Anatomizing the Mechanics of Structural Change*

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Abstract

In this paper we characterize all possible mechanisms of structural change by using a general multisector growth model, where preferences and technologies are not parameterized. We derive the growth rates of sectoral employment shares at the equilibrium of this generic set up. We find 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. Finally, we 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 determining the weight of each mechanism.

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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 U.S. economy. We observe that labor, the valued added and expenditure on consumption have continuously moved out from agriculture to manufactures and services during the period from 1869 to 2005. In particular, employment shares in agriculture and services has respectively decreased and increased monotonically during this period, whereas the employment share in manufactures has followed an inverse U-shaped path. However, while the valued added and expenditure shares in agriculture and services replicate the same dynamics as the employment shares, those shares in manufactures has monotonically gone down. Figure 2 also shows the dynamic path followed by the capital income shares, the Total Factor Productivity (henceforth, TFP) indexes, the prices of the goods and the ratios from the rental rate of labor to the rental rate of capital in these three sectors. We easily derive that the relative price of agriculture in terms of manufactures has decreased, 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 larger in agriculture than in manufactures and services. Our aim in this paper is to disentangle the deep fundamentals of the economic mechanisms behind these patterns of 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.[1] This literature has distinguished between demand-based and supply-based mechanisms of structural change. On the one hand, demand factors are related to income effects due non-homothetic preferences that cause structural change in a growing economy. These factors have 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 aforementioned literature also finds some supply factors that change the relative prices and, therefore, cause structural change through some substitution effect. One of these contributions 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 by the interaction of sectoral production functions with different capital intensities with capital deepening. Finally, Alvarez-Cuadrado et al. (2013) point out that differences in the capital-labor substitution across sectors are also a candidate for a supply factor of structural transformation.

However, there is little consensus in the literature on the relative importance of the suggested mechanisms for explaining the observed structural transformation. There

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

are some applied studies that study the accuracy of some individual mechanism as an isolated explanation of the observed structural change. Dennis and Iscan (2009) quantitatively decompose U.S. reallocation of labor out of agriculture 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 effect to explain U.S. structural change by focusing on how restrictions on preference parameters affect the fit of expenditure rates. Herrendorf et al. (2015) assess how the properties of technology affect the reallocation of production factors across sectors. Moro et al. (2015) study how a model with non-homothetic preferences and home production fit the observed patterns of structural change. Finally, Sweicki (2013) goes a little further to study the relative importance of several mechanisms. He simulates a parametrized general equilibrium model to quantify the relative contribution of four particular mechanisms to structural change experimented by a large set of countries: (i) sector-biased technological change, (ii) non-homothetic preferences, (iii) international trade, and (iv) intersectoral wedges between sectoral rental rates. All of these papers introduce assumptions on the functional forms of both technologies and preferences that may bias the contribution of the different mechamisms of structural change. Therefore, a unified theory of structural change in a general model seems necessary to derive a micro-founded explanation of this process.

The goal of this paper is to bridge the aforementioned gap in the literature by developing a unified analysis of structural change. In particular, we first characterize all possible mechanisms of structural change by using a generic framework, i.e., a model with the minimum set of assumptions and without parametrizing preferences and technologies. We derive the growth rates of sectoral employment shares at the equilibrium of this generic set up. In this way, we are able to derive the economic fundamentals that are behind structural change. We find that those crucial 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; and (iv) the elasticity of substitution between capital and labor in each sector. These economic indicators crucially determine the relative importance of the growth rates of aggregate income, relative prices, rental rates and technological progress for structural change. Obviously, our expression for the process of structural change can be particularized to all of the proposals provided by the existing literature. In the paper we illustrate how these particular mechanisms can be interpreted and explained with our condition for structural change.

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 determining the weight of each mechanism. We show that the following mechanisms have had a large effect on the dynamics of sectoral employment shares: (a) the income effects from the growth of income and from 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. 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 are mainly caused by the income effects. Moreover,

all of these effects have varied along time because of the time-varying nature of the fundamentals determined their contribution.

We believe that our contribution is important for two reasons. It first offers a unified framework to study the structural change and to isolate the economic fundamentals that we should take into account in characterizing this process. For instance, from our general expression for the sectoral reallocation of labor, we can derive the conditions that these fundamentals should satisfy to fit the observed process of structural change. This exercise can be done either by isolating an individual mechanism or by considering the interaction of some mechanisms. As was mentioned before, in the paper we make this exercise for each of the mechanisms already considered by the literature. This allows interpreting and rationalizing the conditions for structural transformation provided by this literature. Sometimes the proposed models disguised these true conditions under seemgly different assumptions.

On the other hand, our analysis contributes to introduce discipline in building multisector growth model for the economic analysis. To consider all of the mechanisms with a significant contribution to the observe structural change, as well as to identify the fundamentals that determine this contribution, seems a necessary requirement to derived unbiased conclusions of analyzing the macroeconomic effects of structural shocks like, for instance, fiscal policy reforms. In other words, these shocks may distort the economy by means of different mechanisms of structural change and, in addition, they may even alter substantially the relative 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 try in this direction, although some other mechanisms may be still skipped.[2]

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 revisits the recent literature on structural change to show how our general formulation can be particularized in these contributions. Section 5 performs an empirical analysis to disentangle the relative importance of the derived mechanisms for the structural change observed in US data. Finally, Section 6 includes some concluding remarks.

2. Theoretical framework

We consider a continuous time, close economy composed of m productive sectors.[3] 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

[2] For instance, we do not consider the effect of international trade in the process of structural change. Uy et al. (2013), Sweicki (2013) and Teignier (2014) show that this may be an important channel to explain the observed structural change.

[3] Our analysis can be extended to incorporate international trade without an extremely large cost. For simplicity of exposition, we have decided to discard this option.

sector-dependent production function:[4]

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

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 measures the efficient units of employment in sector i. We assume that

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

that is, the efficient units of labor gros at the rate γ_i, which can be different across sectors. Hence, technological progress can be sectorally either biased or unbiased.

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

$$y_i = f_i\left(k_i\right), \tag{2.3}$$

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

Finally, perfect competition implies that each production factor is paid according to its marginal productivity. Hence, the following conditions hold:

$$r_i = p_i f_i'\left(k_i\right), \tag{2.4}$$

and

$$w_i = p_i A_i\left[f_i\left(k_i\right) - f_i'\left(k_i\right) k_i\right], \tag{2.5}$$

where r_i and w_i are the rental rates of capital and labor, respectively, in sector i. These rental rate can differ across sectors. This may be the case, for instance, if there exist some costs of moving production factors across sectors (see, e.g., Caselli and Colleman, 2001; Buera and Kaboski, 2009; or Carrera and Raurich, 2016). 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 stock of capital in efficient units of labor k_i is a implicit function of the rental rate ratio ω_i and of the efficient units of labor A_i. Hence, we can write $k_i = \Phi_i\left(\omega_i, A_i\right)$, with

$$\frac{\partial k_i}{\partial \omega_i} = -\frac{\left[f_i'\left(k_i\right)\right]^2}{A_i f_i\left(k_i\right) f_i^{''}\left(k_i\right)} > 0,$$

and

$$\frac{\partial k_i}{\partial A_i} = \frac{f_i'\left(k_i\right)\left[f_i\left(k_i\right) - f_i'\left(k_i\right) k_i\right]}{A_i f_i\left(k_i\right) f_i^{''}\left(k_i\right)} < 0,$$

which follows from the properties of sectoral production functions: $f_i^{'}\left(k_i\right) > 0$ and $f_i^{''}\left(k_i\right) < 0$. Note that the relation between capital in efficient units of labor and the rental rate ratio is sectoral dependent because so are the production functions.

