rate of the rental rate ratio in sector $i$, whose effect on structural change depends on the share of capital income in the sectoral production and the elasticity of substitution between inputs in this sector; (d) the rate of technological change in sector $i$, whose effect depends on the sectoral share of capital income and the TFP-elasticities of capital-labor ratio and output in this sector; and (e) the growth rate of the participation rate $L/N$. Observe that the first four mechanisms may differ across sectors, whereas the last mechanism is sectoral invariant.

We then observe that the dynamics of the sectoral employment shares are driven by income and price effects. We now proceed to decompose the price effect into the substitution effect and the income effect. Any shock altering relative prices affects employment shares by changing the terms of trade between sectors and the purchasing power of income. One should then expect that the effect of the variation in the purchasing power would be driven by the income elasticities, whereas the elasticity of substitution between goods would drive the effects of changes in the terms of trade. By using the Slutsky equation, we know that the price-elasticities of the Marshallian demand are given by

$$\eta_{ij} = \eta_{ij}^{*} - x_j \mu_i, \tag{3.2}$$

where $\eta_{ij}^{*}$ denotes the Hicks-Allen elasticity of substitution, i.e., the price elasticity of the compensated demand of good $i$, which we denote by $h^i(p, v)$, where $v$ is the level of utility. That is,

$$\eta_{ij}^{*} = \frac{\partial h^i(p, v)}{\partial p_j} \frac{p_j}{h^i(p, v)}. \tag{3.3}$$

Equation (3.2) decomposes the effects of a change in the price of good $j$ on the demand of good $i$ into:

1. The *Hicks' substitution effect* given by $\eta_{ij}^{*}$. The variation of the demand of good $i$ when consumers are compensated to maintain the same purchasing power as before the change in the price of good $j$, $p_j$.

2. The *Hicks' income effect* given by $x_j \mu_i$. The variation in the demand of good $i$ that would be derived from the observed change in the purchasing power if the prices will not change at all.

The Hicks-Allen elasticity is then a measure of the net substitutability between consumption goods. However, this elasticity is not usually employed in the literature because it is not symmetric, i.e., $\eta_{ik}^{*}$ may differ from $\eta_{ki}^{*}$. This happens even when the cross substitution effects are symmetric, i.e.,

$$\frac{\partial h^i(p, v)}{\partial p_k} = \frac{\partial h^k(p, v)}{\partial p_i}.$$

The literature offers others elasticities of substitution that are symmetric. In particular, a more useful measure of the substitution effect is the Allen-Uzawa elasticity of substitution that is given by

$$\sigma_{ij} = \frac{E(p, v) E_{ij}(p, v)}{E_i(p, v) E_j(p, v)}, \tag{3.4}$$

where $E(p, v)$ is the expenditure function given by

$$E(p, v) = \min_{c_i \in \Omega} \sum_{i=1}^{m} p_i c_i,$$

with

$$\Omega = \left\{ (c_1, ..., c_m) \in \mathbb{R}_{+}^{m} : v(c_1, ..., c_m) \geq v \right\},$$

and where $E_i(p,v)$ is the derivative of $E(p,v)$ with respect to $p_i$ and $E_{ij}(p,v)$ is the derivative of $E_i(p,v)$ with respect to $p_j$. One interesting property of this Allen-Uzawa elasticity is its relation with the Hicks-Allen elasticity, which is given by

$$\sigma_{ij} = \frac{\eta^*_{ij}}{x_j}. \tag{3.5}$$

Therefore, by substituting (3.5) into (3.2), we can rewrite the price elasticity of the Marshallian demand $\eta_{ij}$ as follows

$$\eta_{ij} = x_j\left(\sigma_{ij} - \mu_i\right). \tag{3.6}$$

At this point, given the previous discussion, we can rewrite the growth rate of the sectoral employment share $u_i$ given by (3.1) as follows:

$$\frac{\dot{u}_i}{u_i} = \mu_i\left[\frac{\dot{c}}{c} - \sum_{j=1}^{m} x_j\left(\frac{\dot{p}_j}{p_j}\right)\right] + \sum_{j=1}^{m}\sigma_{ij}x_j\left(\frac{\dot{p}_j}{p_j}\right) - \alpha_i\pi_i\left(\frac{\dot{\omega}_i}{\omega_i}\right) - \left(\alpha_i\lambda_i + \zeta_i\right)\gamma_i - \frac{\dot{l}}{l}. \tag{3.7}$$

By using this growth rate, we can also directly obtain the change in the composition of employment between two sectors $i$ and $j$ as

$$\begin{aligned}\Delta_{ij} &\equiv \frac{\dot{u}_i}{u_i} - \frac{\dot{u}_j}{u_j} \\ &= \left\{\begin{array}{l}\left(\mu_i - \mu_j\right)\left[\frac{\dot{c}}{c} - \sum_{l=1}^{m} x_l\left(\frac{\dot{p}_l}{p_l}\right)\right] + \sum_{l=1}^{m}\left(\sigma_{il} - \sigma_{jl}\right)x_l\left(\frac{\dot{p}_l}{p_l}\right) \\ -\left[\alpha_i\pi_i\left(\frac{\dot{\omega}_i}{\omega_i}\right) - \alpha_j\pi_j\left(\frac{\dot{\omega}_j}{\omega_j}\right)\right] - \left[\left(\alpha_i\lambda_i + \zeta_i\right)\gamma_i - \left(\alpha_j\lambda_j + \zeta_j\right)\gamma_j\right]\end{array}\right\}\end{aligned} \tag{3.8}$$

From (3.7) and (3.8), we can distinguish the following four mechanisms that are driving structural change in the sectoral composition of employment:

1. *Real Income Effect*. It measures the variation in the sectoral composition of employment derived from the dynamics of real income or, equivalently, real expenditure. It is given by the following term of (3.7):

   $$E_i^{RI} = \mu_i\left[\frac{\dot{c}}{c} - \sum_{j=1}^{m} x_j\left(\frac{\dot{p}_j}{p_j}\right)\right]. \tag{3.9}$$

   This income effect decomposes into a *direct income effect* from changes in the nominal income or expenditure (i.e., the *Marshallian's income effect*), and an *indirect income effect* that derives from changes in the purcharshig power of income as a consequence of the variation in relative prices (i.e., the *Hicks' income effect*). Regarding this, observe that the second term in (3.9) is the response of the Stone's price index, $\ln P^* = \sum_{j=1}^{m} x_j \ln p_j$, to the time variation in sectoral prices $p_j$ when one maintains the consumption shares $x_j$ constant. Note that the magnitude of the total income effect clearly depends on the income elasticity of the demand of good $i$. Hence, as shown in (3.8), this partial effect will generate differences in the dynamic of employment among sectors if and only if the income-elasticities of demand differ across sectors. Therefore, this effect requires preferences to be non-homothetic to generate the necessary gaps between the sectoral income elasticities across sectors.

2. *Demand Substitution Effect.* It measures the variation in the sectoral composition of employment derived from variations in the terms of trade of sectors. This effect is given by the following term of (3.7):

$$E_i^{DS} = \sum_{j=1}^{m} \sigma_{ij} x_j \left( \frac{\dot{p}_j}{p_j} \right). \tag{3.10}$$

The contribution of this effect to the change in the employment share of sector $i$ depends on: (a) the Allen-Uzawa elasticities of demand of good $i$ with respect to the vector of sectoral prices; and (b) the weight that the expenditure on the good whose price is being considered has on the total expenditure on consumption. As follows from (3.8), this partial effect will generate changes in the sectoral composition of employment between two sectors $i$ and $j$ if and only if they exhibit different Allen-Uzawa elasticities of substitution with the other goods, i.e., $\sigma_{il} \neq \sigma_{jl}$ for $l \neq \{i, j\}$.

3. *Technological Substitution Effect.* It measures the variation in the sectoral composition of employment due to changes in the sectoral capital intensities, $k_i$, which derives from the change in the sectoral rental rate ratios. This effect is given by the following term of (3.7):

$$E_i^{TS} = \alpha_i \pi_i \left( \frac{\dot{\omega}_i}{\omega_i} \right). \tag{3.11}$$

The magnitude of this third effect depends on both the share of capital income in output and on the elasticity of substitution between capital and labor in sector $i$. Therefore, the change in the sectoral composition of employment across sectors driven by this partial effect will derive from the weighted differences between the variation in the rental rate ratios across sectors.

4. *Technological Change Effect.* It measures the contribution to structural change of the technological progress that modifies the total factor productivities of sectors. This effect is given by the following term of (3.7):

$$E_i^{TC} = (\alpha_i \lambda_i + \zeta_i) \gamma_i, \tag{3.12}$$

which represents the growth rate of the multi-factor productivity level in sector $i$. Observe that the magnitude of this partial effect also depends on both the share of capital income in output, as well as, the TFP-elasticities of capital-labor ratio and output in sector $i$. We distinguish two components operating in this effect. On the one hand, we have the neutral component of the technological change, which is given by $\zeta_i$ and determines the level effect on the technical efficiency. On the other hand, we also obtain a technical change-driven capital deepening, which is given by $\alpha_i \lambda_i$ and determines the effect on the capital-labor ratio. In any case, the change in the sectoral composition derived from the total technological change effect is determined by the weighted differences among the sectoral technological change. More precisely, this partial effect alters sectoral composition between sectors $i$ and $j$ if and only if $(\alpha_i \lambda_i + \zeta_i)\gamma_i \neq (\alpha_j \lambda_j + \zeta_j)\gamma_j$. Therefore, this technological effect does not require technological change to be sectorally biased. It also arises if $\gamma_i = \gamma_j$ provided that $\alpha_i \lambda_i + \zeta_i \neq \alpha_j \lambda_j + \zeta_j$. It is important to outline that this conclusion is in contrast to those analyses in the literature that consider a more particular set up.

