The Rise of Services and Balanced Growth in Theory and Data*

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Abstract

We investigate the effect of structural transformation on the process of economic growth. Using a two-sector growth model we show that, in addition to lowering the growth rate of GDP (i.e. Baumol's cost disease), structural transformation from manufacturing to services generates other predictions that are in line with cross-country growth facts: an increase in the real investment rate and a decline in the real interest rate and the marginal product of capital as economies develop. Using the model calibrated to U.S. data, we can account for the elasticity of real investment rates to the share of services measured in cross-country data.

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1 Introduction

Since the seminal contribution of Baumol (1967), several papers have discussed the effect of structural transformation (ST hereafter) on aggregate productivity, often labeling this phenomenon as Baumol's cost disease. As ST occurs, the economy experiences a transition from a high TFP growth sector (manufacturing) to one with low TFP growth (services). This transition implies that aggregate productivity slows down, and so does GDP growth. Baumol's cost disease has been extensively discussed and measured both for the U.S. and in a cross-country dimension.[1] However, while the effect on aggregate productivity is well understood, the implications of ST on other aspects of the growth process have received little attention. For instance, a robust observation of the growth process is an increasing real investment rate as income grows, which is typically attributed to a declining price of investment (relative to consumption). ST contributes to this process by moving resources from manufacturing to services. As long as the investment good is more intensive in manufacturing than in services with respect to the consumption good, the relative price of investment declines. In this light, ST endogenously generates investment-specific technological change, also determining its pace. As a result, the evolution of the real investment rate is affected by the pattern of ST.

Here we investigate theoretically and quantitatively the effect of ST on elements of the growth process that have received little attention in previous work, namely the real interest rate (RIR), the marginal Product of Capital (MPK), the capital/output ratio and the investment/output ratio. In the first part of the paper, we assess the the role of ST on growth in the U.S. by using an off the shelf two-sector growth model of ST, first proposed in Boppart (2014). The model displays balanced growth when aggregate output is measured in units of an appropriately chosen numeraire (i.e. the capital good). However, we show that, when aggregate output is measured using standard NIPA methodology to construct GDP from the model's equilibrium, growth becomes "unbalanced" and it is possible to measure the effect of ST on the variables shaping the growth process. Since the post-war period, the U.S. economy has experienced an increase in the share of services in consumption, a decline in the relative price of goods to services, an increase in the real investment to output ratio and an increase in the ratio of real capital services to GDP.[2] These facts suggest that, while

[1]See Echevarria (1997), Nordhaus (2008), Moro (2015) and Duernecker, Herrendorf, and Valentinyi (2017) for instance.

[2]Most of the literature focuses on the constancy of the capital/GDP ratio as measured by NIPA. However, when using BLS estimates of the capital stock (i.e. capital *services*) as in Fernald (2012) and Gourio and Klier (2015), the capital/GDP ratio displays a positive trend. The capital services measured by the BLS are a more appropriate measure of an input in a production function, while the NIPA estimate is more appropriate as a measure of real wealth in the economy.

ST occurs, the U.S. experiences "unbalanced" growth. We thus calibrate the model to replicate certain features of the U.S. economy in the past 65 years: the *average* rate of growth of GDP, the observed change in the share of services in consumption, the increase in the real investment/GDP ratio, and the relative price manufacturing/services. The calibrated model replicates the data targets well and predicts the following patterns over the period: i) a fall in the marginal product of capital (and increase in the real capital to output ratio) of 36% in units of GDP and of 43% in units of aggregate consumption; ii) a decline in the real interest rates of 5% in terms of GDP units and 7% in terms of consumption units; and iii) a decline of the per capita GDP growth rate of 0.37 percentage points (from 2.29% per year to 1.93% per year) from the beginning to the end of the sample period. Our quantitative results suggest that ST has a non-negligible effect on the growth process in the U.S., a country that is typically considered to follow a well defined balanced growth path.

