Sources of Structural Transformation

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Abstract

How much do different theoretical explanations contribute to structural transformation and how heterogeneous is their role across countries? The paper decomposes structural change across the sectors agriculture, manufacturing and services in the United States (1947-2010) and India (1980-2011) into four economic sources. The income effect from improvements in aggregate productivity and factor endowments is the most important driving force in both countries. Differential productivity growth and changes to factor market distortions also contribute to structural changes in the United States, but oppose them in India. The differential capital deepening effect tends to be relatively weak in both countries. Thus the sources of structural transformation exhibit substantial heterogeneity across countries at different levels of development.

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1 Introduction

Structural transformation across the three broad sectors agriculture, manufacturing and services is one of the central features of economic development. There are many economic theories of this phenomenon. The most prominent one is that changes to aggregate productivity and factor endowments increase the productive capacity and hence income of the economy over time. With non-unitary income elasticities of demand based on Engel (1857)'s law these supply side developments cause changes to the sectoral structure like for example in Kongsamut, Rebelo, and Xie (2001). In contrast Baumol (1967) and Ngai and Pissarides (2007) emphasize that productivity growth differs across sectors such that the relative scarcity of different goods and hence their relative price changes over time. If preferences feature a non-unitary elasticity of substitution then this also induces structural change. A related explanation by Acemoglu and Guerrieri (2008) argues that increases in the aggregate capital stock given differences in the sectoral capital intensiveness also affect the relative scarcity of different goods and hence the sectoral composition. Another theory views mobility barriers and distortions to factor markets as important determinants of sectoral structure such that changes to these features explain sectoral reallocation like in Caselli and Coleman (2001) and Hayashi and Prescott (2008). But how important is each of these theoretical explanations for the empirically observed structural transformation? And are the driving forces of structural change relatively uniform or heterogeneous across countries at different levels of development?

The paper provides evidence on these questions by investigating the sources of structural change in a case study of two major economies of the world: the United States during 1947-2010 and India during 1980-2011. These two countries are at a substantially different stage of economic development and structural transformation. In the United States at the beginning of this period services are already the dominant sector and employs more than 50% of total labor. Over time the share of the service sector then increases further, while the shares of both agriculture and manufacturing shrink. In contrast in India initially agriculture is still a very important sector and employs more than 70% of the labor force. Over time the share of agriculture then declines, while the shares of both manufacturing and services increase. Thus a comparison between these two countries provides insights into how much the sources of structural transformation may vary with the level of development.

The analysis is based on a simple general equilibrium model which contains an agricultural, manufacturing and service sector and the four economic mechanisms mentioned above. The ultimate sources of structural change emphasized by each of these economic theories are supply side changes to productivity, factor endowments and the efficiency of factor markets.[1] For each country these driving forces are measured from the data. At the same time the theories also rely on certain fixed features of the economy related to the preferences underlying the demand for different goods and some characteristics of technologies. The parameters of the model corresponding to these features of preferences and technologies are estimated from the data for each country. In each country the observed changes over time to variables like the sectoral shares in total value added, the share of total capital and labor used in each sector, and sectoral relative prices are then decomposed into the contribution of the four theoretical mechanisms.

The first finding is that a model including these four economic mechanisms is indeed rich enough to explain structural transformation in both countries. The decomposition results can be broadly summarized as follows. Improvements in aggregate productivity and factor endowments are the most important explanation for the observed changes to sectoral structure in both countries, but they play a much more important role in India. In the United States differential productivity growth also contributes significantly to structural change and to a lesser extend the same applies to changes to distortions. In contrast in India differential productivity growth constitutes an important opposing force that slows down the observed structural transformation except for the manufacturing sector, and changes to distortions tend to be an opposing force as well. The differential effect of capital deepening is relatively weak in both countries. Thus there is substantial heterogeneity in the sources of structural transformation across countries.

As a quantitative illustration of these findings consider for example the share of total labor employed in the service sector, which increases by about 25 percentage points in the United States during 1947-2010 and 12 percentage points in India during 1980-2011. In the United States the decomposition attributes about 64% of this increase to changes in aggregate productivity and factor endowments, 29% to differential productivity growth, 9% to changes to distortions and −2% to the differential effect of capital deepening. In contrast in India these contributions

[1] The literature often categorizes the different mechanisms into "demand" and "supply" side mechanisms or refers to them as emphasizing "income" versus "relative price" effects. I also frequently use such terminology throughout the paper. However the ultimate sources of structural change in this literature are always supply side changes to productivity, endowments and distortions, which may then either only affect income or relative prices or both. How the supply side change affects sectoral structure also always depends on the characteristics of demand and hence preferences. Thus this terminology is somewhat misleading.

are 186% for changes to aggregate productivity and factor endowments, −70% for differential productivity growth, −8% for changes to distortions and −8% for the differential effects of capital deepening. The exact contributions of course vary somewhat across the considered variables (shares in total value added, labor or capital input) and sectors.

In the United States differential productivity growth is the most important driver of changes to sectoral relative prices. But changes to distortions and differential capital deepening also contribute, and the latter is an opposing force for the price of services relative to manufacturing. In India differential productivity growth contributes substantively to the small change in the relative price of services, while changes to distortions constitute an opposing force of similar magnitude such that these two effects almost cancel. For the price of agriculture relative to manufacturing this pattern is reversed with differential productivity growth being an opposing force and changes to distortions being the main driver.

The paper is related to a large literature on structural transformation, cf. Herrendorf, Rogerson, and Valentinyi (2014) for a survey of prior theoretical and empirical work. Primarily the paper relates to a strand of prior work that aims at quantifying the role of different theoretical sources of structural transformation. Herrendorf, Rogerson, and Valentinyi (2013) investigate how changes to the sectoral composition of consumption demand are driven by income and price effects. Dennis and Iscan (2009) analyse causes for the shift of employment from the agricultural to the whole non-agricultural sector over the last two centuries. Herrendorf, Herrington, and Valentinyi (2015) assess the role of different technological features for labor reallocation across agriculture, manufacturing and services. All these papers focus exclusively on the United States. Swiecki (2017) analyses structural change in a larger sample of countries, but in a model with labor as the only input and no role for capital in production.

The most important contribution of this paper is to investigate the sources of structural change in multiple countries using the canonical model setup with both labor and capital as factors of production. This provides evidence on how much the driving forces of structural change in a developed country like the United States differs from the experience of a developing country like India. Including capital is necessary to ensure that the model is consistent with the main theories of structural change such that one can empirically investigate all the four economic mechanisms. A related important benefit is that the paper can also empirically investigate the sources of the observed reallocation of capital across sectors during the structural transformation, which has so far been neglected by this literature. Another contribution is to employ a simple path-independent decomposition method for the analysis, which may be a useful tool in a large number of other applications as well.

The paper is structured as follows. The setup of the model and the decomposition method are described in section 2. Section 3 presents the data, and how model parameters are estimated and the driving forces are measured from the data. The results on how well the model explains the empirically observed structural changes and how much it attributes to the different theoretical mechanisms are contained in section 4. Section 5 concludes.

2 Theoretical Framework

This section presents a simple general equilibrium model, which nests the four different theoretical mechanisms of structural transformation. It also explains how the model is used to decompose structural change into the contribution of each of these different explanations.

2.1 Model

There are three sectors: agriculture, manufacturing and services, which are indexed by $i = a, m, s$, respectively. Time is discrete and indexed by t. All variables and parameters are country-specific, but a country index is omitted for convenience.