Summarizing, structural change might be driven by several alternative mechanisms. As was suggested by Buera and Kabosky (2009), neither the direct income effect nor the substitution effects are able to offer by themselves alone a good explanation of the observed structural change. Hence, we should consider all of them together as potential explanations of the observed structural change. This requires quantifying their relative contributions to the observed structural change in the data. We will deal with this empirical analysis in the next section.

Finally, we study the relation btween our contribution and the literature in the appendix. We analyze how our condition (3.7) for structural change particularizes when one consider the functional forms of preferences and technologies consided in the literature. In particular, we consider the structural change based on: (a) the non-homothetic preferences introduced by Kongsamunt et al. (2001); (b) the biased technical progress considered by Ngai and Pissarides (2007); (c) the capital deepening proposed by Acemoglu and Guerrieri (2008); (d) the sectoral differences in capital-labor substitution considered by Alvarez-Cuadrado et al. (2017); and (e) the long-run income and price effects introduced by Comin et al. (2015).

## 4. Empirical analysis

We now quantify the contribution of the four mechanisms to the structural change of the US economy over the period 1947-2010. This first requires to estimate the income elasticities $\mu_i$, the Allen-Uzawa elasticities $\sigma_{ij}$, the sectoral elasticities of substitution between capital and labor $\pi_i$, and the sectoral elasticities of output and capital-labor ratio with respect to technical change given by $\zeta_i$ and $\lambda_i$, respectively. To this end, we might directly estimate the system of equations given by (3.7) for all $i \neq m$. This is the procedure usually followed by the related literature to calibrate and estimate parametrized models that incorporate particular mechanisms of structural change (see, e.g., Dennis and Iscan, 2009; Herrendorf et al., 2013; Comin et al., 2015; or Moro et al., 2017). This procedure is useful to discipline the model to replicate, at least partially, the observed patterns of structural change. However, it does not permit to identify the actual sources of structural change and, therefore, to predict the effects of structural shocks in the sectoral composition. More precisely, this identification procedure has some serious problems. Firstly, it imposes that the elasticities participating in these conditions are time-invariant, so that we could not in this way cover possible changes in these elasticities. Secondly, we might obtain biased estimation of the elasticities because: (a) we may be omitting some other mechanisms like, for instance, trade and home production; and (b) the explanatory variables may be highly correlated (for instance, TFPs may be driving some of the variation in relative prices and rental rates). Finally, we could not estimate the elasticities in the manufacturing sector because we cannot characterize the path of employment in this sector without imposing more structure to the model. Hence, we would not derive the true elasticities with this direct procedure.

To overcome these limitations, we derive these elasticities from the separated estimation of a system of demand functions and a system of production cost functions by using flexible functional forms. Therefore, in contrast with usual procedure in the related literature, the sectoral shares of employment are not the dependent variables of our estimation but the expenditure shares and the cost shares. This procedure introduces a large degree of freedom in the estimation of the searched elasticities, so that we are not forcing them to take those values that better help to replicate the observed behavior of the employment shares. After deriving the estimated elasticities, then yes we use the condition (3.7) to measure the accuracy of forecast derived from those estimations, as well as to perform an accounting exercise to obtain the relative contribution of each of the channels driving structural change.

For the analysis we consider three aggregate sectors: agriculture, manufactures and services. We employ the data on consumption in valued added expenditure and on relative prices from Herrendorf et al. (2013), whereas the data on labor and capital compensation, rental rate ratio, employment (people and hours) and sectoral TFPs directly come from US-KLEMS data 2013 release. We must make a methodological clarification before continuing with this empirical analysis. The KLEMS project computes the growth rates of the sectoral TFPs as residuals of the sectoral production functions by assuming Hicks neutral technical progress. Therefore, these growth rates exactly correspond to our Technological Change Effect given by (3.12). This allows the accounting exercise of the relative contribution of each mechanism driving the structural change, although we cannot obtain an estimation of the elasticities $\zeta_i$ and $\lambda_i$.

### 4.1. Estimation of demand elasticities

To obtain the elasticities of demand (i.e., income elasticities $\mu_i$ and Allen-Uzawa elasticities $\sigma_{ij}$), we estimate the *Rotterdam Model of Consumption Demand* proposed by Barten (1964) and Theil (1965), which uses consumer theory to express the growth rate of consumption as a function of the growth rates of real income and relative prices. As is pointed out by Barnett (1981), this model is highly flexible at the aggregate level under weak assumptions. Since we use aggregate data, this model is particularly well suited to the purposes of this section.[6] This model represents the system of demand as

[6]See, for instance, Barnett (1981) for a exhaustive survey of the use of this model for testing the theory of the utility-maximising consumer by clarifying its economic foundations, and highlighting its strengths and weaknesses. More generally, Deaton and Muellbauer (1980) and Deaton (1983) provide two surveys of the literature on the analysis of commodity demands.

follows:

$$x_{it}\log\left(\frac{c_{it}}{c_{it-1}}\right)=\psi_i\left[\log\left(\frac{c_t}{c_{t-1}}\right)-\sum_{j=1}^{m}x_{jt}\log\left(\frac{p_{jt}}{p_{jt-1}}\right)\right]+\sum_{j=1}^{m}\phi_{ij}\log\left(\frac{p_{jt}}{p_{jt-1}}\right),\quad (4.1)$$

for all $i$, and with the following constraints: (i) *Engel aggregation constraint*: $\sum_{j=1}^{m}\psi_j=1$, with $\psi_j\geq 0$; (ii) *Homogeneity constraint*: $\sum_{j=1}^{m}\phi_{ij}=0$; (iii) *Symmetry constraint*: $\phi_{ij}=\phi_{ji}$; and (iv) *Slutsky coefficient matrix* $\Phi=\left[\phi_{ij}\right]$ is negative semidefinite and of rank $m-1$.

Given these constraints, one of the equations characterizing the Rotterdam model is redundant and, therefore, we should exclude it for the estimation.[7] Since in our analysis we use three sectors (agriculture, manufactures and services), we eliminate the equation for the manufacturing sector. Furthermore, and after imposing the homogeneity constraint, we also obtain that the growth rates of consumption in agriculture and services depend on the growth rate of the relative prices of those goods in terms of manufactures, $p_{at}/p_{mt}$ and $p_{st}/p_{mt}$. In this way, we derive the econometric specification that we use to estimate income and Allen-Uzawa elasticities. Finally, we follow Brown and Lee (1992), who incorporate the effect of past consumption to account for the possible existence of intertemporally-dependent preferences behind the observe demand because of, for instance, habit formation in consumption. With all of these features in hand, we obtain

$$z_{it}|_{i=a,s}=\left\{\begin{array}{l}\widehat{\psi}_i\left[\log\left(\frac{c_t}{c_{t-1}}\right)-\sum\limits_{j=a,s,m}x_{jt}^{*}\log\left(\frac{p_{jt}}{p_{jt-1}}\right)-\sum\limits_{j=a,s,m}\widehat{\varphi}_j z_{jt-1}\right]\\+\sum\limits_{j=a,s}\widehat{\phi}_{ij}\left[\log\left(\frac{p_{jt}}{p_{jt-1}}\right)-\log\left(\frac{p_{mt}}{p_{mt-1}}\right)\right]+\widehat{\varphi}_i z_{it-1}+\chi_i+\varepsilon_{it}\end{array}\right\},\quad (4.2)$$

where $\chi_i$ is a constant, $z_{it}=x_{it}^{*}\log\left(c_{it}/c_{it-1}\right)$, $x_{it}^{*}=\left(x_{it-1}+x_{it}\right)/2$ is the average value of the share of good $i$ in full expenditure during the time increment being considered, and $\varepsilon_{it}$ is the error term that we assume homoscedastic and uncorrelated over time. Furthermore, we also assume that this disturbance is normally distributed as $N\left(0,\Omega\right)$, where $\Omega$ is the unknown contemporaneous covariance matrix.

We estimate (4.2) for the demand on agricultural and services goods by using the method of Seemingly Unrelated Regression Estimation since the disturbance vector $\varepsilon$ can be correlated across sectors. We further impose the symmetry constraint $\phi_{ij}=\phi_{ji}$. Note that we can skip the Engel aggregation constraint because we have omitted the equation for manufactures. On the contrary, the restrictions on the Slutsky coefficient matrix $\Phi$ have to be tested after the estimation.

The estimation of (4.2) without any other constraint yields the following Slutsky coefficients: $\widehat{\phi}_{aa}=-0.006960$, $\widehat{\phi}_{as}=0.001778$, $\widehat{\phi}_{am}=0.005182$, $\widehat{\phi}_{ss}=0.023527$, $\widehat{\phi}_{sm}=-0.025305$ and $\widehat{\phi}_{mm}=0.020123$. We then derive that this first estimation satisfies the rank conditon but not the negativity condition of the Slutsky coefficient matrix. Given this rejection of negativity, we have decided to follow Brenton (1994),

[7] Barten (1969) proves that one equation of the demand system is redundant, and the maximum likelihood estimaties of the parameters are invariant to the equation deleted.

among others, and impose an extra restrictive condition on the price parameters $\phi_{ij}$ to achieve the negativity over the sample data.[8] More specifically, we restrict the Slutsky coefficient matrix to satisfy

$$\Phi = (dI)^{-1} d' d - D, \tag{4.3}$$

where $d = (d_a, d_m, d_s)$ is a vector of unknown parameters, $I$ is the 3x1 unit vector and $D$ is a 3x3 diagonal matrix of the elements in vector $d$. Therefore, the Slutsky coefficients are constrained to be

$$\phi_{ij} = \frac{d_i d_j}{\sum\limits_{k=a,m,s} d_k},$$

and

$$\phi_{ii} = \frac{(d_i)^2}{\sum\limits_{k=a,m,s} d_k} - d_i,$$

for $i, j = \{a, m, s\}$. By definition these restricted price coefficient $\phi_{ij}$ satisfy the symmetric and the homogeneity constraints.