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

For our analysis it will be also useful to summarize the firms' optimal behavior by the following fundamentals of sectoral structure of production: (i) the share of capital income in output from sector i, that we denote by α_i; and (ii) the elasticity of substitution between capital and labor in sector i, that we denote by π_i. By using (2.3), (2.4) and (2.5), together with the definition of the rental rate ratio ω_i, we obtain, after some simple algebra, that

$$\alpha_i = \frac{r_i k_i}{p_i y_i} = \frac{f_i'(k_i)\, k_i}{f_i(k_i)}, \tag{2.6}$$

and

$$\pi_i = \left(\frac{\partial k_i}{\partial \omega_i}\right)\left(\frac{\omega_i}{k_i}\right) = -\frac{(1-\alpha_i)\, f_i'(k_i)}{f_i''(k_i)\, k_i}. \tag{2.7}$$

Observe that these two fundamentals α_i and π_i can be different across sectors. In this case, the relative prices p_i depend not only on the exogenous technical change, but they are also endogenously determined by the capital accumulation.

This economy is populated by a unique infinitely-lived representative consumer. This consumer obtains income from renting capital and labor to firms. This income is devoted to either consumption or investment. Therefore, his budget constraint is

$$\sum_{i=1}^{m} (r_i k_i + w_i u_i L) = \dot{K} + (1-\delta) K + \sum_{i=1}^{m} p_i c_i, \tag{2.8}$$

where c_i is the consumption demand of commodity produced by the sector i, and $\delta \in [0,1]$ is the depreciation rate of capital. The representative consumption derives utility from the consumption of m goods. We consider an utility function $u(c_1, ..., c_m)$ that is increasing in each of its arguments and concave.[5] The representative consumer maximizes

$$U = \int_{t=0}^{\infty} e^{-\rho t} u(c_{1t}, ..., c_{mt})\, dt, \tag{2.9}$$

where ρ is the subjective discount rate, subject to the budget constraint (2.8) and the non-negativity constraint in the choice variables. In solving this problem, we might follow a two-step procedure. In the first step, we would solve an intertemporal problem where consumer decides the intertemporal allocation of total expenditure on consumption

$$c = \sum\nolimits_{i=1}^{m} p_i c_i. \tag{2.10}$$

More precisely, we would first solve the problem that consists on maximizing (2.9) subject to (2.8) after having substituted (2.10) into it. Given the optimal path of expenditure $\{c_t\}_{t=0}^{\infty}$, we would face to the intratemporal problem of choosing the sectoral composition of consumption by maximizing (2.9) subject to (2.10).

However, for our analysis, we only need to characterize the properties of the temporal functions of consumption demand. We denote by $c_i = C^i(p, c)$ the

[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.

Marshallian demand consumption for good produced in sector i, where p is the vector of sectoral relative prices, i.e., $p = (p_1, ..., p_m)$. 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

$$\eta_{ij} = \left[\frac{\partial C^i(p,c)}{\partial p_j}\right]\left[\frac{p_j}{C^i(p,c)}\right], \tag{2.11}$$

whereas the income elasticity of this demand is

$$\mu_i = \left[\frac{\partial C^i(p,c)}{\partial c}\right]\left[\frac{c}{C^i(p,c)}\right]. \tag{2.12}$$

Since the demand system satisfies the budget constraint (2.10), we obtain the following properties of this system, which will be relevant for the empirical analysis. First, by derivating (2.10) with respect to expenditure we obtain after some algebra that

$$\sum_{i=1}^{m} \mu_i x_i = 1, \tag{2.13}$$

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, by derivating (2.10) with respect to price p_j we also obtain after some algebra that

$$x_j + \sum_{i=1}^{m} \eta_{ij} x_i = 0, \tag{2.14}$$

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

$$\mu_i + \sum_{j=1}^{m} \eta_{ij} = 0, \tag{2.15}$$

for all $i = 1, 2, ..., m$. The price elasticities (2.11) and the income elasticities (2.12) of the demand, together with the conditions (2.13), (2.14) and (2.15), fully summarize the optimal response of consumers to changes in the economic conditions. Hence, they will be sufficient indicators of the optimal choice of the sectoral composition of demand and expenditure on consumption.

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

$$c_i \equiv C^i(p,c) = A_i u_i L f_i(k_i),$$

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

$$\frac{\dot{u}_i}{u_i} = \frac{\sum_{j=1}^{m} \left(\frac{\partial c_i}{\partial p_j}\right) \dot{p}_j + \left(\frac{\partial c_i}{\partial c}\right) \dot{c}}{c_i} - \frac{f_i'(k_i) \left[\left(\frac{\partial k_i}{\partial \omega_i}\right) \dot{\omega}_i + \left(\frac{\partial k_i}{\partial A_i}\right) \dot{A}_i\right]}{f_i(k_i)} - \gamma_i.$$

By using the definitions of η_{ij}, μ_i, α_i and π_i given respectively by (2.11), (2.12), (2.6) and (2.7), and after some algebra, we derive that

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

We observe that the dynamics of sectoral employment share in a sector $i \neq m$ are driven by the following forces: (a) the growth rate of total expenditure on consumption (or, equivalently, of income), whose relative contribution is given by the income elasticity of the demand of this consumption good; (b) the weighted average of the growth rate of prices of all consumption goods, where the weights are the price-elasticities of the demand of good i with respect the corresponding prices; (c) the growth rate of the rental rate ratio in sector i, whose relative effect depends on the share of capital income in the sectoral production and the elasticity of substitution between inputs in this sector; and (d) the rate of technological change in sector i.

We then observe that the dynamics of the sectoral employment shares are driven by income and price effects. In order to clearly disentangle these two types of effects, we must decompose the price effect into the income effect and substitution effect. 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 η_{ij}^* denotes the Hicks-Allen elasticity of substitution, i.e., the price elasticity of the compensated demand of good i, which we denote by $h^i(p, u)$. That is,

$$\eta_{ij}^* = \left[\frac{\partial h^i(p, u)}{\partial p_j}\right] \left[\frac{p_j}{h^i(p, u)}\right]. \tag{3.3}$$

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

1. A *substitution effect* given by η_{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. An *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.

What literature names price effect of structural change actually includes an income effect, whose relative importance also depends on the income elasticity μ_i. Thus, we should refer to the existence of an income and a substitution effect as sources of structural change. This income effect has to components: (a) a direct effect given by the change in the nominal income; and (b) an indirect effect given by the variation in the purchasing power of income derived from the change in prices. We next propose an analysis that allows to isolate these effects and to develop an accounting exercise for measuring the relative importance of them in explaining the observed structural change.

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., η^*_{ik} may differ from η^*_{ki}. This happens even when the cross substitution effects are symmetric, i.e.,

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

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

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

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

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

with

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

and where $E_i(p,u)$ is the derivative of $E(p,u)$ with respect to p_i and $E_{ij}(p,u)$ is the derivative of $E_i(p,u)$ 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 η_{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:

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

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

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

Equation (3.8) provides the conditions that preferences, technologies and the process of technological progress must jointly satisfy to replicate the observed patterns of structural change. These conditions emerge from the values that the sectoral differences in the income elasticities μ_i, the Allen-Uzawa elasticities σ_{ij}, the capital income shares α_i and the elasticities of substitution between production factors π_i must adopt along the equilibrium path, such that the proposed model is able to replicate the change in the sectoral composition of the employment as is observed in the data.