Each sector produces with a constant returns to scale Cobb-Douglas production function using capital and labor as inputs. The output of goods Y_{it} in sector i and period t is then given by

$$Y_{it} = A_{it} K_{it}^{\alpha_i} L_{it}^{1-\alpha_i}, \qquad i = a, m, s \tag{1}$$

where K_{it} is the capital and L_{it} the labor input. A_{it} refers to total factor productivity, which is exogenously given. The output elasticity of capital is given by the parameter α_i and the output elasticity of labor by $1 - \alpha_i$.

There is a representative firm in each sector which acts as a price-taker on the output, capital and labor market. The price of a unit of the output good of each sector is p_{it}. The rental rates of physical capital r_{it} and wage rates w_{it} may differ between sectors due to exogenously given frictions and imperfections of the capital and labor market. Profit maximization then yields the standard marginal product equations $r_{it} = p_{it}\frac{\partial Y_{it}}{\partial K_{it}}$ and $w_{it} = p_{it}\frac{\partial Y_{it}}{\partial L_{it}}$. But due to the presence of the factor market distortions the factor allocation across sectors is characterized by

$$d_{it}^{K}\ p_{it}\frac{\partial Y_{it}}{\partial K_{it}} = p_{mt}\frac{\partial Y_{mt}}{\partial K_{mt}}, \qquad i = a, s \tag{2}$$

$$d_{it}^{L}\ p_{it}\frac{\partial Y_{it}}{\partial L_{it}} = p_{mt}\frac{\partial Y_{mt}}{\partial L_{mt}}, \qquad i = a, s \tag{3}$$

where d_{it}^{K} and d_{it}^{L} denote the capital and labor wedge between agriculture or services ($i = a, s$) and the manufacturing sector (m). If d_{it}^{K} (d_{it}^{L}) is larger than 1 then the marginal value product of capital (labor) is higher in manufacturing than in sector $i = a, s$, and vice versa. An efficient factor allocation would require the equalization of marginal value products (or equivalently of rental rates and wages) across all sectors ($d_{it}^{K} = d_{it}^{L} = 1$).[2]

Market clearing on the capital and labor market requires that

$$K_{at} + K_{mt} + K_{st} = K_t \tag{4}$$

$$L_{at} + L_{mt} + L_{st} = L_t \tag{5}$$

where K_t and L_t denote the total endowment of capital and labor of the economy, which are exogenously given in each period.

The demand for the output of the different sectors is derived from a population of N_t identical representative households. Following Herrendorf, Rogerson, and Valentinyi (2013) households are assumed to maximize the utility function

$$U(C_{at}, C_{mt}, C_{st}) = \left[\eta_a^{\frac{1}{\varepsilon}}(C_{at} - \gamma_a)^{\frac{\varepsilon-1}{\varepsilon}} + \eta_m^{\frac{1}{\varepsilon}}(C_{mt} - \gamma_m)^{\frac{\varepsilon-1}{\varepsilon}} + \eta_s^{\frac{1}{\varepsilon}}(C_{st} - \gamma_s)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{6}$$

which also nests the standard specifications used by the theoretical literature. The budget constraint of a household reads as

$$p_{at}C_{at} + p_{mt}C_{mt} + p_{st}C_{st} = \frac{Y_t}{N_t} \tag{7}$$

where C_{it} denotes the per capita consumption of goods of sector i. $\frac{Y_t}{N_t}$ denotes per capita income in period t. Households own the total endowment of capital K_t and labor L_t and exogenously supply it to firms. Y_t is the total compensation

[2] There is a long history of thought in development economics on the presence of factor market distortions in particular between the agricultural and the whole non-agricultural sector of the economy. Temple (2005) provides a survey of this dual economy literature. Empirical evidence on the presence of such distortions between sectors is presented by Gollin, Lagakos, and Waugh (2014), Vollrath (2009) and Temple and Wößmann (2006), among others.

of capital and labor in the economy, or equivalently the total value of produced output $\sum_i p_{it}Y_{it}$. The share parameters $\eta_i > 0$ in the utility function sum to one. The parameters γ_i may be positive, negative or zero. Non-zero values of the parameters γ_i make the preferences non-homothetic and generate non-unitary income elasticities of demand. If all γ_i are zero then $\varepsilon > 0$ represents the elasticity of substitution between different goods.

Market-clearing on the output markets requires that for each sector i

$$N_t C_{it} = Y_{it} \tag{8}$$

which assumes that total demand derives from consumption and abstracts from separately modelling the sectoral demand due to investment and government spending and assumes a closed economy. Thus total demand is modelled in a somewhat reduced form way here. However the estimation shows that such a specification is still able to fit the data very well. In other words for the changes to sectoral relative prices and aggregate income observed in the data the specification is able to reproduce the observed changes to the sectoral structure of demand. In principle such a good predictive performance is sufficient for the analysis carried out in this paper.[3]

The economy consists of a sequence of static equilibria. The static equilibrium of each period is given by a set of quantities (Y_{it}, K_{it}, L_{it}, C_{it}) and prices (p_{it}, w_{it}, r_{it}) for all sectors i such that firms maximize profits, households maximize utility and the output, labor and capital markets clear. The exogenous driving forces are sectoral levels of total factor productivity (A_{at}, A_{mt}, A_{st}), total endowments of capital K_t and labor L_t, total population N_t, capital market distortions (d^K_{at}, d^K_{st}) and labor market distortions (d^L_{at}, d^L_{st}). This amounts to a total of 10 exogenous time-varying driving forces of the model. The elasticity parameters of the different sectors (α_a, α_m, α_s) and preference parameters (η_a, η_m, η_s, γ_a, γ_m, γ_s, ε) are held constant over time. Specifying a static model is useful for conducting the decomposition analysis of this paper because it allows to directly feed empirically observed and counterfactual driving forces into the model.

[3]The theoretical literature typically also relies on stylized assumptions on the demand structure. Many theoretical papers assume that investment only consists of manufacturing goods, cf. Herrendorf, Rogerson, and Valentinyi (2014) for a critical discussion. Furthermore, it is quite standard to completely abstract from government expenditures and to assume a closed economy. However there is a small recent literature that analyses the role of international trade for structural change, cf. Swiecki (2017) and the references in Herrendorf, Rogerson, and Valentinyi (2014). A better understanding of the changes to the sectoral structure of consumption, investment, government spending and net exports that underly the observed structural transformation in sectoral total demand is an interesting topic for future research.

The quantitative analysis proceeds in several steps. First the model parameters are estimated and the exogenous driving forces of the model are measured empirically. Details on this step are presented in section 3. The predictions of the parameterized model on the endogenous variables are then compared to the empirically observed process of structural transformation. After confirming that the model does a reasonably good job in explaining the data, the model is used for a decomposition of structural change into the contribution of the different driving forces. The following subsection explains the decomposition method and how the different driving forces are grouped to represent the different theoretical mechanisms emphasized in the literature.

2.2 Decomposition Approach

This section explains how changes to the endogenous variables occurring between 1947 and 2010 in the United States and between 1980 and 2011 in India are decomposed into the contribution of the four different theoretical mechanisms. For this purpose I first develop a path-independent decomposition method and then explain more specifically how the decomposition isolates the different theoretical mechanisms.