We then estimate coefficients $d_i$ instead of the $\phi_{ij}$ coefficients. However, the homogeneity condition implies that not all the elements in $d$ are identified. We then require an additional normalization to identify the parameters in the proposed constrained Rotterdam model, without losing its original flexibility feature. Here, we use:

$$\sum_{k=a,m,s} d_k = 1.$$

Table 1 displays the results of the estimation of the model (4.2) subject to the constraint (4.3) with the previous normalization. By using the Engel aggregation constraint we derive $\widehat{\psi}_a$, whereas we obtain the Slutsky coefficient $\widehat{\phi}_{ij}$ from the negativity condition (4.3). The regression provides a quite good fit. All the marginal budget shares $\widehat{\psi}_i$ exhibit the expected positive sign, which means that the consumption goods are normal goods. Furthermore, all the coefficients are estimated with considerable precision except $\widehat{\psi}_a$ and $\widehat{d}_s$. Finally, we have checked that the Slutsky matrix $\Phi = \left[\widehat{\phi}_{ij}\right]$ is negative semidefine and of rank 2.

[Insert Table 1]

We now deduce the elasticity aggregates from our estimated coefficients. To this end, we use the properties of the Rotterdam model which implies that the estimated income and Allen-Uzawa elasticities are given by $\widehat{\mu}_i = \widehat{\psi}_i / x_i$ and $\widehat{\sigma}_{ij} = \widehat{\phi}_{ij} / (x_i x_j)$, respectively. Obviously, these elasticities are time-varying. Figure 3 shows the time-path of these estimated elasticities and Table 2 displays their cross-time average values. Several properties should be pointed out. Firstly, with respect to income elasticities, we obtain that the three consumption goods are normal goods, although the estimation

[8] This procedure is based on De Boer et al. (1987), who introduces this formulation to constraint the error variance matrix in the estimation of demand systems. Holt and Goodwin (2009) contains a survey of the literature dealing with the negativity conditions on Slutsky matrix for flexible forms of demand systems.

of the income elasticity of agricultural goods exhibits a large variability, such that its confidence interval contains negative values. We observe that the demands of agriculture and services exhibit income elasticities smaller than unity, whereas the demand of manufactures has an income elasticity larger than unity. The literature explaining structural change by means of only non-homothetic preferences usually imposes $\mu_a < \mu_m = 1 < \mu_s$ for the calibration of the proposed models (see, e.g., Kongsamunt et al., 2001). The first inequality is corroborated by our estimations, whereas we obtain instead that $\widehat{\mu}_a < \widehat{\mu}_s < 1$ and $\widehat{\mu}_m > \widehat{\mu}_s$. We can explain the latter result by the fact that manufacturing sector produces durable goods and the service sector produces many basic goods for the consumption basket. Finally, Figure 3 shows that $\widehat{\mu}_a$ are very close to $\widehat{\mu}_s$ at the end of the period, which may be a consequence of the change in the relative aspirations or in the intensity of the minimum consumption requirements experimented by consumers along the development process.

[Insert Figure 3 and Table 2]

With respect to Allen-Uzawa elasticities, we first observe that $\widehat{\sigma}_{as} \neq \widehat{\sigma}_{am} \neq \widehat{\sigma}_{ms}$, and that three consumption goods are Hicks substitutes as $\widehat{\sigma}_{am} > 0$, $\widehat{\sigma}_{as} > 0$ and $\widehat{\sigma}_{ms} > 0$. However, the confidence interval of $\widehat{d_s}$ in the negative constraint (4.3) suggests a large variability of these estimated elasticities, so that we cannot reject these elasticities to be negative. Hence, we cannot reject that the three consumption goods are Hicks complementaries or independent. In any case, we should remark an important difference with respect to the related literature. While those studies analyzing the prices effects on structural change consider functional forms that lead to constant Allen-Uzawa elasticities, our estimations suggest that those elasticities have largely varied along time in the US economy. For instance, Ngai and Pissarides (2007) consider a CES aggregation for the consumption goods, so that all of the Allen-Uzawa elasticities are equal to the elasticity of substitution between goods in this aggregator. Furthermore, since these authors only consider the mechanism based on the biased technological change, this elasticity has to be smaller than one to guarantee that their model replicates the observed structural change. This assumption is also far to be supported by our estimations. Similarly, Comin et al. (2015) considers an indirect utility function that ensures the independence between the income and the price effects, but at the cost of having constant income and Allen-Uzawa elasticities.[9],[10]

### 4.2. Estimation of technological elasticities

We directly compute the capital income shares $\alpha_i$ from information provided by the KLEMS dataset. In addition, we consider that the cost functions are translog-functions and, thus, we derive the associate system of sectoral cost shares.[11] This procedure provides the flexible framework neeed to the estimation of the elasticities $\pi_i$. Denote by $T_i(Y_i, r, w)$ the total cost of production in sector $i$. Because of constant returns to scale, it can be shown that $T_i = Y_i \tau_i(r, w)$, where $\tau_i$ denotes the average cost function. By

[9] These final conclusions can be followed from the appendix.

[10] Herrendorf et al. (2013) does not directly estimate the elasticites of demand, but the parameters of a non-homothetic CES utility function.

[11] See, for example, Jorgenson (1983) and Diewert (1974) for two useful surveys of the topic.

expanding $\ln \tau_i(r, w)$ in a second-order Taylor series about the point $\ln r = \ln w = 0$, by identifying the derivatives of the average cost function as coefficients, and by imposing the symmetry of the cross-price derivatives, we obtain:

$$\ln \tau_i = \beta_0^i + \beta_k^i \ln r_i + \beta_l^i \ln w_i + 0.5 \left[ \delta_{kk}^i (\ln r_i)^2 + \delta_{ll}^i (\ln w_i)^2 \right] + \delta_{kl}^i \ln r_i \ln w_i.$$

This is the translog cost function. By taking derivatives with respect to $\ln r_i$ and $\ln w_i$, we obtain that the cost shares of capital and labor in a sector $i$ are respectively given by:

$$\alpha_i = \beta_k^i + \delta_{kk}^i \ln(r_i) + \delta_{kl}^i \ln(w_i),$$

and

$$1 - \alpha_i = \beta_l^i + \delta_{lk}^i \delta \ln(r_i) + \delta_{ll}^i \ln(w_i),$$

with the following conditions: $\beta_k^i + \beta_l^i = 1$, $\delta_{kl}^i = \delta_{lk}^i$, and $\delta_{kk}^i + \delta_{kl}^i = \delta_{lk}^i + \delta_{ll}^i = 0$. By imposing these constraints, and taking the labor income shares $1 - \alpha_i$ directly from data, we then estimate the following system of equations:

$$\alpha_{it} = \beta_k^i - \delta_{kk}^i \ln(\omega_{it}) + \varepsilon_{it} \tag{4.4}$$

for all $i = \{a, s, m\}$, and where $\varepsilon_{it}$ is the error term that we assume homoscedastic and uncorrelated over time. Furthermore, we also assume that this disturbance is normally distributed as $N(0, \Omega)$, where $\Omega$ is the unknown contemporaneous covariance matrix. Since the disturbance vector $\varepsilon$ can be correlated across sectors, we estimate the system composed of the three equations in (4.4) by using the method of Seemingly Unrelated Regression Estimation. Table 3 provides the estimates of the full set of parameters in (4.4). All the parameters are estimated with a large precision.

[Insert Table 3]

We now deduce sectoral elasticities of substitution between capital and labor $\pi_i$ from our estimated coefficients. Note that those are the elasticities of the marginal costs with respect to rental rates. Hence, we obtain:

$$\widehat{\pi}_{it} = 1 - \frac{\widehat{\delta}_{kk}^i}{\alpha_{it}(1 - \alpha_{it})}.$$

Observe that these elasticities are time-varying. Figure 4 shows the time-path of these estimated elasticities and Table 2 displays their average values. We can reject that $\widehat{\pi}_i = 1$, i.e., Cobb-Douglas technologies at the sectoral level. Herrendorf et al. (2015) has estimated CES production functions at sectoral level for US. They show that the elasticities are different from one, with the elasticity being lower than one for both services and manufactures and larger than one for agriculture. We also obtain that capital and employment are complements in services and substitutes in agriculture. However, our estimates indicate that these production factors are also substitutes in manufactures. These are robust findings as these elasticities remains almost constant along the entire period.