From (3.7) and (3.8), we can decompose the different mechanism that are driving the structural change. In particular, we distinguish the following four channels of structural change:

1. *Real Income Effect.* The variation in the sectoral composition of demand and expenditure derived from the dynamics of real income or, equivalently, real expenditure c. This partial effect is given by the following term of (3.7):

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

   This income effect that decomposes into a *direct income effect* from changes in the nominal income or expenditure, and an *indirect income effect* that derives from changes in real income as a consequence of the variation in relative prices. 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. In any case, the relative importance of the total income effect clearly depends on the income elasticity of the demand of good i. Hence, this partial effect will generate differences in the dynamic of employment among sectors if and only if the income-elasticities of demand differs 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.* The variation in the sectoral composition of demand and expenditure on consumption derived from the change in the relative prices when consumers are compensated by the corresponding reduction in their purchasing power. 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 relative 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. Therefore, 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.* The variation in the sectoral capital intensities k_i derived 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 relative importanceof this third effect depends on both the share of capital income in output and 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, where the weights are given by the sectoral capital income share and the sectoral elasticity of substitution between capital and labor.

4. *Technological Change Effect.* The variation in the sectoral structure derived from the technological progress that modifies the total factor productivities of sectors. This effect is given by the following term of (3.7):

$$E_i^{TC} = (\alpha_i \pi_i - 1)\, \gamma_i. \tag{3.12}$$

Observe that the relative importance of this partial effect also depends on both the share of capital income in output and the elasticity of substitution between capital and labor in sector i. Hence, the change in the sectoral composition derived from this 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 $(\alpha_i \pi_i - 1)\, \gamma_i \neq (\alpha_j \pi_j - 1)\, \gamma_j$. Therefore, this effect on sectoral composition do not require technological change to be sectoral-biased. It also arise if $\gamma_i = \gamma_j$ provided that $\alpha_i \pi_i \neq \alpha_i \pi_i$. This is conclusion is a relevant insight of our analysis.

Observe that the indirect income effect in (3.9) covers the potential interaction of the income and price effects for structural change pointed out by the literature. For instance, a price variation caused by a biased technological change affects the sectoral structure by altering the purchasing power of income and the terms of trade between goods. The former effect is determined by the income elasticities, whereas the later one is driven by the elasticities of substitution. The literature either does not usually make the former decomposition of price effect or it omits the indirect income effect by considering homothetic preferences. However, to isolate the former effect is thus crucial for a well understanding of the observed process of structural change.

Summarizing, structural change might be driven by several alternative and non-exclusive 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 contributions to the observed structural change in the data. These contributions might change across time and they can also differ across countries. We will deal with this empirical analysis below. Before that, we next place our contribution in the literature by studying how our condition (3.7) for structural change concretizes in several mechanisms of structural change existing in that literature. This will help us to understand the utility of equation (3.7) for the analysis of structural change.

4. Revisiting the related literature

We now apply the previous analysis to those models of structural change commonly used by the literature on economic growth and development. All of these proposals arise from considering particular properties for preferences and technologies. Our purpose in this sectios then requires computing the income elasticities, the Allen-Uzawa elasticities, the sectoral capital income shares and the elasticities of substitution between production factors. We must also compute the growth rate of expenditure, of relative prices, of rental rate ratio in these models and of technological progress across sectors. 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 by Alvarez-Cuadrado and Long (2011); and, (e) Long-run income and prices effects of structural change by Comin et al. (2015). We next analyze each of these proposals.

4.1. 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.[6] Let us illustrate the mechanics of this proposal. As in Kongsamunt et al. (2001), we consider a model with sectoral production functions given by

$$Y_i = F_i\left(s_i K, A_i u_i L\right) = F\left(s_i K, A_i u_i L\right),$$

that is, production functions are identical in all sectors. 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 $p_i/p_m = (A_m/A_i)^{1-\alpha}$. 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

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

supply-side properties imply that the following partial effects in (3.11) are not operative in this model: (a) the demand substitution effect E_i^{DS}, because of the Homogeneity Condition (2.15) of demand system; 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:

$$u = \frac{\left[\sum_{i=1}^{m} \theta_i \left(c_i - \overline{c}_i\right)^{\rho}\right]^{\frac{1-\sigma}{\rho}} - 1}{1-\sigma}. \tag{4.1}$$

where $\varepsilon = 1/(1-\rho)$ is now the elasticity of substitution between effective consumptions $c_i - \overline{c}_i$ for all $i = 1, ..., m$. However, the elasticity between gross consumptions c_i should be computed because is not only determined by ε but also by the minimum consumptions $\overline{c}_i$. In any case we assert that the later elasticity is not relevant for structural change.

We derive in Appendix A the following properties of the system of consumption demand under these preferences:

$$\mu_i = \left(\frac{c}{c-\overline{c}}\right)\left(1 - \frac{\overline{c}_i}{c_i}\right), \tag{4.2}$$

for all i,

$$\sigma_{ij} = \varepsilon \mu_i \mu_j \left(1 - \frac{\overline{c}}{c}\right), \tag{4.3}$$

for all $i \neq j$, and

$$\sigma_{ii} = \left(\frac{\varepsilon \mu_i}{x_i}\right)\left(1 - \frac{\overline{c}}{c}\right)\left(x_i \mu_i - 1\right), \tag{4.4}$$

for all i, and where $\overline{c} = \sum_{i=1}^{m} p_i \overline{c}_i$.

Therefore, given the assumptions on technologies, we conclude from (3.8) that the change in the sectoral compostion between any sectors i and j is only driven in this case by the real income effect defined in (3.9).[7] 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 agriculture 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 agriculture goods should be smaller than that for services to be able to replicate the observed structural change in those economies. Equivalently, this requirement translates into the condition that minimum requirement in consumption should be larger for the agriculture good than for services. Although this condition should be empirically tested, the data seems to corroborate it. Finally, we must remark that the

[7] 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.

structural change crucially depends on the ratio $\frac{\overline{c}_i}{c_i}$, 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.

4.2. Structural change based on sectoral-biased technical progress

Baumol (1967) asserted that differential productivity growth across sectors would be the engine of the structural change. Ngai and Pissarides (2007) illustrate the mechanics of this second thesis of structural change by considering an exogenous and sectoral-biased process of technological progress. More precisely, they propose a growth model similar to the one considered in the previous subsection with two main exceptions. 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 the new framework in explaing the change in the sectoral composition of the 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., $\gamma_i \neq \gamma_j$. 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 $p_i/p_m = (A_m/A_i)^{1-\alpha}$. 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 compostion 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

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

This condition imposes a condition on the elasticity of substitution between goods ε. Provided that technological progress is sectoral-biased, structural change takes place if and only if $\varepsilon \neq 1$. Furthermore, observed data show that the structural change in the developed economies consists on 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. Ngai and Pissarides (2007) obtain the same conditon on the elasticity of substitution. In fact, these authors originally considered a Hicks neutral technological change, i.e., $Y_i = A_i F(s_i K, u_i L)$. In this case, we obtain $p_i/p_m = A_m/A_i$ and, thus, $\Delta_{ij} = (\varepsilon - 1)\left(\gamma_i - \gamma_j\right)$.

4.3. 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 because the increase in the capital-labor ratio raises the contribution of sector with greater capital intensity to aggregate output. 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

$$Y_i = A_i u_i L \left(k_i\right)^{\varphi_i}, \tag{4.5}$$

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

$$\Delta_{ij} \equiv \frac{\dot{u}_i}{u_i} - \frac{\dot{u}_j}{u_j} = -\varepsilon\left(\frac{\dot{p}_i}{p_i} - \frac{\dot{p}_j}{p_j}\right) + \left(\varphi_j - \varphi_i\right)\left(\frac{\dot{\omega}}{\omega}\right), \tag{4.6}$$

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 the production increases more in the sector more capital intensive. 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 reinforces the initial sectoral reallocation of inputs.

Note that Conditions (2.4) and (2.5) imply under the technologies (4.5) that

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

and

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

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 (4.6) that

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

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 (φ_i/φ_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) provided that $\varphi_i/\varphi_j > 1$ 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., $\varepsilon < 1$.