2.2.1 A Path-Independent Decomposition Method

This section presents the general idea of the decomposition approach. For simplicity I refer to the first and the final year of the period over which the decomposition is carried out for each country as period 1 and 2. I also group the exogenous driving forces of the model into the ones related to sectoral levels of total factor productivity $A_t = (A_{at}, A_{mt}, A_{st})$, factor market distortions $D_t = (d_{at}^K, d_{st}^K, d_{at}^L, d_{st}^L)$, and factor endowments $E_t = (K_t, L_t, N_t)$. The vector of endogenous variables in each period t is determined by a function F of the exogenous variables A_t, D_t and E_t, where F is given by the model of the previous subsection. Accordingly, the endogenous variables in period 1 are given by $F(A_1, D_1, E_1)$ and in period 2 by $F(A_2, D_2, E_2)$. The change of the endogenous variables between the two time periods is then denoted by $\Delta = F(A_2, D_2, E_2) - F(A_1, D_1, E_1)$. The general aim is to decompose this change into the contribution of the four different theoretical mechanisms, which in turn each emphasize different changes to the driving forces and partly rely on specific parameter constellations.

However in order to explain the idea of the decomposition method I first only decompose Δ into the contribution of the changes in A_t, D_t and E_t occurring between period 1 and 2. Denote these contributions by Δ_A, Δ_D and Δ_E, respectively. In such a nonlinear setting decompositions are riddled with problems. For example just using simple and intuitive comparisons like "what would have been the change to the outcome variables if only A_t had changed" or "what would have been the change to the outcome variables if only A_t had not changed" is plagued by path dependencies related to the order in which the different explanations are entered in the decomposition. In order to overcome these problems the paper applies the following simple idea.

As illustrated by the cuboid in figure 1 there are six different direct paths from (A_1, D_1, E_1) to (A_2, D_2, E_2) involving three steps where in each step one of the variables A_t, D_t and E_t is switched from its period 1 to its period 2 level. In each of the three steps along such a path one can evaluate the change to the endogenous variables resulting from the respective change in either A_t, D_t or E_t from their period 1 to period 2 level conditional on the respective fixed values of the other driving forces. Denote these changes to the endogenous variables by $\delta_A(D_d, E_e) = F(A_2, D_d, E_e) - F(A_1, D_d, E_e)$, $\delta_D(A_a, E_e) = F(A_a, D_2, E_e) - F(A_a, D_1, E_e)$ and $\delta_E(A_a, D_d) = F(A_a, D_d, E_2) - F(A_a, D_d, E_1)$. As an example consider the path with a first step from (A_1, D_1, E_1) to (A_2, D_1, E_1), then from (A_2, D_1, E_1) to (A_2, D_2, E_1) and in the final step from (A_2, D_2, E_1) to (A_2, D_2, E_2). For this path one then obtains $\delta_A(D_1, E_1) = F(A_2, D_1, E_1) - F(A_1, D_1, E_1)$, $\delta_D(A_2, E_1) = F(A_2, D_2, E_1) - F(A_2, D_1, E_1)$ and $\delta_E(A_2, D_2) = F(A_2, D_2, E_2) - F(A_2, D_2, E_1)$. One can easily verify that for each of these paths the contributions of A_t, D_t or E_t sum to the overall change in the endogenous variables Δ, i.e. $\delta_A(.)+\delta_D(.)+\delta_E(.) = \Delta$. But of course the magnitude of δ_A, δ_D and δ_E and hence the contribution of A_t, D_t or E_t depends for a general model F on which of these six paths is chosen.

The idea how to achieve path-independency is then simply to take the average over the values of δ_A, δ_D and δ_E occurring for each of these six possible paths to evaluate the overall contribution of the changes to A_t, D_t and E_t over time, i.e. Δ_A, Δ_D and Δ_E, respectively. These simple averages over all paths turn out to be weighted averages of the simple comparisons given by

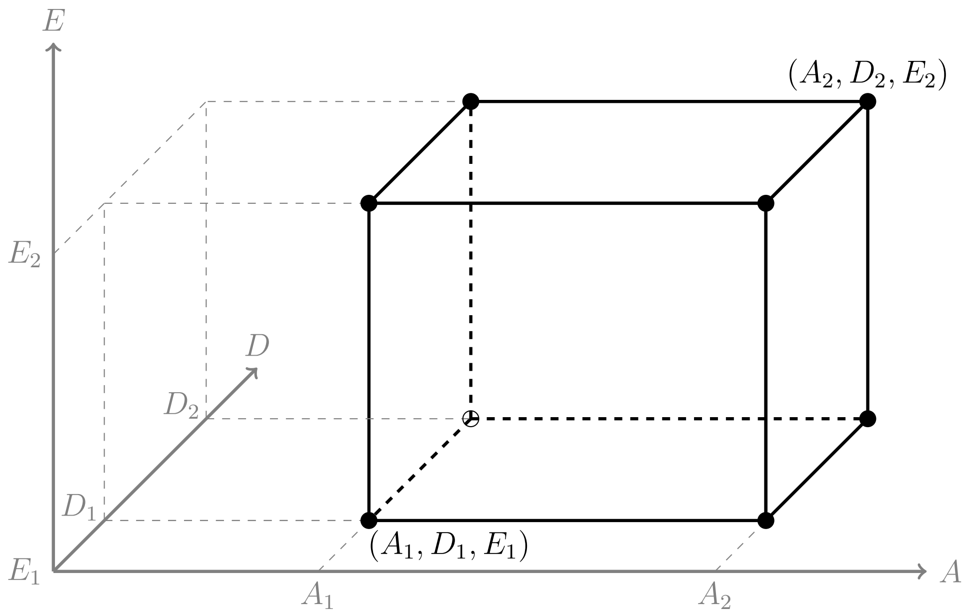
$$\Delta_A = \frac{1}{6}\left[2\delta_A(D_1, E_1) + \delta_A(D_2, E_1) + \delta_A(D_1, E_2) + 2\delta_A(D_2, E_2)\right] \tag{9}$$

$$\Delta_D = \frac{1}{6}\left[2\delta_D(A_1, E_1) + \delta_D(A_2, E_1) + \delta_D(A_1, E_2) + 2\delta_D(A_2, E_2)\right] \tag{10}$$

$$\Delta_E = \frac{1}{6}\left[2\delta_E(A_1, D_1) + \delta_E(A_2, D_1) + \delta_E(A_1, D_2) + 2\delta_E(A_2, D_2)\right] \tag{11}$$

which of course also satisfy $\Delta_A + \Delta_D + \Delta_E = \Delta$. Note that the intuitive com-

Figure 1: Illustration of Decomposition Paths



parisons of "what would have been the change to the outcome variables if only A_t had changed" ($\delta_A(D_1, E_1)$) and "what would have been the change to the outcome variables if only A_t had not changed" ($\delta_A(D_2, E_2)$) receive a higher weight here. The reason is that these comparisons are in fact each located on two out of the six possible paths.

This decomposition method follows a similar idea to what Shorrocks (2013) calls a *Shapley* decomposition. The difference is that Shorrocks considers a setting where an outcome variable depends on whether some explanatory factors are present or absent, while here I consider how a change to an outcome variable depends on the changes to some explanatory factors. The presented decomposition method and its properties readily generalize to a general number of n driving forces because one always just has to form an average over all $n!$ possible paths. This path-independent decomposition method can in principle be used in many area of economics to decompose some difference in outcomes across time periods, individuals or groups into the contributions of the underlying differences in the driving forces.