[Insert Figure 4]

### 4.3. Accounting of mechanisms

The purpose of this subsection is to measure the importance of each mechanism. To this end, we first compute the estimated sectoral employment shares and, furthermore, we measure how these estimates fit actual shares in the data. In addition, we build the counterfactual values of the sectoral employment shares that would arise if we turn off one of the mechanisms of structural change in (3.7). We then compute the change in the fit derived from this counterfactual experiment. More precisely, using the estimations in the previous subsections, we build the following counterfactual employment shares for agricultural and services sectors:

$$\widehat{u}_{it} = e^{\widehat{G}_{it}} \widehat{u}_{it-1},$$

for $i = \{a, s\}$ and with

$$\widehat{u}_{i1} = e^{\widehat{G}_{i1}} u_{i0},$$

where $u_{i0}$ is the actual value of the US employment share in sector $i$ in 1947, and $\widehat{G}_{it}$ is the estimated growth factor in (3.7) that is defined as the sum of the following mechanisms of structural change: the growth rate from the Real Income Effect,

$$\widehat{G}_{it}^{RI} = \widehat{\mu}_i \left[ \dot{c}/c - \sum_{j=a,m,s} x_j \left( \dot{p}_j / p_j \right) \right];$$

the growth rate from the Demand Substitution Effect,

$$\widehat{G}_{it}^{DS} = \sum_{j=a,m,s} \widehat{\sigma}_{ij} x_j \left( \dot{p}_j / p_j \right);$$

the growth rate from the Technological Substitution Effect, $\widehat{G}_{it}^{TS} = -\alpha_i \widehat{\pi}_i \left( \dot{\omega}_i / \omega_i \right)$; and the growth rate from the Technological Change Effect, $\widehat{G}_{it}^{TC} = \left( \alpha_i \lambda_i + \zeta_i \right) \gamma_i$. Remember that US-Klems data 2013 provides directly the entire value of this effect $G_{it}^{TC}$, so that we do not need to estimate the elasticities $\lambda_i$ and $\zeta_i$. Finally, the counterfactural employment shares of manufactures are directly obtained by using the market clearing condition in the labor marked $\widehat{u}_{mt} = 1 - \widehat{u}_{at} - \widehat{u}_{st}$.

Figure 5 compares the path of the counterfactual employment shares $\{\widehat{u}_{it}\}_{t=1948}^{2005}$ with the one followed by actual shares $\{u_{it}\}_{t=1948}^{2005}$. We first observe that the fit of the counterfactual shares to the actual shares are not perfect. This is a consequence of two facts: (a) the luck of precision in the estimation of the elasticities; and, more importantly, (b) the omission of other possible mechanisms of structural change like, for instance, resource allocation to home production and leisure or international trade.

[Insert Figure 5]

However, the goodness of fit is still very large as is confirmed by the Pearson's correlation coefficient ($R$), the root mean-square error ($RMSE$) and the Theil U statistic ($U$) of the regression of the actual employment shares with respect to the counterfactual shares provided by Table 4. This table analyzes the performance of the simulation containing all mechanisms as well as the counterfactual simulations where one of the mechanism is turned off. Hence, their results provides an accounting exercise of the contribution of the different mechanisms for the entire sample period. We make this exercise for each sector. Our simulations show that the technological change and the technological substitution effects are the main mechanisms in explaining the evolution of the employment share in agriculture. Observe that the $RMSE$ , for instance, largely increases when one of these mechanisms are turned off. By the contrary, the real income effect and the technological substitution effect are basically the main mechanisms for the evolution of the employment share in services, although the technological substitution effect has some incidence. Hence, all mechanisms play a significant role in explaining the structural change observed throughout the sample period.[12] All of these mechanisms are then possible sources for the transmission of structural shocks like, for instance, fiscal policy to the aggregate economy.

[Insert Table 4]

The results in Table 4 illustrate that the mechanisms operate in opposite direction, so that the structural change results from the counterbalance among these mechanisms. The sign of Pearson's correlation coefficient $R$ informs about the direction of the force that each mechanism exerts on the sectoral employment shares. Thus, if a negative coefficient results from eliminating one mechanism, this implies that the employment share would exhibit the opposite trend without the participation of this mechanism. In other words, we could conclude that this mechanism dominates in driving the employment behavior in that sector.

To show the specific contribution of each mechanism, we next simulate the predicted path of the ratio between the shares of employments in agriculture and in services: $u_a/u_s$. Table 5 shows the performance of the simulations of the ratio $u_a/u_s$. We observe that the largest contribution to the evolution of this ratio comes from the Technological Substitution Effect and the Demand Substitution Effect. Table 6 shows the contribution of each mechanism to the growth rate of the actual ratio $u_a/u_s$ for the entire sample period and for some subperiods. We observe that the four mechanism explain together almost 72% of the growth rate of the ratio $u_a/u_s$ in the entire period 1947-2010. The unexplained 28% of the growth is due to the omission of mechanisms and the errors in the estimation of the demand and technological mechanisms. Except for the Demand Substitution Effect, the other mechanism has a positive contribution to the observe decrease in this ratio. We also conclude that the Technological Change Effect has the larger contribution (57%), followed by the Real Income effect (23%), Demand Substitution Effect ($-14\%$) and, finally, the Technological Substitution Effect (6%). This ranking and the contribution of the mechanism largely change along the sample period. In particular, we should remark the large variability in the length and the sign of the contribution from the Technological Substitution Effect.

[Insert Tables 5 and 6]

[12] Buera and Kabosky (2009) asserts that several mechanisms should be considered together to account for the entire set of facts on structural change.

One advantage of our analysis is that we can decompose the observed patterns of structural change in two elements: (a) the contribution of the primary variation in prices, income and sectoral TFPs; and (b) the contribution of the changes in preferences and technologies, which are covered by the variation in demand and technological elasticities (i.e., $\mu_i$, $\sigma_{ij}$, $\alpha_i$ and $\pi_i$). In order to measure the relative contribution of these two set of elements, we now repeat the previous analysis by taking the value of these elasticities at their respective cross-time average values (see Table 2). In this way, we approximate the contribution of the variation in prices, income and sectoral TFPs to the observed structural change in the entire sample period. Of course, the contribution of the variation in the elasticities can be derived as a residual. Figure 6 and Table 7 provide the fit of these new counterfactual simulations. The results on the relative contribution of the four derived mechanisms (i.e., real income, demand substitution, technological substitution and technological change effects) still maintain when we consider time invariant elasticities. Furthermore, and more remarkly, the performance of our simulations worsens when the elasticities are taken constant. This is specially clear in the case of agriculture, whereas the performance is only slightly worse in manufactures and services. Therefore, assuming functional forms for preferences and technologies that imply constant elasticities limits the ability of the models to explain the structural change.

[Insert Figure 6 and Table 7]

We conclude that the four mechanisms of structural change characterized in this paper have contributed substantially to the observed structural change in US from 1947 to 2005. As was shown, they may drive structural change in opposite directions. However, the observed structural change is the final result from the balance between these forces. Hence, any multisector growth model built to analyze the effects of structural shocks like, for instance, fiscal policy should consider all those mechanisms. Otherwise, one can derive biased results of those effects.

## 5. Concluding Remarks

We have developed a theoretical and empirical analysis to identify all possible mechanisms driving the observed structural change and to disentangle the deep fundamentals of these factors. We have found that the following mechanisms have had a large effect on the dynamics of sectoral employment shares: (i) the income effects from the growth of income and from changes in relative prices; and (ii) the demand substitution and technological substitution effects caused by the variation of prices derived from sectoral-biased technological progress, capital deepening and sectoral differences in capital-labor substitution. The income effect from the growth of income and the technological effects have reallocated labor from agriculture to manufactures and services, whereas the demand substitution effect and the income effect, both derived from the variation in relative prices, have considerably restrained the previous movement of labor. Furthermore, we have shown that the economic fundamentals that are behind of structural change are: (i) the income elasticities of the demand for consumption goods; (ii) the Allen-Uzawa elasticities of substitution between consumption goods; (iii) the capital income shares in sectoral outputs; and (iv) the elasticity of substitution between capital and labor in each sector. These economic indicators determine the relative importance of the growth rates of aggregate income, relative prices, rental rates and technological progress for the structural change.

The research in this paper could be improved and extended in some directions. In the theoretical part, we could include international trade, home production and leisure. On the one hand, we conjecture that an important fundamental driving the effect of international trade would be the elasticities of demand for imported goods and the Allen-Uzawa elasticities of substitution between domestic and foreign consumption goods. In this sense, the analysis should not be very different to that developed in this paper after having incorporated foreign consumption goods to the composite good from which individuals derive utility. On the other hand, in the case of leisure and home production, one would expect that the complementarity between goods and services would be crucial for the structural change as was pointed out by Cruz and Raurich (2018).

The empirical part of our analysis might be modified in the following points. First, we might also estimate the demand elasticities by using a more flexible functional form for the indirect utility function. In other words, we might confront whether or not the estimation of a translog indirect utility function is more precise than the estimation of the Rotterdam model considered in the paper. Second, we might try to improve the estimation procedure by considering other methods and by extending the length of the period. Finally, we might perform a cross-country analysis conditioned on the availability of data.

In addition to the previous extensions, we might also postulate a dynamic general equilibrium model that includes all the mechanisms of structural change. We should calibrate this model by using our estimations of the fundamentals behind these mechanisms. This would first allow us to study numerically how is the fit of the observed structural change. We then can use this model to develop experiments to assess the effects of fiscal policy and public regulations on sectoral and aggregate variables.

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# Appendix

## A. Revisiting the related literature

We apply our general analysis in the paper to those models of structural change commonly used by the literature on economic growth and development. All of these proposals assume particular functional forms for preferences and technologies. In this section, we compute the income elasticities, the Allen-Uzawa elasticities, the sectoral capital income shares, the elasticities of substitution between production factors and the TFP-elasticities of capital-labor ratio and output for these particular functional forms. We will focus on the following proposals: (a) Structural change based on non-homothetic preferences introduced by Kongsamunt et al. (2001); (b) Structural change based on biased technical progress considered by Ngai and Pissarides (2007); (c) Structural change based on capital deepening proposed by Acemoglu and Guerrieri (2008); (d) Sectoral differences in capital-labor substitution considered by Alvarez-Cuadrado et al. (2017); and (e) Long-run income and price effects of structural change introduced by Comin et al. (2015). We next analyze each of these proposals.