In the second part of the paper we turn to assessing the role of ST using cross-country data. Specifically, we focus on the well known observation that real investment rates increase with economic development (Barro (1991), Hsieh and Klenow (2007)). To do this, we compare the performance of the ST model with that of a standard investment-specific technological change (ISTC) theory in which the relative price of investment declines exogenously over time at a constant pace. We first show that the ST model displays a set of additional predictions with respect to the ISTC model which are qualitatively consistent with cross-country data: 1) the rise of the services share in GDP as income grows (Herrendorf, Rogerson, and Valentinyi (2014)); 2) the decline in the growth rate of GDP as the share of services grows (Echevarria (1997), Moro (2015)); 3) a declining real interest rate as income grows (Barro and Sala-i-Martín (2004, p. 13)); and 4) an acceleration of ISTC as income grows (Samaniego and Sun (2016)). Second, we use the model to assess to what extent the process of ST can account for the elasticity of real investment rates to the share of services. By using data from the International Comparisons Program (PWT) we compute this elasticity for the benchmark years 1980, 1985, 1996, 2005 and 2011, finding an average value across years of 0.61. We tie our hands by using the same parametrization arising from the U.S. calibration to calculate the elasticity of the real investment rate with respect to the share of services that arises along the growth path of the model, and compare it with that estimated in the data. The model provides an elasticity of 0.63, virtually the same as in the data. When we use the ISTC model calibrated to the U.S. to compute the elasticity of real investment rates to the income level, we find a substantial difference: 0.43 in the data versus 0.19 in the model. Thus, the ST model performs substantially better than the ISTC in predicting real investment rates. The main reason behind this finding is due to the acceleration of ISTC as income grows. A model of exogenous ISTC cannot capture this acceleration by construction. Instead, the model of ST endogenously generates it due to the changing composition of consumption.The mechanics of the effect of ST on the growth process can be explained as follows. In the model, sectoral TFP grows at a constant (but different) rate in the two sectors, which implies a constant decline in the relative price of goods/services, as observed in the U.S. in the post-war period. This minimal assumption, when paired with non-homothetic preferences, leads to a change in the composition of consumption (i.e. structural change) given by the rise of the services sector.[3] As ST occurs, growth in the model is balanced in the sense that the growth rate of aggregate output, the capital/output ratio, the investment rate and the real interest rate are all constant over time. This is what happens in the models in Kongsamut, Rebelo, and Xie (2001), Ngai and Pissarides (2007) and Boppart (2014). The typical definition of balanced growth in these *models*, however, relies on expressing all variables, including aggregate output, in terms of a numeraire. This is usually the price of capital. Instead, these works are silent about the growth properties of the economy if real variables are expressed in terms of units of another good.[4] We show here that the concept of balanced growth strictly depends on the units variables are expressed in. This is relevant when bringing the *model* to the *data*, because GDP in the data differs from nominal aggregate output divided by the price of one good. Instead, real GDP in the data is constructed using a chain-weighted Fisher index. Roughly speaking, the Fisher index weights the growth rate of individual components of GDP by their shares in GDP. This implies that, even if variables grow at a constant rate, if these rates are different and there is ST, the growth rate of GDP is non-constant over time. This non-constancy of the growth rate is then associated with trends in the marginal product of capital, the real interest rate, the capital-output ratio, and the real investment-output ratio.

Our work is related to several streams of the literature. Here we discuss those most closely related, in addition to the ones mentioned above. First, this paper belongs to a broad ongoing research project pointing out that the measurement of the multi-sector model with NIPA methodology is key for the model to generate aggregate dynamics that are comparable with the data. Within this line of research, Duernecker, Herrendorf, and Valentinyi (2017) study the effect of ST on the slowdown of aggregate productivity in the U.S. and make predictions on the future path of this variable. They consider a sequence of static economies in a three sector model and focus mainly on the different evolution of TFP within services

[3]Buera and Kaboski (2012a) and Buera and Kaboski (2012b) investigate the theoretical mechanism that lead the services sector to grow along the growth path, linking this process to the rise of the skill premium, economies of scale, and home production.