4.4. Sectoral differences in capital-labor substitution

Alvarez-Cuadrado and Long (2011) shows that differences in the degree of capital-labor substitutability 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., $\alpha_i \neq \alpha_j$).

By estimating sectoral constant elasticity of substitution and Cobb-Douglas production functions, Herrendorf et al. (2015) shows that biased technological progress across sectors are the dominant force behind the structural change experienced by US economy after the II World War. Furthermore, they conclude that any other sectoral technological factor is of second-order importance. That is, structural change is mainly determined by the demand substitution effect E^{DS} and the technological change effect E^{TC} in (3.8), whereas the technological substitution effect E^{TS} would have influence only in the margin. Even a Cobb-Douglas production function with equal income shares (i.e., with $\pi_i = 1$ and $\alpha_i = \alpha$ for all i) does a reasonable job in replicating the observed structural change if one considers sectoral-biased technological change.

4.5. Long-run income and prices effects of structural change

As was pointed before, some authors like, for instance, Buera and Kabosky (2009) defend 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 (4.1) with sectoral production functions that only differ in the rates of technological change (in particular, let us consider again a Harrow-neutral technological progress). In this case we observe that:

1. The income effects driven structural change vanish in the long-run as the economy grows because $\frac{\bar{c}_i}{c_i}$ 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 (4.3) that the Allen-Uzawa elasticities σ_{ij} are function of income elasticities μ^i and μ^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

$$\sum_{i=1}^{m} \theta_i v^{\frac{\varepsilon_i - \eta}{\eta}} c_i^{\frac{\eta-1}{\eta}} = 1. \tag{4.7}$$

We derive in Appendix B the following properties of the system of consumption demand under these preferences: $\sigma_{ij} = \eta$ for all $i \neq j$, $\sigma_{ii} = \eta (x_i - 1) / x_i$ and

$$\mu_i = \eta + (1-\eta) \left(\frac{\varepsilon_i - \eta}{\overline{\varepsilon} - \eta} \right), \tag{4.8}$$

where $\overline{\varepsilon} = \sum_{i=1}^{m} \varepsilon_i x_i$. As in Subsection 4.2, 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

$$\Delta_{ij} = (\mu_i - \mu_j) \left\{ \frac{\dot{c}}{c} - \sum_{k=1}^{m} \left[x_k \left(\frac{\dot{p}_k}{p_k} \right) \right] \right\} + \eta \left(\frac{\dot{p}_j}{p_j} - \frac{\dot{p}_i}{p_i} \right) + (1-\alpha) (\gamma_j - \gamma_i). \tag{4.9}$$

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 show in Appendix B that

$$\frac{\dot{c}}{c} = \left(\frac{\overline{\varepsilon} - \eta}{1-\eta} \right) \left(\frac{\dot{v}}{v} \right) + \sum_{k=1}^{m} x_k \left(\frac{\dot{p}_k}{p_k} \right). \tag{4.10}$$

Inserting (4.10) in (4.9), and using (4.8) and the fact that $\frac{\dot{p}_k}{p_k} = (1-\alpha)(\gamma_m - \gamma_k)$ as was shown in the previous section, we obtain

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

which is exactly the expression of structural change provided by Comin et al. (2015).[8]

5. Empirical analysis

In this section we try to quantify the empirical contribution of these four channels for the structural change in US economy over the period 1948-2005. This first requires to estimate or calibrate the income elasticities μ_i, the Allen-Uzawa elasticities σ_{ij} and the elasticities of substitution between capital and labor π_i. To this end, we might directly estimate the system of structural change given by (3.7) for all $i \neq m$. This is the procedure usually follow by the related literature to calibrate models that incorporates

[8] Comin et al. (2015) assume a Hicks-neutral technological progress and, therefore, the parameter α does not appear in their formula of Δ_{ij}.

particular mechanims of structural change (see, e.g., Dennis and Iscan, 2009; Herrendorf et al., 2013 and 2015; Moro et al., 2016). However, 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, this imposes that the elasticities participating in these conditions are time-invariant, so that we could not in this way cover possible changes in preferences and technologies. 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, with this direct procedure, we would not derive the true elasticities, so that this is an unusable exercise for prediction and policy analysis.

To overcome this limitation, we derive these elasticities from the estimation of a system of demand and a system of production costs. After deriving the estimated elasticities, we use the condition (3.7) to perform an accounting exercise to obtain the relative contribution of each of the channels. For this analysis we consider three aggregate sectors: agriculture, manufactures and services. We employ the data on consumption in valued added expenditure (excluding government) and on relative prices from Herrendorf et al. (2013), whereas the data on labor and capital compensation, rental rate ratio, employment and sectoral TFPs come from World KLEMS data 2013 release.

5.1. Estimation of demand elasticities

For obtaining the elasticities of demand (i.e., income elasticities μ_i and Allen-Uzawa elasticities σ_{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.[9] This model represents the system of demand as follows:

$$x_{it} \log\left(\frac{c_{it}}{c_{it-1}}\right) = \left\{ \begin{array}{c} \psi_i \left[\log\left(\frac{c_t}{c_{t-1}}\right) - \sum_{j=1}^{m} x_{jt} \log\left(\frac{p_{jt}}{p_{jt-1}}\right) \right] \\ + \sum_{j=1}^{m} \phi_{ij} \log\left(\frac{p_{jt}}{p_{jt-1}}\right) \end{array} \right\}, \tag{5.1}$$

for all $i \neq m$, and with the following constraints:

[9] 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) provides two surveys on the literature on the analysis of commodity demands.

- Engel aggregation constraint:

$$\sum_{j=1}^{m} \psi_j = 1,$$

with $\psi_j \geq 0$.

- Homogeneity constraint:

$$\sum_{j=1}^{m} \phi_{ij} = 0.$$

- Symmetry constraint:

$$\phi_{ij} = \phi_{ji}.$$

- *Slutsky matrix* $[\phi_{ij}]$ is negative semidefine 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.[10] Since in our analysis we use three sectors (agriculture, manufactures and services), we eliminate the equation for one sector, say manufactures that was taken as numeraire. In this way, and after imposing the homogeneity constraint, we derive the econometric specification that we use to estimate income and Allen-Uzawa elasticities. Finally, we follow Brown and Lee (1992) who incorporate effect of past consumption to account for the posible 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

$$z_{it-1}\big|_{i=a,s} = \left\{ \begin{array}{c} \chi_i + \widehat{\psi}_i \left[\log\left(\frac{c_t}{c_{t-1}}\right) - \sum\limits_{j=a,s,m} x_{jt}^* \log\left(\frac{p_{jt}}{p_{jt-1}}\right) - \sum\limits_{j=a,s,m} \widehat{\varphi}_j z_{jt-1} \right] \\ + \sum\limits_{j=a,s} \widehat{\phi}_{ij} \left[\log\left(\frac{p_{jt}}{p_{jt-1}}\right) - \log\left(\frac{p_{mt}}{p_{mt-1}}\right) \right] + \widehat{\varphi}_i z_{it-1} + \varepsilon_{it} \end{array} \right\}, \tag{5.2}$$

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

We estimate (5.2) for the demand on agriculture and services goods by using the method of *Seemingly Unrelated Regression Estimation* since the disturbance vector ε 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 restriction on the Slutsky matrix has to be tested after the estimation.