### A.1. Structural change based on non-homothetic preferences

One existing thesis to explain the observed structural change is based on the sectoral differences in the response of the demand to the growth of income.[13] Let us illustrate the mechanics of this proposal. As in Kongsamunt et al. (2001), we consider a model where production functions are identical in all sectors, i.e., $Y_i = F\left(s_i K, u_i L, A_i\right)$. Consider also that there is free mobility of capital and labor across sectors, so that rental rates are the same in all the sectors, i.e., $r_i = r$, $w_i = w$ and, thus, $\omega_i = \omega$. We also assume unbiased technological change, so that $\gamma_i = \gamma$ for all sector $i$. Since $r_i = r$ for all $i$, we can derive from (2.4) that the relative prices are $p_i/p_m = \left(A_m/A_i\right)^{\zeta}$. Hence, the relative prices are time invariant under these technologies, so that $\dot{p}_i/p_i - \dot{p}_m/p_m = 0$ for all $i$. All of these supply-side properties imply that the following partial effects in (3.8) are not operative in this model: (a) the demand substitution effect $E_i^{DS}$, because the relative prices $p_i/p_m$ are constant and the Homogeneity Contition (2.17) implies that $\sum_{j=1}^{m} \sigma_{ij} x_j = 0$; and (b) the technological substitution effect $E_i^{TS}$ because $k_i = k$, $\alpha_i = \alpha$ and $\pi_i = \pi$ for all sector $i$ in this case. The dynamics of the sectoral employment shares are then only driven by the real income effect $E_i^{RI}$, and the technological change effect $E_i^{TC}$.

Consider also the following Stone-Geary preferences, which are a particular form of non-homothetic preferences:

$$u = \frac{\left[\sum_{i=1}^{m} \theta_i \left(c_i - \overline{c}_i\right)^{\rho}\right]^{\frac{1-\sigma}{\rho}} - 1}{1-\sigma}. \tag{A.1}$$

[13] See, e.g., Matsuyama (1992), Echevarria (1997), Laitner (2000), Caselli and Coleman (2001), Kongsamut et al. (2001), and Gollin et al. (2002).

where $\varepsilon = 1/(1-\rho)$ is now the elasticity of substitution between effective consumptions $c_i - \overline{c}_i$ for all $i = 1, ..., m$.[14] To derive the consumption demands, we first maximize (A.1) subject to the constraint (2.12). From the first order condition of this problem, we obtain

$$\frac{\theta_i \left(c_i - \overline{c}_i\right)^{\rho-1} \left[\sum_{i=1}^{m} \theta_i \left(c_i - \overline{c}_i\right)^{\rho}\right]^{\frac{1-\sigma}{\rho}-1}}{p_i} = \frac{\theta_j \left(c_j - \overline{c}_j\right)^{\rho-1} \left[\sum_{i=1}^{m} \theta_i \left(c_i - \overline{c}_i\right)^{\rho}\right]^{\frac{1-\sigma}{\rho}-1}}{p_j},$$

for all $i$ an $j$. Manipulating this expression, we obtain

$$p_j \left(c_j - \overline{c}_j\right) = \left(\frac{\theta_j}{\theta_i}\right)^{\varepsilon} p_i^{\varepsilon} p_j^{1-\varepsilon} \left(c_i - \overline{c}_i\right). \tag{A.2}$$

We now manipulate constraint (2.12) to obtain

$$\sum_{i=1}^{m} p_i \left(c_i - \overline{c}_i\right) + \underbrace{\sum_{i=1}^{m} p_i \overline{c}_i}_{\overline{c}} = c.$$

Finally, we substitute (A.2) in the previous equation to get:

$$\left[\frac{p_i^{\varepsilon}\left(c_i - \overline{c}_i\right)}{\theta_i^{\varepsilon}}\right] \underbrace{\left[\sum_{k=1}^{m} \theta_k^{\varepsilon} p_k^{1-\varepsilon}\right]}_{P} + \overline{c} = c. \tag{A.3}$$

Equation (A.3) defines implicitly the demand for good $c_i$ as function of prices, income or total expenditure $c$ and minimum consumptions. Note that $P$ is not the usual consumption price index associated with a CES consumption index. This standard consumption price index would be $P^{\frac{1}{1-\varepsilon}}$. However, we can define $P$ as an alternative price index.

We next characterize the properties of these consumption demands by deriving the income and the price elasticities. Firstly, by applying the implicit function theorem to (A.3), we obtain

$$\frac{\partial c_i}{\partial c} = \frac{\theta_i^{\varepsilon}}{p_i^{\varepsilon} P} = \frac{c_i - \overline{c}_i}{c - \overline{c}}.$$

Hence the income elasticity is given by

$$\mu_i = \left(\frac{c}{c - \overline{c}}\right)\left(1 - \frac{\overline{c}_i}{c_i}\right), \tag{A.4}$$

for all $i$.

[14] The elasticity between gross consumptions $c_i$ should be computed because is not only determined by $\varepsilon$ but also by the minimum consumptions $\overline{c}_i$. In any case, we assert that this elasticity is not relevant for structural change.

Secondly, by applying the implicit function theorem to (A.3) we obtain

$$\frac{\partial c_i}{\partial p_i} = -\frac{\varepsilon\left(c_i - \overline{c}_i\right)}{p_i} + \left(\frac{c_i - \overline{c}_i}{c - \overline{c}}\right)\left[\varepsilon\left(c_i - \overline{c}_i\right) - c_i\right],$$

and

$$\frac{\partial c_i}{\partial p_j} = \left(\frac{c_i - \overline{c}_i}{c - \overline{c}}\right)\left[\varepsilon\left(c_j - \overline{c}_j\right) - c_j\right].$$

Hence the *own price elasticity* is given by

$$\eta_{ii} = -\varepsilon\left(1 - \frac{\overline{c}_i}{c_i}\right) + \mu_i x_i\left[\varepsilon\left(1 - \frac{\overline{c}_i}{c_i}\right) - 1\right]. \tag{A.5}$$

In the same way we can compute the *cross price elasticity* as

$$\eta_{ij} = \mu_i x_j\left[\varepsilon\left(1 - \frac{\overline{c}_j}{c_j}\right) - 1\right]. \tag{A.6}$$

Finally, by using the Slustky Equation (3.2), we obtain respectively from (A.5) and (A.6)

$$\eta^*_{ii} = \varepsilon\left(1 - \frac{\overline{c}_i}{c_i}\right)\left(\mu_i x_i - 1\right),$$

and

$$\eta^*_{ij} = \mu_i x_j \varepsilon\left(1 - \frac{\overline{c}_j}{c_j}\right).$$

With this value we use the property $\eta^*_{ij} = x_j\sigma_{ij}$ to derive the Allen-Uzawa elasticities in this case:

$$\sigma_{ij} = \varepsilon\mu_i\mu_j\left(1 - \frac{\overline{c}}{c}\right), \tag{A.7}$$

for all $i \neq j$, and

$$\sigma_{ii} = \left(\frac{\varepsilon\mu_i}{x_i}\right)\left(1 - \frac{\overline{c}}{c}\right)\left(x_i\mu_i - 1\right), \tag{A.8}$$

for all $i$.

Therefore, given the assumptions on technologies, we conclude from (3.8) that the change in the sectoral composition between any sectors $i$ and $j$ is only driven in this case by the real income effect defined in (3.9).[15] This follows from the fact that the technological change effect $E_i^{TC}$ is the same across sectors under these assumptions. In historical data for developed countries, we observe a substantial shift of employment from agricultural to service sector. Hence, this demand-based mechanism, which reduces exclusively to the real income effect $E_i^{RI}$, requires that the income elasticity of demand for agricultural goods should be smaller than that for services to be able to replicate the observed structural change in those economies. In terms of the utility function (A.1), this requirement translates into the condition that minimum requirement in consumption should be larger for the agricultural good than

[15] Observe that Kongsamunt et al. (2001) imposed $\overline{c} = 0$ to generate an equilibrium path that exhibits, after some period, balanced growth of aggregate variables together with a substantial structural change at the sectoral level. However, this assumption is irrelevant for having structural change.

for services. Finally, we must remark that structural change crucially depends on the ratio $\overline{c}_i/ c_i$, which measures the intensity of minimum consumption requirement on the good produced by each sector. As shown in Alonso-Carrera and Raurich (2015), this intensity determines the value of the income elasticity of the demand of these goods and, therefore, governs structural change.