2.2.2 Isolating the Different Theoretical Explanations

While the previous subsection introduced the general principles of the decomposition method, this subsection explains how in this specific application one needs to further decompose Δ_A and Δ_E to align the overall decomposition with the four theoretical mechanisms. First I further decompose Δ_A into the effect of a common component of productivity growth and the effect of differential productivity growth across sectors, or in other words into an income and relative price effect. Denote these two components by $\Delta_A^{\widetilde{g}}$ and $\Delta_A^{g_i}$, respectively. For this purpose define the vector of counterfactual productivity levels in period 2 for a common productivity growth rate as $\widetilde{A}_2 = (\widetilde{A}_{a,2}, \widetilde{A}_{m,2}, \widetilde{A}_{s,2})$ where $\widetilde{A}_{i,2} = A_{i,1} \times (1+\widetilde{g})$. Here $\widetilde{g}$ represents a hypothetical common growth rate of productivity and is defined such that real total income in period 2 evaluated at the hypothetical vector $(\widetilde{A}_2, D_2, E_2)$ is the same as for the actual vector (A_2, D_2, E_2). In other words $\widetilde{g}$ is chosen such that it captures all of the real income change occurring between period 1 and 2, and the remaining shift from $\widetilde{A}_2$ to A_2 then represents the pure relative price effect coming from differential productivity growth. Then define the simple comparisons for the change from A_1 to the hypothetical level $\widetilde{A}_2$ as $\delta_A^{\widetilde{g}}(D_d, E_e) = F(\widetilde{A}_2, D_d, E_e) - F(A_1, D_d, E_e)$ and from $\widetilde{A}_2$ to the actual level A_2 as $\delta_A^{g_i}(D_d, E_e) = F(A_2, D_d, E_e) - F(\widetilde{A}_2, D_d, E_e)$. The elements of the decomposition of Δ_A are then computed as

$$\Delta_A^{\widetilde{g}} = \frac{1}{6}\left[2\delta_A^{\widetilde{g}}(D_1,E_1) + \delta_A^{\widetilde{g}}(D_2,E_1) + \delta_A^{\widetilde{g}}(D_1,E_2) + 2\delta_A^{\widetilde{g}}(D_2,E_2)\right] \quad (12)$$

$$\Delta_A^{g_i} = \frac{1}{6}\left[2\delta_A^{g_i}(D_1,E_1) + \delta_A^{g_i}(D_2,E_1) + \delta_A^{g_i}(D_1,E_2) + 2\delta_A^{g_i}(D_2,E_2)\right] \quad (13)$$

which implies $\Delta_A = \Delta_A^{\widetilde{g}} + \Delta_A^{g_i}$.

The next step is to decompose the effect of changing factor endowments Δ_E into a component for a hypothetical common capital intensiveness and the remaining part with differing capital intensiveness across sectors. This again relates to the difference between the income and relative price effect of changing factor endowments. The two components are denoted by $\Delta_E^{\widetilde{\alpha}}$ and $\Delta_E^{\alpha_i}$, respectively. Then determine a hypothetical common elasticity parameter $\widetilde{\alpha}$ such that real total income in period 2 with hypothetical parameters $\alpha_i = \widetilde{\alpha}$ in all sectors is the same as in a situation with the actual parameters α_i. In a hypothetical situation with $\alpha_i = \widetilde{\alpha}$ changes to E_t only involve an income effect, but no relative price effects. Then define the simple comparisons for a change from E_1 to E_2 for the hypothetical situation with $\alpha_i = \widetilde{\alpha}$ as $\delta_E^{\widetilde{\alpha}}(A_a, D_d) = F(A_a, D_d, E_2; \alpha_i = \widetilde{\alpha}) - F(A_a, D_d, E_1; \alpha_i = \widetilde{\alpha})$ and for the part netting out this effect as $\delta_E^{\alpha_i}(A_a, D_d) = [F(A_a, D_d, E_1; \alpha_i = \widetilde{\alpha}) - F(A_a, D_d, E_1)] + [F(A_a, D_d, E_2) - F(A_a, D_d, E_2; \alpha_i = \widetilde{\alpha})]$. The elements of the decomposition of Δ_E are then computed as

$$\Delta_E^{\widetilde{\alpha}} = \frac{1}{6}\left[2\delta_E^{\widetilde{\alpha}}(A_1, D_1) + \delta_E^{\widetilde{\alpha}}(A_2, D_1) + \delta_E^{\widetilde{\alpha}}(A_1, D_2) + 2\delta_E^{\widetilde{\alpha}}(A_2, D_2)\right] \quad (14)$$

$$\Delta_E^{\alpha_i} = \frac{1}{6}\left[2\delta_E^{\alpha_i}(A_1, D_1) + \delta_E^{\alpha_i}(A_2, D_1) + \delta_E^{\alpha_i}(A_1, D_2) + 2\delta_E^{\alpha_i}(A_2, D_2)\right]. \quad (15)$$

such that again $\Delta_E = \Delta_E^{\widetilde{\alpha}} + \Delta_E^{\alpha_i}$ holds.

2.2.3 Final Decomposition

Putting all these steps together the overall decomposition of Δ into the contribution of the four theoretical mechanisms conducted in this paper is given by

$$\Delta = \Delta_A^{\widetilde{g}} + \Delta_E^{\widetilde{\alpha}} + \Delta_A^{g_i} + \Delta_E^{\alpha_i} + \Delta_D \quad (16)$$

where $(\Delta_A^{\widetilde{g}} + \Delta_E^{\widetilde{\alpha}})$ captures the effects from advances in aggregate productivity and factor endowments (the "income effect") emphasized by Kongsamut, Rebelo, and Xie (2001). $\Delta_A^{g_i}$ represents the effect of sectoral differences in productivity growth rates proposed by Baumol (1967) and Ngai and Pissarides (2007). $\Delta_E^{\alpha_i}$ accounts for the differential effects of capital deepening due to differences in capital intensiveness across sectors as studied by Acemoglu and Guerrieri (2008). Finally, Δ_D captures the impact of changes to factor market distortions emphasized for example by Caselli and Coleman (2001) and Hayashi and Prescott (2008).

3 Data and Measurement

This section describes the data sources, estimation of model parameters and measurement of the exogenous driving forces of structural change.

3.1 Data

The data on sectoral structure comes from the World KLEMS project, which provides industry level data for the United States (1947-2010) and India (1980-2011).[4] I aggregate the original industry level data for each country to the three broad sectors agriculture, manufacturing and services. Following Herrendorf, Rogerson,

[4]The specific used data is the April 2013 release for the United States supplemented by information on capital stocks from the EUKLEMS November 2009 release, and the December 2016 release for India. The data or links to the data are available at: http://www.worldklems.net

and Valentinyi (2014) the agricultural sector consists of agriculture, forestry, hunting and fishing, the manufacturing sector represents the manufacturing, mining and construction industries, and the service sector consists of all other industries. The final data set then contains for each sector and year information on nominal and real value added, the labor and capital input, price indices and labor compensation. In both countries the labor and capital input account for quality changes over time. In addition to quality changes the labor input in the United States also accounts for hours worked, while in India it accounts only for the number of workers. Data on total population for each country is obtained from the Penn World Tables (version 9.0).

3.2 Parameter Estimation

The technology parameters α_i are set equal to one minus the average labor income share in each sector. The resulting numbers for the two countries are reported in table 1. In the United States manufacturing is the least capital intensive sector with an output elasticity of capital of about 0.3. Agriculture and services are similar in their capital intensiveness with output elasticities of capital of 0.43 and 0.42, respectively. In India production in agriculture is the least capital intensive with a value of α_a of 0.45, while manufacturing and services have output elasticities of capital of 0.51 and 0.5.