Table 1 displays the results of the estimation of the model (5.2). By using Engel aggregation and homogeneity constraints we can compute the corresponding

[10] 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.

coefficients for the manufactures: $\widehat{\psi}_m = 0.439104$, $\widehat{\phi}_{am} = 0.005606$, $\widehat{\phi}_{mm} = 0.019488$ and $\widehat{\phi}_{ms} = -0.025094$. Apparently, the regression provides a quite good fit. All the marginal budget shares $\widehat{\psi}_i$ exhibit de 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 $\widehat{\phi}_{as}$. We believe that this is a consequence of the necessity good nature of the consumption goods produced by the agriculture. Finally, we have checked that the Slutsky matrix $\left[\phi_{ij}\right]$ is negative semidefine and of rank $m - 1 = 2$.

[Insert Table 1]

We now deduce 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 average values. Several properties should be pointed out at this point. Firstly, with respect to income elasticities, we obtain that the three consumption goods are normal goods, although the estimation of the income elasticity of agriculture goods exhibit a large variability, such that its confidence interval contains negative values. We observe that the demands of agriculture and services exhibits income elasticity smaller than unity, whereas the demand of manufactures exhibit an income elasticity larger than unity. The literature explaining structural change by means of 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 $\widehat{\mu}_m > \widehat{\mu}$. 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 $\widehat{\mu}_a > \widehat{\mu}_s$ at the end of the series, which may be a consequence of the change in the relative aspirations or necessities in consumption experimented by consumers at the development process.

[Insert Figure 3 and Table 2]

With respect to Allen-Uzawa elasticities, we first observe that $\widehat{\sigma}_{as} \neq \widehat{\sigma}_{am} \neq \widehat{\sigma}_{ms}$, which means that the composite consumption are not given by standard CES aggregator of the consumption goods c_a, c_m and c_s. Furthermore, we also conclude that agriculture goods are Hicks substitutes of manufactures and services as $\widehat{\sigma}_{am} > 0$ and $\widehat{\sigma}_{as} > 0$. However, the confidence interval shows a large variability of these estimated elasticities, such that we can not reject these elasticities to be negative. Hence, we cannot reject that agriculture goods are Hicks complementaries or independent of manufactures and services. In addition, we also obtain $\widehat{\sigma}_{sm} < 0$, so that services and manufactures are Hicks complementaries.

5.2. Estimation of technological elasticities

For estimating the fundamentals of sectoral production (i.e., capital income shares α_i and elasticity of substitution π_i) we can consider that the cost functions are given

by translog-functions and, thus, derive the associate system of sectoral cost shares.[11] 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 τ_i denotes the average cost function. By 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 a coefficients, and by imposing the symmetry of the cross-price derivatives, we obtain:

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

This is the translog cost function. By taking derivatives with respect to $\ln r$ and $\ln w$ 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 this constraints, and taking the labor income shares $1 - \alpha_i$ directly from data, we then estimate the following equation:

$$\alpha_{it} = \beta_k^i - \delta_{kk}^i \ln(\omega_{it}) + \varepsilon_{it} \tag{5.3}$$

for all $i = \{a, s, m\}$, and where ε_{it} is the disturbance that we assume homoscedastic and uncorrelated over time. Furthermore, we also assume that this disturbance is normally distributed as $N(0, \Omega)$, where Ω is the unknown contemporaneous covariance matrix. Since the disturbance vector ε can be correlated across sectors, we estimate the system composed of the three equations (5.3) by using the method of Seemingly Unrelated Regression Estimation. Table 3 provides the estimates of the full set of parameters in (5.3). All the parameters are estimated with a large precision.

[Insert Table 3]

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

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

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

Observe that these elasticities are time-varying. Figure 4 shows the time-path of these estimated elasticities and Table 4 displays their average values. We can reject that $\widehat{\pi}_i = 1$, i.e., Cobb-Douglas technologies at the sectoral level. More precisely, as was suggested, for instance, by Alvarez-Cuadradro et al. (2013), we obtain that capital and labor are complementary in services, whereas they are substitutes in manufactures and agriculture. These elasticities maintain these features along the entire dynamic path. In fact, these elasticities remains almost constant along the entire period.

[Insert Figure 4 and Table 4]

5.3. Accounting for the importance of each determinant

For the purpose of this subsection, we develop the following experiment. We first compute the estimated sectoral employment shares and, furthermore, we measure how these estimates fit the actual shares in 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) was operative. 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:

$$\widetilde{u}_{it} = \widetilde{u}_{it-1}(1 + G_{it}),$$

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

$$\widetilde{u}_{i1} = u_{i0}(1 + G_{i1}),$$

where u_{i0} is the actual value of the US employment share in sector i at 1947; and G_{it} is the growth factor implied by each of the mechanisms of structural change in (3.7):

- The growth rate from the Real Income Effect:

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

- The growth rate from the Demand Substitution Effect:

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

- The growth rate from the Technological Substitution Effect:

$$G_{it}^{TS} = -\alpha_i \widehat{\pi}_i \left(\frac{\dot{\omega}_i}{\omega_i} \right)$$

- The growth rate from the Technological Change Effect:

$$G_{it}^{TC} = (\alpha_i \widehat{\pi}_i - 1)\, \gamma_i.$$

We then compare the path of the counterfactual employment shares $\{\widetilde{u}_i\}_{t=1948}^{2005}$ with the one followed by actual shares $\{u_i\}_{t=1948}^{2005}$. Figure 5 provides the results of this comparison. 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 coefficient of correlation (R^2) and the root mean-square error ($RMSE$) of the regression of the actual employment shares with respect to the counterfactual shares provided by Table 5 and 6, respectively. This tables analyzes the performance of the counterfactual simulations containing all mechanisms as well as the 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, and we also provide the overall performance, which is computed as a weighted average of the sectoral performance with the sectoral employment shares as the weights. Our simulations explains much more than the 92% of the variation in the employment shares and, moreover, this performance is better in services and manufactures than in agriculture. In addition, we observe, that the technological change and the technological substitution effects are the main mechanisms in explaining the evolution of the employment share in agriculture, whereas the real income effect is the main mechanism for the evolution of the employment share in services. Therefore, as is shown by the last column of the aforementioned tables, all the mechanisms have a significative role in explaining the structural change observed in the entire 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 Tables 5 and 6]

One advantage of our analysis is that it allows for decomposing 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., μ_i, σ_{ij}, α_i and π_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 values (see Tables 2 and 4). 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 Tables 7 and 8 provides the fit of these new counterfactual simulations. The results on the relative contribution of the four derived mechanism (i.e., real income,

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

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 is slightly worse when the elasticities are taken constant, although this conclusion can marginally change depending on which of the four mechanisms is turned off.

[Insert Figure 6 and Tables 7 and 8]

An alternative way of studying the performance of our estimations is by means of comparing the actual and the counterfactural dynamic evolution of the ratio between the employment share in agriculture and in services. Figure 7 and Table 9 provides the results of this exercise. We can confirm the previous conclusions. On the one hand, we observe that all the mechanisms have a significative contribution to explaining the dynamics of these ratio. In addition, we also see that the performance is slightly better by taking time-varying elasticities.

[Insert Figure 7 and Table 9]

We then 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. Hence, any multisector growth model built to predict the effects of structural shocks like, for instance, fiscal policy should consider those mechanisms as fundamentals. Otherwise, one can derive biased results of those effects.

6. 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 should be improved and extended in some directions. In the theoretical part, we should first 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 good 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 (2015). Secondly, the theoretical analysis should be also extended to derive the conditions that makes structural change, jointly driven by all of the considered mechanisms, compatible with the existence of balanced growth of aggregate variables as the data suggest.

The empirical part of our analysis might be modified in the following points. First, we should 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 should 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 used this model to develop experiments to assess the effects of fiscal policy and public regulations on sectoral and aggregate variables.

References

[1] Acemoglu, D. and Guerrieri, V. (2008). Capital deepening and non-balanced economic growth. *Journal of Political Economy* 116, 467-498.