### A.2. Structural change based on sectoral-biased technical progress

Baumol (1967) asserted that differential productivity growth across sectors would be the engine of structural change. Ngai and Pissarides (2007) illustrate the mechanics of this second thesis of structural change by introducing an exogenous and sectoral-biased process of technological progress in a multisector growth model. More precisely, they propose a growth model similar to the one considered in the previous subsection with two main differences. On the one hand, they consider that there are not minimum consumption requirements, i.e., $\overline{c}_i = 0$ for all $i$. Observe that the following properties hold with this assumption: $\mu_i = 1$, $\sigma_{ij} = \varepsilon$ for $i \neq j$ and $\sigma_{ii} = \varepsilon (x_i - 1) /x_i$. Therefore, as follows from (3.8), the real income effect $E_i^{RI}$ is not operative in this new framework in explaining the change in the sectoral composition of employment. In addition, the aforementioned authors also assume that production functions are Cobb-Douglas and identical in all sectors except for their rates of total factor productivity growth. More precisely, they consider that technological change is sectoral-biased (i.e., $\gamma_i \neq \gamma_j$) and Hicks-neutral (i.e., $\lambda_i = 0$ and $\zeta_i = 1$). As in the model of the previous subsection, this firstly implies that the technological substitution effect effect $E_i^{TS}$ in (3.8) is not operative because $\alpha_i = \alpha$, $\pi_i = 1$, $r_i = r$, $w_i = w$ and, thus, $\omega_i = \omega$. Furthermore, since $r_i = r$ for all $i$, we can derive from (2.4) and (2.5) that the relative prices are as before $p_i/p_m = (A_m/A_i)$. However, relative prices are now time varying with $\dot{p}_i/p_i - \dot{p}_m/p_m = (1 - \alpha) (\gamma_m - \gamma_i)$ because of the sectoral-biased technological change.

Therefore, in the model proposed by Ngai and Pissarides (2007) the change in the sectoral composition between any sectors $i$ and $j$ is fully determined by the demand substitution effect $E_i^{DS}$ and the technological change effect $E_i^{TC}$ in (3.8). In particular, by using the value of the Allen-Uzawa elasticities and the growth rate of relative prices in this model we obtain from (3.8) that

$$\Delta_{ij} \equiv \frac{\dot{u}_i}{u_i} - \frac{\dot{u}_j}{u_j} = (\varepsilon - 1) \left(\gamma_i - \gamma_j\right).$$

This condition imposes a condition on the elasticity of substitution between goods $\varepsilon$. Provided that technological progress is sectoral-biased, structural change takes place if and only if $\varepsilon \neq 1$. Furthermore, observed data show that structural change in the developed economies consists of a shift of employment from agriculture to services, as well as a larger growth rate of TFP in the former sector than in the latter. Hence, we need to impose that $\varepsilon < 1$ to replicate this pattern of structural change with the model considered in this subsection.

### A.3. Structural change based on capital deepening

Acemoglu and Guerrieri (2008) proposed an alternative way of incorporating the thesis proposed by Baumol (1967): structural change is a consequence of the combination of sectoral differences in capital output elasticities with capital deepening. In this case, the increase in the capital-labor ratio raises the productivity of the sector with greater capital intensity relative to the other sectors, which causes differential productivity growth across sectors. To illustrate this thesis, consider a model with homothetic preferences (i.e., $\mu_i = 1$ for all $i$), unbiased technological change (i.e., $\gamma_i = \gamma$ for all sector $i$), free mobility of capital and labor across sectors (i.e., $r_i = r$, $w_i = w$ and $\omega_i = \omega$), and sectoral technologies that exhibit different capital income shares. In particular, consider that the production functions are given by (2.1) with $\pi_i = 1$ for all $i$, such that

$$Y_i = A_i u_i L (k_i)^{\varphi_i}. \tag{A.9}$$

In this case, since $\alpha_i = \varphi_i$ for all $i$, $\mu_i = 1$ for all $i$, $\sigma_{ij} = \varepsilon = 1/(1-\rho)$ for all $i \neq j$, $\sigma_{ii} = \varepsilon (x_i - 1)/x_i$ for all $i$, $\lambda_i = 0$ and $\zeta_i = 1$, we obtain from (3.8) that structural change is given by

$$\Delta_{ij} \equiv \frac{\dot{u}_i}{u_i} - \frac{\dot{u}_j}{u_j} = -\varepsilon \left( \frac{\dot{p}_i}{p_i} - \frac{\dot{p}_j}{p_j} \right) + \left( \varphi_j - \varphi_i \right) \left( \frac{\dot{\omega}}{\omega} \right), \tag{A.10}$$

i.e., only the demand substitution effect $E^{DS}$ and the technological substitution effect $E^{TS}$ are operative in this model economy. The dynamic adjustment of aggregate capital-labor ratio $k$ alters the sectoral composition through two channels. Firstly, capital deepening implies that production increases more in the sector with a larger capital output elasticity. In addition, this first change in the sectoral composition of aggregate production alters the relative prices and, therefore, the sectoral composition of demand for consumption goods, which also changes the sectoral reallocation of inputs.

Note that Conditions (2.4) and (2.5) imply under the technologies (A.9) that

$$k_i = \left( \frac{\varphi_i}{1 - \varphi_i} \right) \omega,$$

and

$$\frac{p_i}{p_j} = \left[ \frac{\varphi_j^{\varphi_j} \left(1 - \varphi_j\right)^{(1-\varphi_j)}}{\varphi_i^{\varphi_i} \left(1 - \varphi_i\right)^{(1-\varphi_i)}} \right] \omega^{\varphi_j - \varphi_i},$$

so that

$$\frac{\dot{p}_i}{p_i} - \frac{\dot{p}_j}{p_j} = \left( \varphi_j - \varphi_i \right) \left( \frac{\dot{\omega}}{\omega} \right).$$

Hence, we obtain from (A.10) that

$$\Delta_{ij} = (1 - \varepsilon) \left( \varphi_j - \varphi_i \right) \left( \frac{\dot{\omega}}{\omega} \right).$$

Structural change requires in this case $\varepsilon \neq 1$ and $\varphi_j \neq \varphi_i$. Therefore, in this case, the relative capital shares across sectors $(\varphi_i/\varphi_j)$ also determine the direction and intensity of structural change. In particular, we can directly derive the conditions to replicate $\Delta_{ij} < 0$ observed in the data (where $i$ is agriculture and $j$ services) when $\varphi_i/\varphi_j > 1$, as is suggested by Valentinyi and Herrendorf (2008). Capital deepening implies that $\dot{\omega} > 0$ and the relative price of agriculture decreases. Hence, structural change reallocates labor from agriculture to services ($\Delta_{ij} < 0$) if and only if the goods produced in these sectors are complements, i.e., $\varepsilon < 1$.

### A.4. Sectoral differences in capital-labor substitution

Alvarez-Cuadrado et al. (2017) shows that differences in the degree of substitutability between capital and labor across sectors also determine the relative importance of the technological substitution effect of structural change. We observe this by noting that in this case $\pi_i \neq \pi_j$, which determines the value and the sign of technological substitution effect $E^{TS}$ in (3.11). Furthermore, observe that $\pi_i \neq \pi_j$ also implies that capital income shares differ across sectors (i.e., $\alpha_i \neq \alpha_j$). In this case, as capital accumulates, $\dot{\omega} \neq 0$ and $\dot{p}_l \neq 0$ for $l = i, j$, and if we assume homothetic preferences and non-biased, Hicks-neutral technological change, we obtain $\Delta_{ij} = E^{DS} + E^{TS}$.

### A.5. Long-run income and prices effects of structural change

As was pointed out before, some authors like, for instance, Buera and Kabosky (2009), argue that one should combine income and price effects to replicate satisfactorily the observed patterns of structural change. However, this interaction may exhibit some methodological inconveniences. To be more precise, consider a model that combines the non-homothetic preferences (A.1) with sectoral production functions that only differ in the rates of technological change (in particular, let us consider again a Hick-neutral technological progress). In this case, we observe that:

1. The income effects driving structural change vanish in the long-run as the economy grows because $\bar{c}_i / c_i$ tends to cero for all $i$. Therefore, structural change is only generated by price effects in the long run.

2. Some parameters simultaneously determine both income and price effects. Observe from (A.7) that the Allen-Uzawa elasticities $\sigma_{ij}$ are functions of income elasticities $\mu^i$ and $\mu^j$ for these preferences. Therefore, the income and price effects in (3.8) depend on the same fundamentals, which may complicate the empirical identification of these mechanisms.

Comin et al. (2015) solve these two drawbacks of the models of structural change by considering a non-homothetic generalization of the standard Constant Elasticity of Substitution (CES) aggregator for consumption. In particular, they consider the following preferences:

$$u = \frac{v^{1-\sigma} - 1}{1 - \sigma},$$

where $v$ is a composite good given by

$$\sum_{i=1}^{m} \theta_i v^{\frac{\varepsilon_i - \eta}{\eta}} c_i^{\frac{\eta-1}{\eta}} = 1. \tag{A.11}$$

With these preferences, the marshallian demands are given by

$$c_i = \theta_i \left( \frac{p_i}{Q} \right)^{-\eta} v^{\varepsilon_i}, \tag{A.12}$$

with

$$Q \equiv \frac{c}{v} = \left(\frac{1}{v}\right)\left[\sum_{i=1}^{m} \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{A.13}$$

By inserting (A.13) in (A.12), we obtain

$$c_i = \theta_i p_i^{-\eta} c^{\eta} v^{\varepsilon_i - \eta}, \tag{A.14}$$

and

$$x_i = \frac{\theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}}{\sum_{i=1}^{m} \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}}. \tag{A.15}$$

Log-differentiating the previous expression of $c_i$ with respect to $c$, we obtain

$$\left(\frac{\partial c_i}{\partial c}\right)\left(\frac{1}{c_i}\right) = \frac{\eta}{c} + \left(\frac{\varepsilon_i - \eta}{v}\right)\left(\frac{\partial v}{\partial c}\right). \tag{A.16}$$

By applying the implicit function theorem to (A.13) we obtain after some simple algebra:

$$\frac{\partial v}{\partial c} = \frac{(1-\eta)\, v}{c\,(\overline{\varepsilon} - \eta)}.$$