Table 1: Parameters

	Technologies			Preferences					
Country	α_a	α_m	α_s	η_a	η_m	η_s	γ_a	γ_s	ε
United States	0.43	0.30	0.42	0.02	0.18	0.80	0.79	-17.08	0.51
India	0.45	0.51	0.50	0.05	0.26	0.68	6.31	-3.96	0.00

The estimation of preference parameters in each country proceeds similarly to Herrendorf, Rogerson, and Valentinyi (2013). The demand functions for each good i are expressed in budget share form as a function of nominal per capita income Y_t/N_t and prices p_{it}, which read as

$$\frac{p_{it}C_{it}}{Y_t/N_t} = \frac{p_{it}\gamma_i}{Y_t/N_t} + \frac{\eta_i p_{it}^{1-\varepsilon}}{\sum_j \eta_j p_{jt}^{1-\varepsilon}} \left(1 - \frac{\sum_j p_{jt}\gamma_j}{Y_t/N_t}\right). \tag{17}$$

The resulting equations are treated as a system of nonlinear seemingly unrelated regressions and estimated by a simple nonlinear least squares procedure. The observed price indices for each sector are normalized such that the initial price is 100 and the parameter γ_m is restricted to be equal to zero. The resulting point estimates of the parameters for each country are reported in table 1. Note that in both countries γ_a is positive and γ_s is negative.[5]

3.3 Measurement of Driving Forces

The growth rates g_{it} of sectoral productivity A_{it} are measured by a growth accounting exercise consistent with the assumed production functions. Here the observed growth in the capital and labor input weighted by their respective factor income shares are subtracted from the observed growth rate of real value added given by

$$g_{it} = \log \frac{V_{i,t}^{real}}{V_{i,t-1}^{real}} - \alpha_i \log \frac{K_{i,t}}{K_{i,t-1}} - (1-\alpha_i) \log \frac{L_{i,t}}{L_{i,t-1}}.$$

Note that real value added (denoted by V_{it}^{real}) corresponds to value added evaluated at the constant prices of some base year p_{ib}, i.e. $V_{it}^{real} = p_{ib} Y_{it}$. Thus the growth rate of real value added corresponds to the growth rate of the quantity Y_{it} in the model. The resulting productivity growth rates g_{it} are both sector and period specific. Table 2 reports as a summary statistic the average annual growth rate of productivity for each sector and country. One observes that in the United States during 1947-2010 productivity growth was fastest in agriculture and slowest in services. In contrast in India measured productivity growth is highest in services and lowest in manufacturing. In the United States this pattern of sectoral productivity growth rates and the observed structural transformation is qualitatively consistent with the theoretical mechanism of Baumol (1967) and Ngai and Pissarides (2007). However this is not the case in India. Here only the pattern between agriculture and manufacturing is consistent with the observed reallocation from agriculture to manufacturing according to the theory, but the pattern between agriculture and services is not.

The initial level of sectoral productivity A_{i1} is normalized such that the initial price of each sector is approximately equal to 100. This is done by setting

$$A_{i1} = \frac{1}{100} \frac{V_{i1}}{K_{i1}^{\alpha_i} L_{i1}^{1-\alpha_i}}$$

where all variables on the left-hand side refer to variables observed in the data

[5]The standard errors of the estimated coefficients are not reported here, but are generally small such that these coefficients are also statistically significantly different from zero.

and V_{i1} refers to nominal value added in the first period. This ensures that prices in the model are consistent with the normalization of prices used in the demand estimation. Sectoral productivity A_{it} in each period is then constructed as $A_{it} = A_{i,1} \times \exp(\sum_{\tau=2}^{t} g_{i\tau})$.

Table 2: Summary Information on Driving Forces

	Average Growth Rates (%)					Change from first to final year			
Country	A_a	A_m	A_s	$\frac{K}{N}$	$\frac{L}{N}$	$d^L_{a1} \to d^L_{aT}$	$d^L_{s1} \to d^L_{sT}$	$d^K_{a1} \to d^K_{aT}$	$d^K_{s1} \to d^K_{sT}$
U.S.	2.6	1.0	0.3	2.7	0.2	2.2 → 2.5	1.3 → 1.3	1.6 → 1.3	3.1 → 1.3
India	0.7	-0.6	1.7	5.5	0.3	3.9 → 2.5	0.9 → 0.5	1.0 → 0.5	1.7 → 0.9

The aggregate endowments of capital K_t and labor L_t are measured by the sum of these variables across sectors in each period in the data. The number of households N_t is determined by the observed total population of each country. The average annual growth rates of capital per person and labor per person are also reported in table 2. One observes that both variables are growing over time, but capital grows faster than labor in both countries. Thus there is capital deepening because capital becomes relatively more abundant over time.

It is also the case that these observations on the growth of productivity and endowments show that total income is increasing over time in both countries (notwithstanding the fact that productivity growth in manufacturing in India is negative). Thus together with the estimated preference parameters this indicates that income effects play a role in the two countries during the observed time periods as emphasized by Kongsamut, Rebelo, and Xie (2001).

For the assumed Cobb-Douglas production functions one can measure the distortion terms d^L_{it} and d^K_{it} for $i = a, s$ in each period t as

$$d^K_{it} = \frac{\alpha_m \frac{V_{mt}}{K_{mt}}}{\alpha_i \frac{V_{it}}{K_{it}}}$$

$$d^L_{it} = \frac{(1-\alpha_m)\frac{V_{mt}}{L_{mt}}}{(1-\alpha_i)\frac{V_{it}}{L_{it}}}$$

where V_{it} refers to nominal value added. Table 2 reports as a summary statistic how these distortions change between the first and last period observed for each country. In the United States there is a consistent pattern of distortions against manufacturing, which means that the marginal product of labor and capital is higher in manufacturing than in agriculture and services. Over time the capital wedges fall, but the labor wedges remain roughly constant or even increase a bit. The pattern for India is more nuanced. Here factor markets are initially either undistorted or also distorted against manufacturing. Over time the labor wedge between agriculture and manufacturing and the capital wedge between services and manufacturing which are both initially distorted against manufacturing move closer to the no distortion case. In contrast the labor allocation between services and manufacturing and the capital allocation between agriculture and manufacturing which are initially close to being undistorted become distorted in favor of manufacturing such that the marginal product in the respective other sector becomes larger than in manufacturing.