[2] Alonso-Carrera, J. and Raurich, X. (2016). Labor mobility, structural change and economic growth. *UBEconomics Working Papers* E15/325.

[3] Alvarez-Cuadrado, F., Van Long, N. and Poschke, M. (2013). Capital Labor Substitution, Structural Change and Growth. Manuscript, McGill University, Montreal.

[4] Barnett, W.A. (1981). *Consumer demand and labor supply.* Amsterdam: North-Holland Publishing Company.

[5] Barten, A.P. (1964). Consumer Demand Functions Under Conditions of Almost Additive Preferences. *Econometrica* 32, 1-38.

[6] Barten, A.P. (1969). Maximum Likelihood Estimation of Complete System of Demand Equations. *European Economic Review* 1, 7-73.

[7] Baumol, W. (1967). Macroeconomics of unbalanced growth: the anatomy of urban crisis. *American Economic Review* 57, 415-426.

[8] Brown, M.C. and Lee, J.Y. (1992). Adynamic differential demand system: an application of translation. *Southem Journal of Agricultural Economics* 24, 1-10.

[9] Buera, F. and Kaboski, J. (2009). Can traditional theories of structural change fit the data? *Journal of the European Economic Association* 7, 469-477.

[10] Caselli, F., Coleman, J.W. II. (2001). The U.S. structural transformation and regional convergence: A reinterpretation. *Journal of Political Economy* 109, 584-616.

[11] Comin, D., Lashkari, D., Mestieri, M. (2015). Structural change with long-run income and price effects. NBER Working Papers 21595.

[12] Cruz, E., Raurich, R. (2015). Leisure time and the sectoral compostion of employment. Manuscript.

[13] Deaton, A. (1983). Demand analysis. *Handbook of Econometrics,* Z. Griliches and M. Intriligator (eds.). Amsterdam: North-Holland Publishing Company.

[14] Deaton, A., Muellbauer, J. (1980). *Economics and consumer behavior. New York: Cambridge University Press.*

[15] Dennis, B.N., Iscan, T.B. (2009). Engel versus Baumol: Accounting for structural change using two centuries of U.S. data. *Explorations in Economic History* 46, 186-202.

[16] Diewert, E. (1974). Applications of duality theory. *Frontiers in Quantitative Economics,* M. Intriligator and D. Kendrick (eds.). Amsterdam: North-Holland Publishing Company.

[17] Echevarria, C. (1997). Changes in sectoral composition associated with economic growth. *International Economic Review* 38, 431-452.

[18] Foellmi, R., Zweimüller, J. (2008). Structural change, Engel's consumption cycles and Kaldor's facts of economic growth. *Journal of Monetary Economics* 55, 1317-1328.

[19] Gollin, D., Parente, S.L., Rogerson, R. (2002). The role of agriculture in development. *American Economic Review, Papers and Proceedings* 92, 160-164.

[20] Herrendorf, B., Rogerson, R. and Valentinyi, Á. (2013). Two Perspectives on Preferences and Structural Transformation, *American Economic Review* 103, 2752-2789.

[21] Herrendorf, B., Rogerson, R. and Valentinyi, Á. (2014). Growth and structural transformation. *Handbook of Economic Growth,* P. Aghion and S.N. Durlauf (eds.). Amsterdam: North-Holland Publishing Company.

[22] Herrendorf, B., Herrington, C. and Valentinyi, Á. (2015). Sectoral technology and structural transformation. *American Economic Journal: Macroeconomics*, 7, 104-133.

[23] Jorgenson, D. (1983). Econometric methods for modeling producer behavior. *Handbook of Econometrics,* Z. Griliches and M. Intriligator (eds.). Amsterdam: North-Holland Publishing Company.

[24] Kongsamunt, P., Rebelo, S., Xie, D. (2001). Beyond balanced growth. *Review of Economic Studies* 68, 869-882.

[25] Laitner, J. (2000). Structural change and economic growth. *Review of Economic Studies* 67, 545-561.

[26] Matsuyama, D. (1992). A simple model of sectoral adjustment. *Review of Economic Studies* 59, 375-388.

[27] Moro, A., Moslehi, S., Tanaka, S. 2016. Does home production drive structural transformation? *American Economic Journal: Macroeconomics*, in press.

[28] Ngai, R., Pissarides, C. (2007). Structural change in a multisector model of growth. *American Economic Review* 97, 429-443.

[29] Swiecki, T. (2013). Determinants of Structural Change. Manuscript.

[30] Teignier, M. (2014). The Role of Trade in Structural Transformation. Manuscript.

[31] Theil, H. (1965). The Information Approach to Demand Analysis. *Econometrica* 33, 67-87.

[32] Uy, T., Yi, K., Zhang, J. (2013). Structural change in an open economy. *Journal of Monetary Economics* 60, 667-682.

[33] Valentinyi, Á. and Herrendorf, B. (2008). Measuring factor income shares at the sectoral level. *Review of Economic Dynamics* 11, 820-835.

Appendix

A. Consumption demand with CES preferences

Consider the utility function (4.1). To derive the consumption demands, we first maximize (4.1) subject to the constraint 2.10. From the first order condition of this problem, we obtain

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

for all i an j. Manipulating this expression we obtain

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

We now manipulate constraint (2.10) to obtain

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

Finally, we substitute (A.1) in the previous equation to get:

$$\left[\frac{p_i^{\varepsilon} (c_i - \overline{c}_i)}{\theta_i^{\varepsilon}} \right] \underbrace{\left[\sum_{k=1}^{m} \theta_k^{\varepsilon} p_k^{1-\varepsilon} \right]}_{P} + \overline{c} = c. \tag{A.2}$$

Equation (A.2) 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.2) 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

$$\mu_i = \left(\frac{c}{c - \overline{c}} \right) \left(1 - \frac{\overline{c}_i}{c_i} \right). \tag{A.3}$$

Secondly, by applying the implicit function theorem to (A.2) we obtain

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

and

$$\frac{\partial c_i}{\partial p_k} = \left(\frac{c_i - \overline{c}_i}{c - \overline{c}}\right)\left[\varepsilon\left(c_k - \overline{c}_k\right) - c_k\right].$$

Hence the *own price elasticity* is given by

$$\eta_{ii} = -\varepsilon\left(1 - \frac{\overline{c}_i}{c_i}\right) + \mu_i x_i\left[\varepsilon\left(1 - \frac{\overline{c}_i}{c_i}\right) - 1\right]. \tag{A.4}$$

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

$$\eta_{ik} = \mu_i x_k\left[\varepsilon\left(1 - \frac{\overline{c}_k}{c_k}\right) - 1\right]. \tag{A.5}$$

Finally, by using the Slustky Equation (3.2), we obtain respectively from (A.4) and (A.5)

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

and

$$\eta^*_{ik} = \mu_i x_k \varepsilon\left(1 - \frac{\overline{c}_k}{c_k}\right).$$

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

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

and

$$\sigma_{ik} = \varepsilon \mu_i \mu_k\left(1 - \frac{\overline{c}}{c}\right).$$

B. Consumption demand in Comin et al. (2015)

Comin et al. (2015) characterize the marshallian demand as

$$c_i = \theta_i\left(\frac{p_i}{Q}\right)^{-\eta} v^{\varepsilon_i}, \tag{B.1}$$

with

$$Q \equiv \frac{c}{v} = \left(\frac{1}{v}\right)\left[\sum_{i=1}^{m} \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}\right]^{\frac{1}{1-\eta}}. \tag{B.2}$$

By inserting (B.2) in (B.1), we obtain

$$c_i = \theta_i p_i^{-\eta} c^{\eta} v^{\varepsilon_i - \eta}, \tag{B.3}$$

and

$$x_i = \frac{\theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}}{\sum_{i=1}^{m} \theta_i v^{\varepsilon_i - \eta} p_i^{1-\eta}}. \tag{B.4}$$

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

$$\left(\frac{\partial c_i}{\partial c}\right)\left(\frac{1}{c_i}\right) = \frac{\eta}{c} + \left(\frac{\varepsilon_i - \eta}{v}\right)\left(\frac{\partial v}{\partial c}\right). \tag{B.5}$$

By applying the implicit function theorem to (B.2) we obtain after some simple algebra:

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

Plugging this derivative in (B.5), we directly obtain the expression (4.8) for the income elasticity.