Plugging this derivative in (A.16), we obtain for the income elasticity as

$$\mu_i = \eta + (1-\eta)\left(\frac{\varepsilon_i - \eta}{\overline{\varepsilon} - \eta}\right), \tag{A.17}$$

where $\overline{\varepsilon} = \sum_{i=1}^{m} \varepsilon_i x_i$. Finally, by differentiating (A.14) we also obtain the price elasticities as

$$\eta_{ii} = -\eta + (\varepsilon_i - \eta)\left(\frac{p_i}{v}\right)\left(\frac{\partial v}{\partial p_i}\right),$$

and

$$\eta_{ik} = (\varepsilon_i - \eta)\left(\frac{p_k}{v}\right)\left(\frac{\partial v}{\partial p_k}\right).$$

By applying the implicit function theorem to (A.13), we obtain after some simple algebra:

$$\frac{\partial v}{\partial p_i} = -\frac{(1-\eta)\, x_i v}{(\overline{\varepsilon} - \eta)\, p_i}.$$

Hence, we can rewrite the price elasticities as

$$\eta_{ii} = \eta(x_i - 1) - x_i \mu_i,$$

and

$$\eta_{ik} = \eta x_k - x_k \mu_i.$$

Using (3.2), we directly derive the Allen-Uzawa elasticities of substitution: $\sigma_{ik} = \eta$ and

$$\sigma_{ii} = \frac{\eta(x_i - 1)}{x_i}.$$

As in Subsection A.2, we also consider that the production functions are Cobb-Douglas and identical in all sectors except for their rates of total factor productivity growth, such that $\alpha_i = \alpha$, $\pi_i = 1$, $r_i = r$, $w_i = w$ and, thus, $\omega_i = \omega$. In this case, we obtain from (3.8) that

$$\Delta_{ij} = \left(\mu_i - \mu_j\right) \left\{ \frac{\dot{c}}{c} - \sum_{k=1}^{m} \left[ x_k \left( \frac{\dot{p}_k}{p_k} \right) \right] \right\} + \eta \left( \frac{\dot{p}_j}{p_j} - \frac{\dot{p}_i}{p_i} \right) + \left(\gamma_j - \gamma_i\right). \tag{A.18}$$

Comin et al. (2015) do not express structural change as a function of the growth rate of consumption expenditure $c$, but as a function of the growth rate of composite good $v$. However, we can prove their structural change condition is equivalent to (A.18). By log differentiating (A.13) with respect to time , we obtain

$$\left( \frac{\dot{c}}{c} \right) = \left[ \frac{ \left(\frac{\dot{v}}{v}\right) \sum_{i=1}^{m} \left(\varepsilon_i - \eta\right) \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta} + \sum_{i=1}^{m} \left(1 - \eta\right) \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta} \left( \frac{\dot{p}_i}{p_i} \right) }{ \left(1 - \eta\right) \sum_{i=1}^{m} \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta} } \right].$$

By using (A.15), we directly obtain

$$\frac{\dot{c}}{c} = \left( \frac{\overline{\varepsilon} - \eta}{1 - \eta} \right) \left( \frac{\dot{v}}{v} \right) + \sum_{k=1}^{m} x_k \left( \frac{\dot{p}_k}{p_k} \right). \tag{A.19}$$

Finally, inserting (A.19) in (A.18), and using (A.17) and the fact that $\frac{\dot{p}_k}{p_k} = (\gamma_m - \gamma_k)$ as was shown in the previous section, we obtain

$$\Delta_{ij} = \left(\varepsilon_i - \varepsilon_j\right) \left( \frac{\dot{v}}{v} \right) + \left(1 - \eta\right) \left(\gamma_j - \gamma_i\right),$$

which is exactly the expression of structural change provided by Comin et al. (2015).

## B. Figures and Tables

**Table 1. Estimation of Rotterdam Model of demand**

| Coefficient | Estimator | Confidence interval (95%) | |
|---|---|---|---|
| $\widehat{\chi}_a$ | $-0.000084$ (0.000060) | $-0,000204$ | 0.000036 |
| $\widehat{\chi}_s$ | $-0.000496^{*}$ (0.0000257) | $-0,000547$ | $-0.000045$ |
| $\widehat{\psi}_a$ | 0.009004 (0.015163) | $-0.021322$ | 0.039330 |
| $\widehat{\psi}_s$ | $0.596349^{***}$ (0.029624) | 0.537101 | 0.655597 |
| $\widehat{d}_a$ | $0.993421^{***}$ (0.002082) | 0.989257 | 0.997585 |
| $\widehat{d}_s$ | 0.000629 (0.002783) | $-0.004937$ | 0.006195 |
| $\widehat{\varphi}_a$ | $0.744703^{***}$ (0.075444) | $0,593815$ | 0.895591 |
| $\widehat{\varphi}_m$ | $0.899917^{***}$ (0.044764) | 0.810389 | 0.989445 |
| $\widehat{\varphi}_s$ | $1.028800^{***}$ (0.034598) | 0.959604 | 1.0967996 |

R-squared: 0.8794 for Agriculture and 0.9919 for Services

P-values: * p<0.1 ** p<0.05 *** p<0.01

Standard errors of the estimated coefficients are in parentheses

**Table 2. Cross-time average values of demand and technological elasticities**

| Sector | Income Elasticities ($\widehat{\mu}_i$) | Allen-Uzawa Elasticities ($\widehat{\sigma}_{ij}$) | | | Techn. substitution Elasticities ($\widehat{\pi}_i$) |
|---|---|---|---|---|---|
| | | Agriculture | Manufactures | Services | |
| Agriculture | 0.3810 | $-14.6972$ | 1.2324 | 0.0348 | 1.1543 |
| Manufactures | 1.7521 | 1.2325 | $-0.1227$ | $2.3 \times 10^{-5}$ | 1.1199 |
| Services | 0.8241 | 0.0348 | $2.3 \times 10^{-5}$ | $-0.0012$ | 0.7403 |

**Table 3. Estimation of translog cost functions**

| Coefficient | Estimator | Confidence interval (95%) | |
|---|---|---|---|
| $\widehat{\beta}_k^a$ | 0.450785*** (0.012571) | 0.425643 | 0.475927 |
| $\widehat{\beta}_k^m$ | 0.315050*** (0.004897) | 0.305256 | 0.324844 |
| $\widehat{\beta}_k^s$ | 0.380031*** (0.002249) | 0.375733 | 0.384329 |
| $\widehat{\delta}_{kk}^a$ | −0.037105** (0.018358) | −0.073821 | −0.000389 |
| $\widehat{\delta}_{kk}^m$ | −0.025135*** (0.006643) | −0.038421 | −0.0118490 |
| $\widehat{\delta}_{kk}^s$ | 0.063090*** (0.002482) | 0.058126 | 0.068054 |

R-squared: 0.05 (Agriculture), 0.13 (Manufactures) and 0.90 (Services)

P-values: * p<0.1 ** p<0.05 *** p<0.01

Standard errors of the estimated coefficients are in parentheses

**Table 4. Performance of the simulations**

| | *Pearson's R coef.* | *RMSE* | *Theil U statistic* |
|---|---|---|---|
| *Employment share in agriculture:* $u_a$ | | | |
| Model (all mechanisms) | 0.9627 | 0.0280 | 0.1609 |
| (-) Real income effect | 0.9719 | 0.0179 | 0.1070 |
| (-) Demand subst. effect | 0.9588 | 0.0215 | 0.1276 |
| (-) Tech. subst. effect | 0.9365 | 0.0652 | 0.3171 |
| (-) Tech. change effect | −0.3423 | 0.1359 | 0.5124 |
| *Employment share in servcies:* $u_s$ | | | |
| Model (all mechanisms) | 0.9691 | 0.0445 | 0.0335 |
| (-) Real income effect | −0.9671 | 0.3591 | 0.3420 |
| (-) Demand subst. effect | 0.9691 | 0.0441 | 0.0332 |
| (-) Tech. subst. effect | 0.9667 | 0.1897 | 0.1228 |
| (-) Tech. change effect | 0.9849 | 0.0517 | 0.0375 |
| *Employment share in manufactures:* $u_m$ | | | |
| Model (all mechanisms) | 0.9692 | 0.0244 | 0.0451 |
| (-) Real income effect | −0.8697 | 0.3464 | 0.4117 |
| (-) Demand subst. effect | 0.9634 | 0.0275 | 0.0502 |
| (-) Tech. subst. effect | 0.6654 | 0.2037 | 0.5262 |
| (-) Tech. change effect | 0.9130 | 0.1368 | 0.3026 |

**Table 5. Performance of the simulations of $u_a/u_s$**

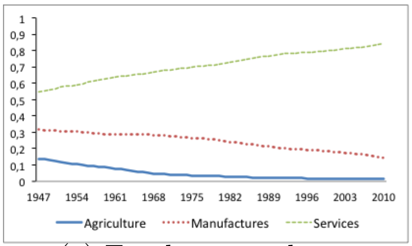
| | *Pearson's R coef.* | *RMSE* | *Theil U statistic* |
|---|---|---|---|
| Model (all mechanisms) | 0.9696 | 0.0499 | 0.1619 |
| (-) Real income effect | 0.9677 | 0.1666 | 0.4093 |
| (-) Demand subst. effect | −0.6735 | 0.3695 | 0.6297 |
| (-) Tech. subst. effect | 0.4285 | 0.2673 | 0.5400 |
| (-) Tech. change effect | 0.9103 | 0.0965 | 0.2802 |