4 Results

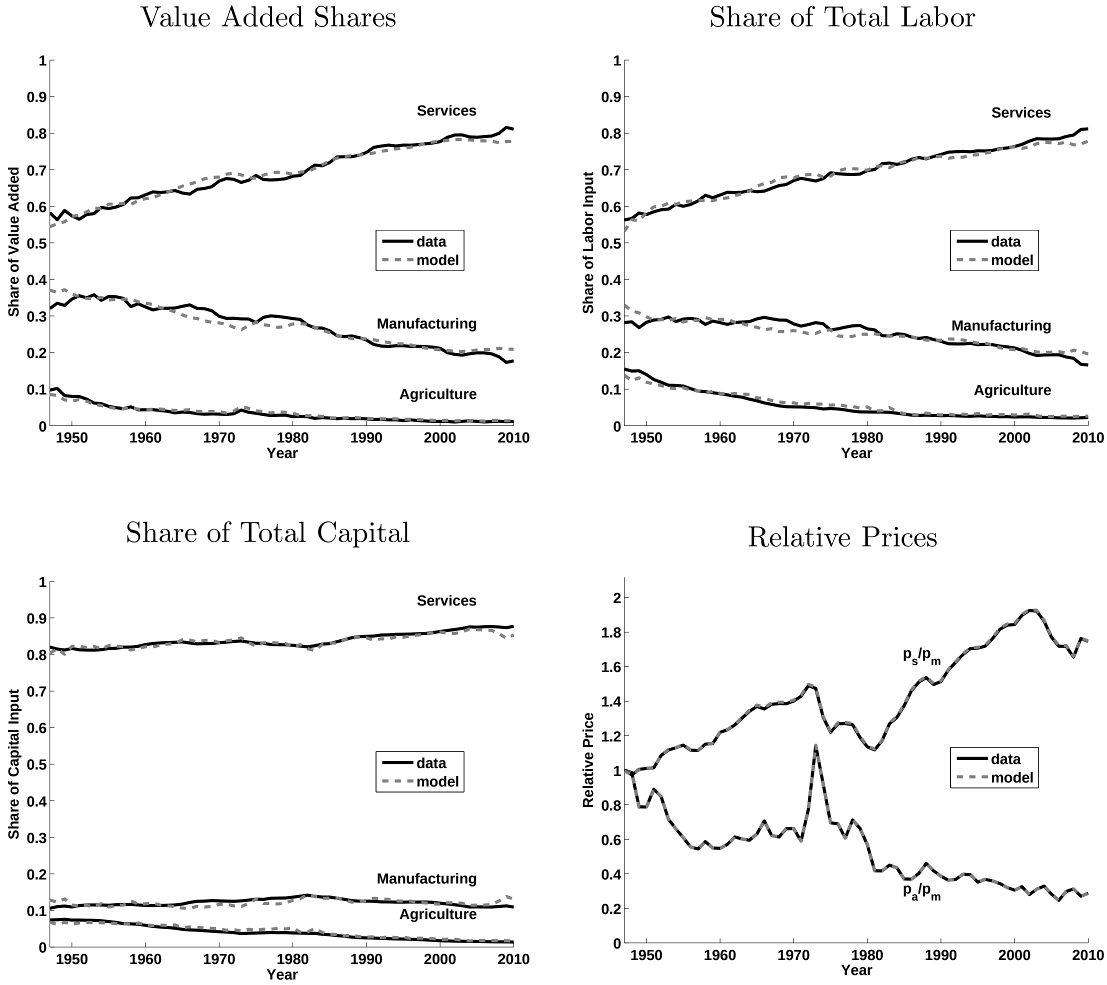
This section first examines how well the model fits the observed structural transformation in the United States and India. Afterwards the model is used to decompose structural transformation into the contribution of the four theoretical mechanisms.

4.1 Explaining Structural Transformation

Figures 2 and 3 compare model predictions on sectoral value added shares, sectoral shares of the total labor and capital input and sectoral relative prices to the data for the United States (1947-2010) and India (1980-2011), respectively. It turns out that the parameterized model fits the data very well. This shows that models with the four theoretical mechanisms are in principle rich enough to explain the observed structural transformation. This is not the case for more parsimonious models with only the income and differential productivity effect as shown by Buera and Kabowski (2009).

The graphs also show that the approach used to measure the driving forces and estimate model parameters is successful in fitting the model to the data. This is a result of the way how the demand estimation, the measurement of distortions and the measurement of productivity interact with each other. Given correct prices and income levels the demand estimation ensures that consumers demand approximately the correct budget shares, which due to the market-clearing condition for goods ensures that sectoral value added shares and levels will also be correct. But given approximately correct value added levels the measurement of distortions forces the level of labor and capital input in each sector to also roughly be correct. Finally, given that value added and input levels are about right the measurement

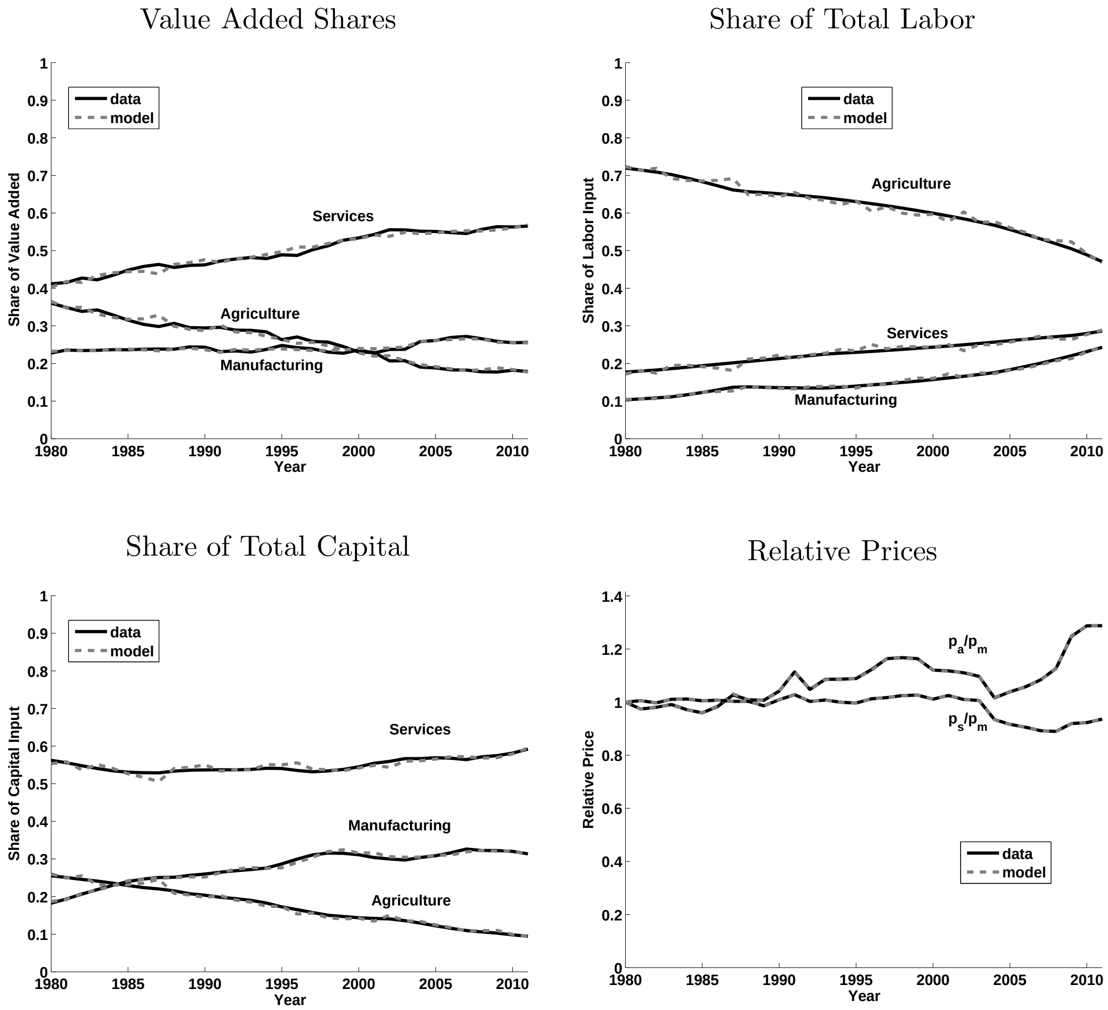
Figure 2: United States (1947-2010)



of productivity ensures that prices and nominal income levels are approximately correct. Thus all endogenous variables in the model are simultaneously forced to be close to the data.