Finally, by differentiating (B.3) we 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 (B.2), 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

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

Finally, by log differentiating (B.2) with respect to time , we obtain

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

By using (B.4), we directly obtain (4.10).

C. Figures and Tables

Table 1. Estimation of Rotterdam Model of consumption demand

Dependent variable	Coefficient	Estimator	Confidence interval (95%)	
Income effect on agriculture	ψ_a	0.012414 (0.012221)	−0.012028	0.036856
Income effect on services	ψ_s	0.548482*** (0.028858)	0.490766	0.606498
Effect of own price on agriculture	ϕ_{aa}	−0.006938*** (0.001896)	−0.010730	−0.003146
Cross-sectoral effect of price	ϕ_{as}	0.001332 (0.002496)	−0.003660	0.006324
Effect of own price on services	ϕ_{ss}	0.023762** (0.028195)	0.008912	0.038612
Lag effect from agriculture	φ_a	0.732701*** (0.072610)	0.587481	0.877921
Lag effect from manufactures	φ_m	0.878282*** (0.044934)	0.788414	0.968150
Lag effect from services	φ_s	0.783695*** (0.074314)	0.635067	0.932323

R-squared: 0.881211 for Equation of Agriculture and 0.993160 for Equation of 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 elasticities

	Estimator	Confidence interval (95%)	
Income elasticities:			
Agriculture ($\widehat{\mu}_a$)	0.5253	−0.5090	1.5596
Services ($\widehat{\mu}_s$)	0.7580	0.6782	0.8378
Manufactures ($\widehat{\mu}_m$)	1.9495	1.5847	2.3142
Allen-Uzawa elasticities of substitution:			
Agriculture ($\widehat{\sigma}_{aa}$)	−15.6019	−24.1291	−7.0746
Services ($\widehat{\sigma}_{ss}$)	0.0458	0.0172	0.0744
Manufactures ($\widehat{\sigma}_{mm}$)	0.4044	−0.1896	0.9985
Agric-Serv ($\widehat{\sigma}_{as}$)	0.0743	−0.2041	0.3526
Agric-Manuf ($\widehat{\sigma}_{am}$)	1.1690	−0.6627	3.0006
Serv-Manuf ($\widehat{\sigma}_{sm}$)	−0.1509	−0.2702	−0.0316

Table 3. Estimation of translog cost functions

Coefficient	Estimator	Confidence interval (95%)	
$\widehat{\beta}_k^a$	0.458430*** (0.013973)	0.430484	0.486376
$\widehat{\beta}_k^m$	0.316203*** (0.004974)	0.306255	0.326151
$\widehat{\beta}_k^s$	0.379527*** (0.002211)	0.375105	0.383949
$\widehat{\delta}_{kk}^a$	−0.033605** (0.015061)	−0.063727	−0.003483
$\widehat{\delta}_{kk}^m$	−0.023842*** (0.006111)	−0.036064	−0.011620
$\widehat{\delta}_{kk}^s$	0.062458*** (0.002503)	0.057452	0.067464

R-squared: 0.0452 for Agriculture, 0.1398 for Manufactures and 0.896 for Services

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

Standard errors of the estimated coefficients are in parentheses

Table 4. Cross-time average values of technological substituion elasticities

	Estimated elasticity: $\widehat{\pi}_i$	Confidence interval	
Agriculture	1.139625	1.015177	1.264779
Manufactures	1.113667	1.055289	1.171597
Services	0.742881	0.728842	0.769083

Table 5. Goodness of fit: Coefficient of determination (R^2)

	Agriculture	Manufactures	Service	Overall
Model (all mechanisms)	0.9279	0.9918	0.9975	0.9928
(-) Real income effect	0.9739	0.9837	0.8983	0.9227
(-) Demand subst. effect	0.9493	0.6867	0.9976	0.9196
(-) Tech. subst. effect	0.7965	0.7259	0.9949	0.9200
(-) Tech. change effect	0.6011	0.7201	0.9960	0.9101

Table 6. Goodness of fit: Root mean-square error ($RMSE$)

	Agriculture	Manufactures	Service	Overall
Model (all mechanisms)	0.0214	0.0675	0.0857	0.0782
(-) Real income effect	0.0110	0.0607	0.3739	0.2804
(-) Demand subst. effect	0.0160	0.4999	0.0880	0.1848
(-) Tech. subst. effect	0.0505	0.5841	0.1533	0.2532
(-) Tech. change effect	0.1045	0.5299	0.0570	0.1741

Table 7. Fit with constant elasticities: R^2

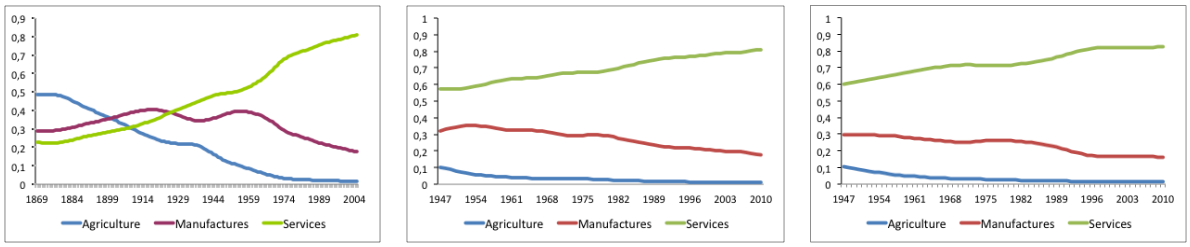
	Agriculture	Manufactures	Service	Overall
Model (all mechanisms)	0.8960	0.9901	0.9969	0.9904
(-) Real income effect	0.9684	0.9829	0.8983	0.9222
(-) Demand subst. effect	0.9415	0.7092	0.9972	0.9245
(-) Tech. subst. effect	0.7430	0.7533	0.9939	0.9234
(-) Tech. change effect	0.5766	0.7456	0.9957	0.9149

Table 8. Fit with constant elasticities: $RMSE$

	Agriculture	Manufactures	Service	Overall
Model (all mechanisms)	0.0432	0.0486	0.0895	0.0773
(-) Real income effect	0.0233	0.0621	0.3697	0.2784
(-) Demand subst. effect	0.0182	0.5493	0.0876	0.1967
(-) Tech. subst. effect	0.0892	0.6129	0.1426	0.2545
(-) Tech. change effect	0.4534	0.5773	0.0605	0.2050

Table 9. Fit of dynamics of ratio $\frac{u_a}{u_s}$

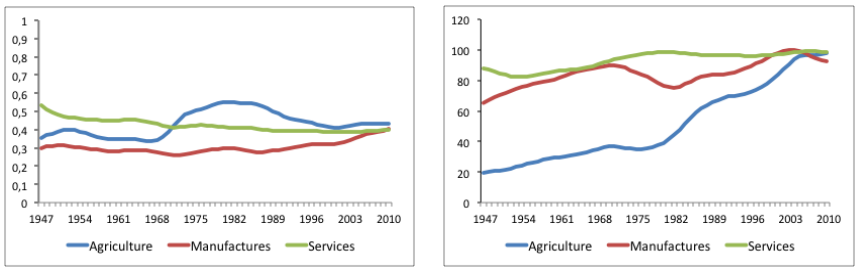
	Time-varying elasticities		Constant elasticities	
	R^2	$RMSE$	R^2	$RMSE$
Model (all mechanisms)	0.9208	0.0400	0.8749	0.0809
$(-)$ Real income effect	0.8393	0.0689	0.8240	0.1000
$(-)$ Demand subst. effect	0.9409	0.0322	0.9310	0.0365
$(-)$ Tech. subst. effect	0.8730	0.0491	0.8097	0.1010
$(-)$ Tech. change effect	0.6552	0.1453	0.6190	0.2239