**Table 6: Accounting for the mechanisms' contributions to the growth of $u_a/u_s$**

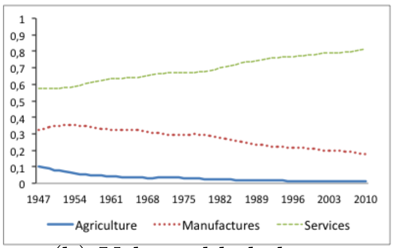
| Period | All mechanisms | RI Effect | DS Effect | TS Effect | TC Effect |
|---|---|---|---|---|---|
| 1947-2010 | 71.48% | 22.95% | −14.04% | 5.56% | 57.01% |
| 1947-1970 | 70.85% | 24.12% | −2.85% | 9.47% | 40.11% |
| 1970-1990 | 69.44% | 25.18% | −18.71% | −5.20% | 68.17% |
| 1990-2000 | 96.51% | 18.42% | −60.51% | 46.35% | 92.25% |
| 2000-2010 | 56.16% | 5.11% | −37.07% | −26.66% | 114.77% |

**Table 7. Fit with constant elasticities: *RMSE***

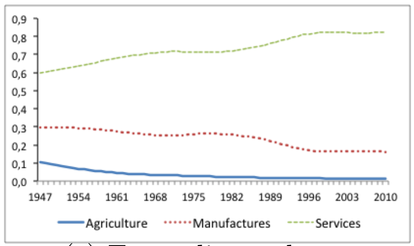
| | Agriculture | Services | Manufactures |
|---|---|---|---|
| Model (all mechanisms) | 0.0562 | 0.0475 | 0.0252 |
| (-) Real income effect | 0.0370 | 0.3530 | 0.3287 |
| (-) Demand subst. effect | 0.0232 | 0.0470 | 0.0289 |
| (-) Tech. subst. effect | 0.1155 | 0.1783 | 0.2185 |
| (-) Tech. change effect | 0.1962 | 0.0554 | 0.1744 |




(a) Employment shares



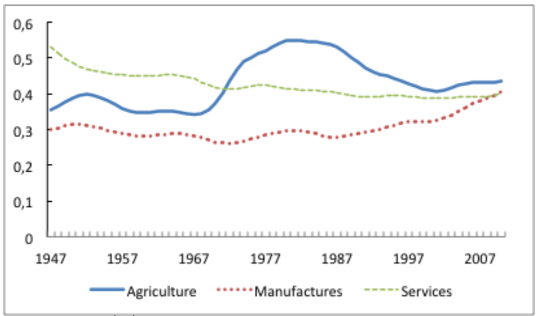

(b) Value added shares



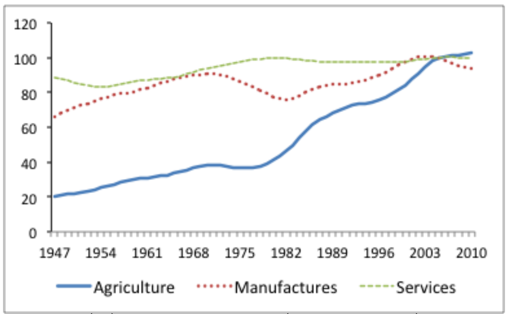

(c) Expenditure shares

Source: World KLEMS data 2013 realese and Herrendorf et al. (2013)

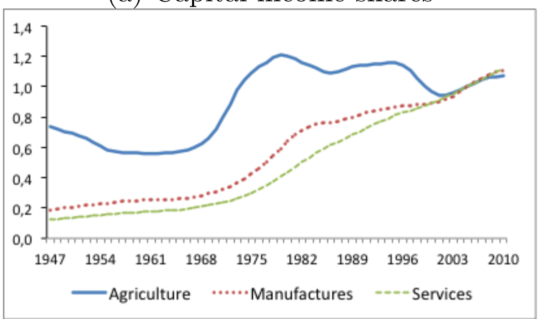
**Figure 1. Patterns of Structural Change in US.**



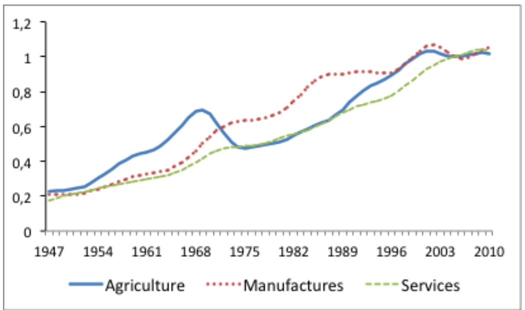

(a) Capital income shares




(b) TFP index (2005=100)



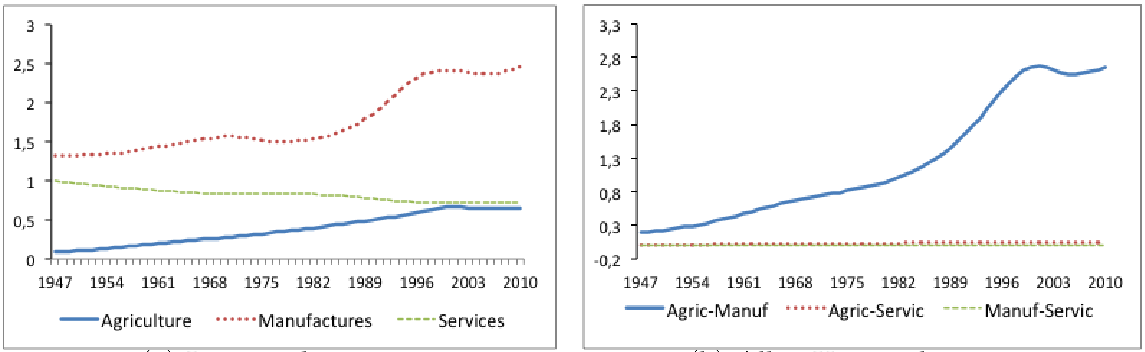

(c) Price index (2005=1)




(d) Rental ratio $w/r$ (2005=1)

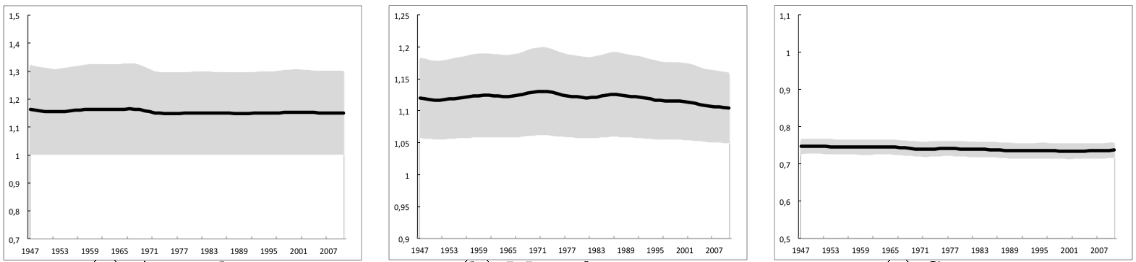
Source: World KLEMS data 2013 realese and Herrendorf et al. (2013)

**Figure 2. Sectoral dynamics in US.**



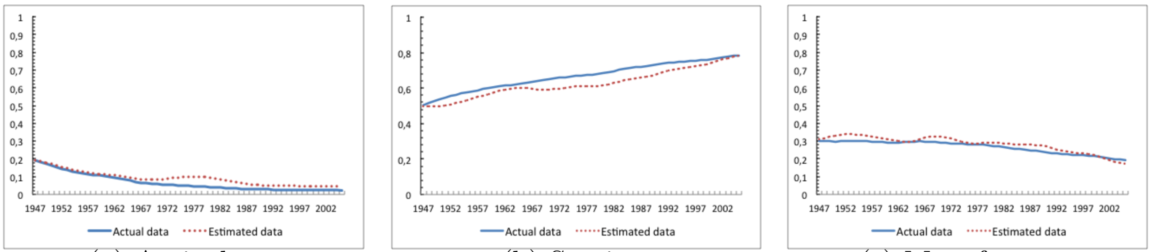

(a) Income elasticities (b) Allen-Uzawa elasticities

**Figure 3. Estimated dynamics of demand elasticities**



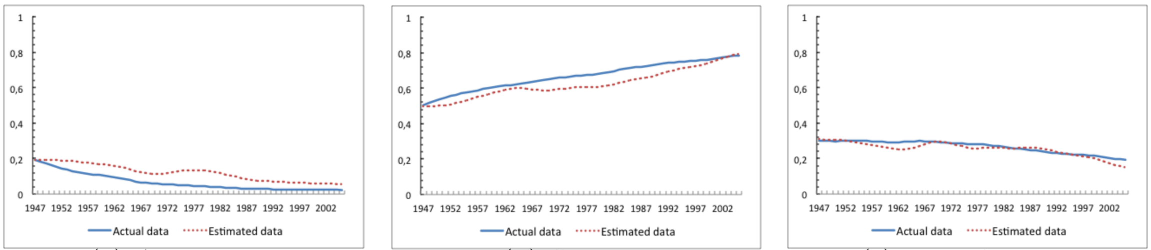
(a) Agriculture (b) Manufactures (c) Services

**Figure 4. Estimated dynamics of technological substitution elasticities**




(a) Agriculture (b) Services (c) Manufactures

**Figure 5. Fit of the sectoral employment shares**




(a) Agriculture (b) Services (c) Manufactures

**Figure 6. Fit of the sectoral employment shares with constant elasticities**