One also observes notably different empirical patterns of structural change across countries which reflect that they are at different stages of economic development. In India initially most of the labor force is still employed in agriculture though agriculture is no longer the largest sector in total value added. In advanced countries the manufacturing sector exhibits a hump-shaped pattern over the course of structural transformation, cf. Herrendorf, Rogerson, and Valentinyi (2014). But India is still in the ascending part of the manufacturing hump such that the shares of both manufacturing and services increase over time, while the share of agriculture declines. In addition to labor reallocation there is also a substantive reallocation of capital at least between agriculture and manufacturing. In

Figure 3: India (1980-2011)



contrast at the beginning of the observation period in the United States the service sector is already the largest sector. The U.S. manufacturing sector is past its peak such that over time the share of both agriculture and manufacturing decline, while the share of services increases. Sectoral shares of capital are more stable than in India. There are also marked differences across countries in how relative prices change over time. In the United States the relative price of agriculture declines and the one of services decreases (both relative to the manufacturing sector). In contrast, in India the relative price of agriculture increases over time, while the relative price of services almost stays constant or declines weakly.

4.2 Decomposition

Table 3 presents the decomposition results for the United States (1947-2010) and India (1980-2011). For several key variables the table reports the change over the whole time period Δ observed in the data and in the model, and the absolute and relative contribution of the four theoretical mechanisms to this change. The variables are sectoral value added shares y_i, labor input shares ℓ_i and capital input shares κ_i (all measured in percent) for each sector i, and price ratios of agriculture and services relative to manufacturing $\frac{p_a}{p_m}$ and $\frac{p_s}{p_m}$.

In the United States during the time period of 1947 to 2010 the income effect contributes the most to the observed structural changes in sectoral shares of value added, labor and capital. The relative contribution of the income effect $(\Delta_A^{\tilde{g}} + \Delta_E^{\tilde{\alpha}})$ is usually between about $50 - 70\%$. Differential productivity growth and changes to distortions also play a role. With the former having a relative contribution of about $20 - 40\%$ $(\Delta_A^{g_i})$ and the latter about 10% (Δ_D). The effect of capital deepening given differential capital intensiveness $(\Delta_E^{\alpha_i})$ is relatively weak.

Differential productivity growth is the main driver of relative price changes over time in the United States, with a relative contribution of around 80%. About 16% of the change to the agricultural relative price is explained by capital deepening given differential capital intensiveness and only 5% by changes to distortions. In contrast changes to distortions explain 55% of the change in the relative price of services, while the differential capital deepening effect constitutes an opposing effect of about 33%. Naturally, advances in aggregate productivity and factor endowments do not affect relative prices much. The effect is not completely zero here because the effect of sectoral differences in α_i has only been eliminated for changes to factor endowments and not for changes to aggregate productivity.

In India during 1980 to 2011 the income effect is also by and large the dominant force behind the changes to sectoral shares of value added, labor and capital. However for most variables its relative contribution exceeds 100%. Differential productivity growth only contributes substantially to the structural changes for the manufacturing sector, while it constitutes a significant opposing force for the changes to services and a weak opposing force for the movements out of agriculture. Again the differential effects associated with capital deepening tend to be weak for the changes to quantities. The effects of changes to distortions are somewhat heterogeneous and for some variables contribute to and for others oppose the observed changes.

The increase in the agricultural relative price in India is mainly driven by the

Table 3: Decomposition Results

United States (1947-2010)

Var.	Δ Data	Δ Model	Absolute Contribution $\Delta_A^{\tilde{g}}+\Delta_E^{\tilde{\alpha}}$	$\Delta_A^{g_i}$	$\Delta_E^{\alpha_i}$	Δ_D	Relative Contribution (in %) $\Delta_A^{\tilde{g}}+\Delta_E^{\tilde{\alpha}}$	$\Delta_A^{g_i}$	$\Delta_E^{\alpha_i}$	Δ_D
$y_a(\%)$	-8.5	-7.2	-3.6	-2.9	0.1	-0.8	50	40	-1	11
$y_m(\%)$	-14.3	-16.2	-11.9	-2.9	0.9	-2.3	74	18	-6	14
$y_s(\%)$	22.9	23.3	15.5	5.8	-1.0	3.1	66	25	-4	13
$\ell_a(\%)$	-13.3	-11.2	-6.2	-4.9	0.4	-0.5	56	44	-4	5
$\ell_m(\%)$	-11.6	-13.4	-9.6	-2.2	0.1	-1.8	72	16	-1	13
$\ell_s(\%)$	24.9	24.6	15.8	7.1	-0.6	2.3	64	29	-2	9
$\kappa_a(\%)$	-6.0	-5.2	-3.5	-2.7	-0.1	1.2	68	52	3	-23
$\kappa_m(\%)$	0.3	0.2	-7.9	-1.7	1.5	8.3	-3585	-766	681	3770
$\kappa_s(\%)$	5.7	5.0	11.4	4.4	-1.4	-9.5	229	88	-27	-190
$\frac{p_a}{p_m}$	-0.71	-0.71	0.01	-0.57	-0.11	-0.03	-1	80	16	5
$\frac{p_s}{p_m}$	0.75	0.75	0.01	0.58	-0.25	0.41	1	77	-33	55

India (1980-2011)

Var.	Δ Data	Δ Model	Absolute Contribution $\Delta_A^{\tilde{g}}+\Delta_E^{\tilde{\alpha}}$	$\Delta_A^{g_i}$	$\Delta_E^{\alpha_i}$	Δ_D	Relative Contribution (in %) $\Delta_A^{\tilde{g}}+\Delta_E^{\tilde{\alpha}}$	$\Delta_A^{g_i}$	$\Delta_E^{\alpha_i}$	Δ_D
$y_a(\%)$	-18.2	-18.8	-23.5	1.7	-0.4	3.4	125	-9	2	-18
$y_m(\%)$	2.8	2.3	2.5	11.1	-0.0	-11.3	108	491	-1	-498
$y_s(\%)$	15.4	16.5	21.0	-12.8	0.4	7.9	127	-77	3	48
$\ell_a(\%)$	-24.9	-25.5	-30.6	1.1	1.6	2.4	120	-4	-6	-10
$\ell_m(\%)$	14.0	13.8	8.8	7.1	-0.6	-1.5	64	51	-4	-11
$\ell_s(\%)$	10.9	11.7	21.8	-8.2	-1.0	-0.9	186	-70	-8	-8
$\kappa_a(\%)$	-16.1	-16.7	-17.7	1.6	0.4	-1.0	106	-9	-2	6
$\kappa_m(\%)$	13.1	12.5	-0.3	11.8	-0.4	1.3	-2	94	-3	11
$\kappa_s(\%)$	3.0	4.2	17.9	-13.4	-0.0	-0.4	431	-321	-0	-9
$\frac{p_a}{p_m}$	0.29	0.29	-0.01	-0.47	0.08	0.69	-4	-163	28	239
$\frac{p_s}{p_m}$	-0.06	-0.06	-0.00	-0.73	0.01	0.66	2	1142	-9	-1035

Notes: y_i: value added share of sector i. ℓ_i: sectoral share in total labor input. κ_i: sectoral share in total capital input. $\frac{p_i}{p_m}$: relative price of sector i relative to manufacturing. Δ: absolute change of the respective variable between first and last period. $\Delta_A^{\tilde{g}}+\Delta_E^{\tilde{\alpha}}$: effect of advances in aggregate productivity and factor endowments. $\Delta_A^{g_i}$: effect of differential productivity growth. $\Delta_E^{\alpha_i}$: differential capital deepening effect. Δ_D: effect of changes to distortions. Detailed definitions are provided in section 2.2.

changes to distortions, while differential productivity growth has a large opposing effect. This pattern is reversed for explaining the small observed decline in the relative price of services.