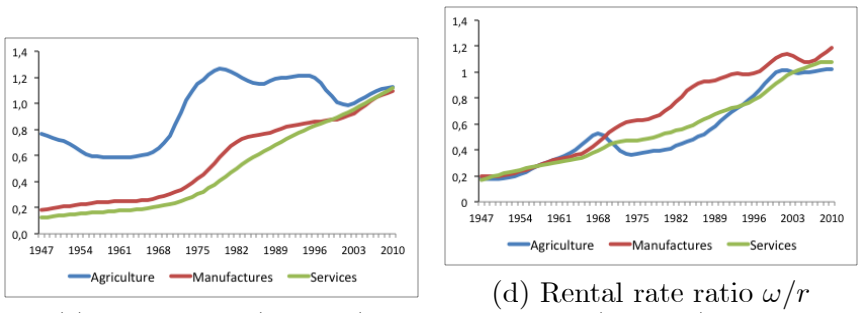
(a) Labor shares (b) Value added shares (c) Consumption shares

Source: Historial statistics of U.S. and Herrendorf et al. (2013)

Figure 1. Patterns of Structural Change in US.



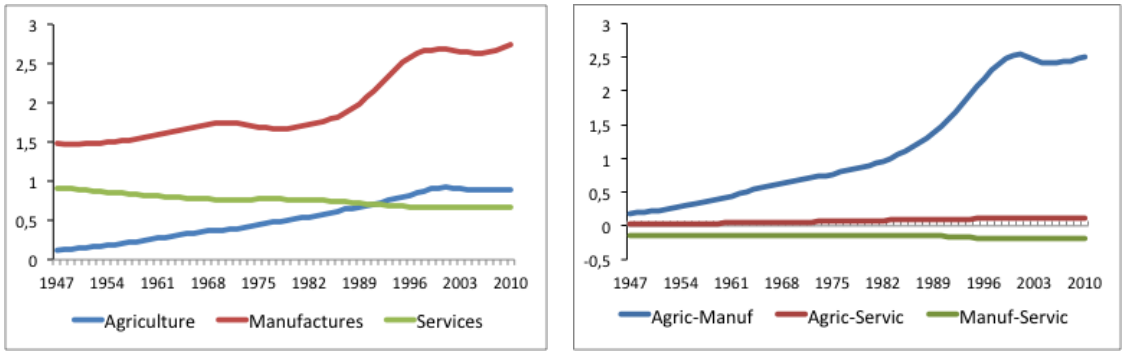
(a) Capital income shares (b) TFP index (2005=100)



(c) Price index (2005=1) (d) Rental rate ratio ω/r (2005=1)

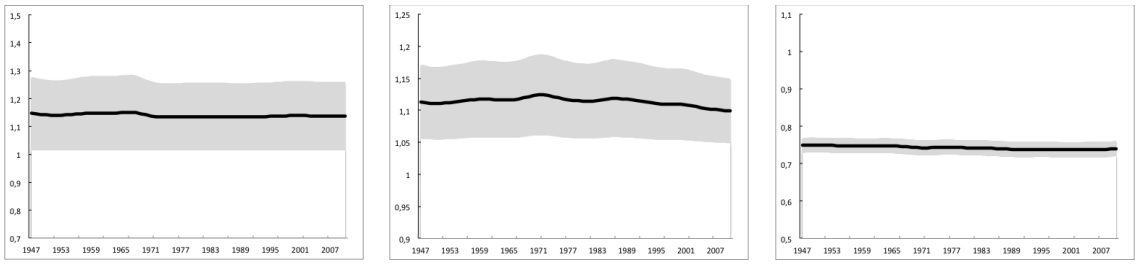
Source: World KLEMS data 2013 realese and Herrendorf et al. (2013)

Figure 2. Sectoral dynamics in US.



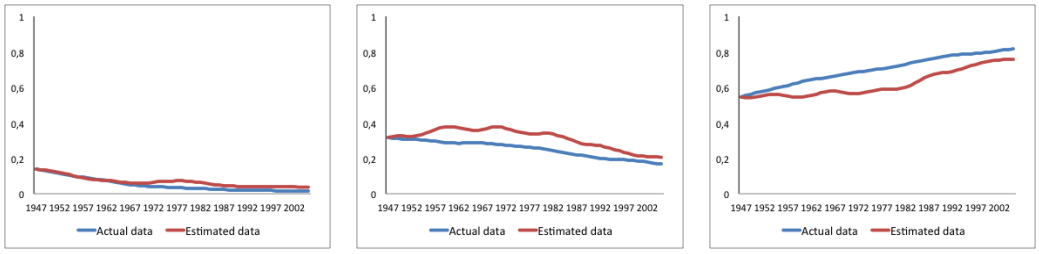
(a) Income elasticities (b) Allen-Uzawa elasticities

Figure 3. Estimated dynamics of demand elasticities



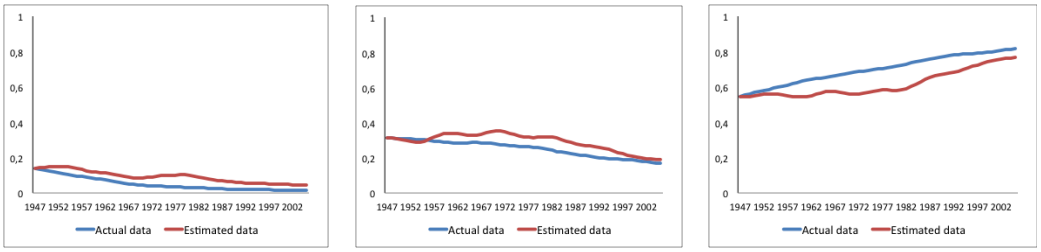
(a) Agriculture (b) Manufactures (c) Services

Figure 4. Estimated dynamics of technological substitution elasticities



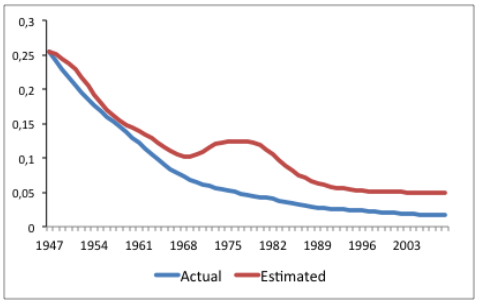
(a) Agriculture (b) Manufactures (c) Services

Figure 5. Fit of the sectoral employment shares

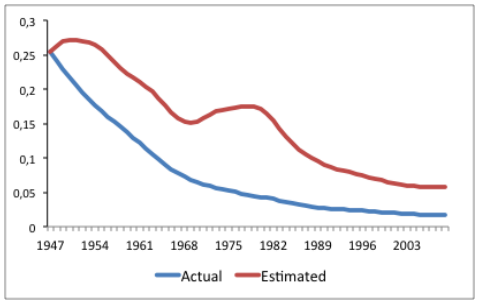


(a) Agriculture (b) Manufactures (c) Services

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



(a) With time-varying elasticities



(b) With constant elasticities

Figure 7. Fit of dynamics of ratio $\frac{u_a}{u_s}$