Overall these results show that all four theoretical mechanisms are useful for understanding certain aspects of the process of structural transformation. The quantitative importance and the direction of the different sources of structural transformation differ substantially across countries at different levels of economic development. The income effect is a very important contributor to structural transformation in both countries, but more so in India. In contrast, differential productivity growth contributes significantly to structural changes in the United States, but with the exception of manufacturing has an effect opposing the observed structural changes in India. The impact of changes to distortions and differential capital deepening tend to be smaller in absolute magnitude. But all sources except for the income effect help to understand relative price changes during the structural transformation.

One question that comes to mind is of course whether these patterns for India are also representative for the experience of the United States at an earlier stage of the structural transformation where agriculture was still more important. Though long-run time series data is available for the United States this data only covers agriculture versus non-agriculture and not the three sectors analysed here. Nevertheless Alvarez-Cuadrado and Poschke (2011) and Dennis and Iscan (2009) provide evidence that during earlier periods in U.S. history productivity in agriculture grew more slowly than in non-agriculture and the price of agricultural to non-agricultural goods increased. This would be consistent with differential productivity growth also being a force opposing the observed structural change during such a period.

5 Conclusions

The paper has investigated the quantitative role of the four main theoretical explanations for structural transformation and how they contribute to this process in the United States during 1947-2010 and India during 1980-2011. In the United States the income effect from advances in aggregate productivity and factor endowments is the most important force driving structural transformation. But differential productivity growth also contributes substantively and to a somewhat smaller extend changes to distortions contribute as well. The differential capital deepening effect is relatively unimportant. In India the by far dominant force behind structural change is the income effect of improved aggregate productivity and factor endowments. Differential productivity growth is a quantitatively large force opposing or slowing down the observed structural transformation except for the rise in the manufacturing sector. Changes to distortions and the differential capital deepening effect are relatively weak opposing forces. Thus the analysis provides evidence for substantial heterogeneity in the sources of structural transformation across countries at different levels of development.

The paper provides a first attempt to quantify the four main theories and sources of structural transformation in multiple countries at different levels of development. However there is great potential to expand and improve this analysis in future research. For instance it would be desirable to analyse more countries, though data availability is unfortunately a severe obstacle for such attempts especially for developing countries. There is also scope for modifying several features of the theoretical framework such as allowing for sectoral differences in the substitutability of capital and labor (Alvarez-Cuadrado, Long, and Poschke 2017) or to use alternative preference specifications (Boppart 2014; Comin, Lashkari, and Mestieri 2017). A more detailed modelling and empirical investigation of the different components of demand (consumption, investment, government spending, net exports) and their sectoral composition and dynamics would also be useful. Allowing for an open economy one could in principle also analyse how supply-side changes to productivity, factor endowments and distortions in foreign countries affect the sectoral structure in the domestic economy as suggested by Matsuyama (2009). However the framework and results of this paper are a useful starting point and benchmark to explore such features in future research.

References

Acemoglu, D. and V. Guerrieri (2008). Capital Deepening and Nonbalanced Economic Growth. *Journal of Political Economy 116*(3), 467–498.

Alvarez-Cuadrado, F., N. V. Long, and M. Poschke (2017). Capital-Labor Substitution, Structural Change, and Growth. *Theoretical Economics 12*(3), 1229–1266.

Alvarez-Cuadrado, F. and M. Poschke (2011). Structural Change out of Agriculture: Labor Push versus Labor Pull. *American Economic Journal: Macroeconomics 3*(3), 127–158.

Baumol, W. J. (1967). Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis. *American Economic Review 57*(3), 415–426.

Boppart, T. (2014). Structural Change and the Kaldor Facts in a Growth Model with Relative Price Effects and Non-Gorman Preferences. *Econometrica 82*(6), 2167–2196.

Buera, F. J. and J. P. Kabowski (2009). Can traditional Theories of Structural Change fit the Data? *Journal of the Euopean Economic Association 7*(2-3), 469–477.

Caselli, F. and W. J. Coleman (2001). The U.S. Structural Transformation and Regional Convergence: A Reinterpretation. *Journal of Political Economy 109*(3), 584–616.

Comin, D., D. Lashkari, and M. Mestieri (2017). Structural Change with Long-Run Income and Price Effects. *Working Paper*.

Dennis, B. N. and T. B. Iscan (2009). Engel versus Baumol: Accounting for Structural Change using Two Centuries of U.S. Data. *Explorations in Economic History 46*(2), 186–202.

Engel, E. (1857). Die Productions- und Consumtionsverhältnisse des Königreichs Sachsen. *Zeitschrift des statistischen Bureaus des Königlich Sächsischen Ministerium des Inneren 8-9*, 1–54.

Gollin, D., D. Lagakos, and M. E. Waugh (2014). The Agricultural Productivity Gap. *Quarterly Journal of Economics 129*(2), 939–993.

Hayashi, F. and E. C. Prescott (2008). The Depressing Effect of Agricultural Institutions on the Prewar Japanese Economy. *Journal of Political Economy 116*(4), 573–632.

Herrendorf, B., C. Herrington, and A. Valentinyi (2015). Sectoral Technology and Structural Transformation. *American Economic Journal: Macroeconomics 7*(4), 104–133.

Herrendorf, B., R. Rogerson, and A. Valentinyi (2013). Two Perspectives on Preferences and Structural Transformation. *American Economic Review 103*(7), 2752–2789.

Herrendorf, B., R. Rogerson, and A. Valentinyi (2014). Growth and Structural Transformation. In P. Aghion and S. N. Durlauf (Eds.), *Handbook of Economic Growth*, Volume 2B, pp. 855–941. Amsterdam: Elsevier.

Kongsamut, P., S. Rebelo, and D. Xie (2001). Beyond Balanced Growth. *Review of Economic Studies 68*(4), 869–882.

Matsuyama, K. (2009). Structural Change in an Interdependent World: A Global View of Manufacturing Decline. *Journal of the Euopean Economic Association 7*(2-3), 478–486.

Ngai, L. R. and C. A. Pissarides (2007). Structural Change in a Multisector Model of Growth. *American Economic Review 97*(1), 429–443.

Shorrocks, A. F. (2013). Decomposition Procedures for Distributional Analysis: A Unified Framework based on the Shapley Value. *Journal of Economic Inequality 11*(1), 99–126.

Swiecki, T. (2017). Determinants of Structural Change. *Review of Economic Dynamics 24*, 95–131.

Temple, J. (2005). Dual Economy Models: A Primer for Growth Economists. *The Manchester School 73*(4), 435–478.

Temple, J. and L. Wößmann (2006). Dualism and Cross-Country Growth Regressions. *Journal of Economic Growth 11*(3), 187–228.

Vollrath, D. (2009). How Important are Dual Economy Effects for Aggregate Productivity? *Journal of Development Economics 88*(2), 325–334.