[4]Note, however, that both Ngai and Pissarides (2007) and Boppart (2014) point out that the real rate of interest declines along the balanced growth path of their models. Here we use the model to quantify this effect for the U.S. economy during the period 1950-2015 together with the other variables of interest.

sectors.[5] Our focus here is to analyze the effect of ST on several variables which, in addition to GDP growth, are important to describe the growth process within and across countries. For this purpose, we study a two sector model and focus on the distinction between balanced growth in theory and unbalanced growth in the data using a model with capital, which allows us to measure the evolution of the marginal product of capital and the real investment rate along the growth path. Duernecker, Herrendorf, and Valentinyi (2018) provide analytical expressions for the differences in GDP growth obtained using NIPA-consistent Fisher index and various numeraires in different versions of the multisector growth model. Their focus is on the time-series evolution of GDP growth in the U.S. economy. Here, instead, we mainly focus on the effect of ST for the evolution of great ratios and also study its consequences in a cross-country perspective.

This paper also relates ST and growth in a cross-country perspective. While ST appears as a robust regularity across countries, few papers study its role in shaping the various aspects of the growth process in a cross-country dimension, with two exceptions being Echevarria (1997) and Moro (2015). Echevarria (1997) is the first paper explicitly investigating the effect of ST on growth in a multi-sector growth model, finding a hump-shaped pattern of growth rates depending on the stage of ST. Moro (2015) studies the effect of ST on growth using Fisher chain-weighted index to measure GDP but abstracts from capital accumulation, and focuses on the effect of structural transformation on GDP growth and volatility. Modeling capital accumulation is key here, as it allows to measure the effect of ST on the real interest rate, the marginal product of capital, and the real investment-output and capital-output ratios, something not explored in either Echevarria (1997) or Moro (2015), who focus mainly on GDP growth. By doing this, we relate ST to the well documented cross-country increase in real investment rates as income grows discussed, for instance, in Barro (1991), Hsieh and Klenow (2007) and, more recently, in García-Santana, Pijoan-Mas, and Villacorta (2016), and find that a model of ST without distortions can account well for this pattern.[6]

The remainder of the paper is organized as follows. Section 2 presents some data facts for the U.S. economy; in section 3 we present the model and in section 4 we show how to measure the model's equilibrium with NIPA methodology. In section 5 we calibrate the model to U.S. data and use it as a measurement tool to assess the implications for the marginal product of capital, the real interest rate, and the growth rate of GDP. In section 6 we discuss the international evidence and use the model to assess how much ST can explain of cross-country differences in investment rates and we compare the predictions of our model with those of a

[5] IMF (2018) also emphasizes the heterogeneity of the service sector in productivity trends.

[6] García-Santana, Pijoan-Mas, and Villacorta (2016) also find that nominal investment rates display a hump shaped pattern with development. Our focus here is mainly on real investment rates, which increase with economic development.

model with investment-specific technical change. In section 7 we conclude.

2 Stylized facts for the U.S.

We present a set of facts that describe the U.S. growth process and that we use to calibrate the model in section 5. We pay special attention to the measurement of variables in a way that is consistent with the two-sector model presented below. The key variables are the relative price of goods over services, the investment to GDP ratio measured in real terms, the capital-GDP ratio measured in real terms, and the nominal share of services consumption in total personal consumption expenditure. In the two-sector model below we assume that the manufacturing sector produces a good that can be used both for investment and for consumption of manufacturing. Thus, in the data we construct a *price of goods* which is a Fisher chain-weighted price index of consumption goods and gross domestic investment (GDI).[7]

The relative price goods/services is obtained from NIPA tables as the *price of goods* (constructed as described above) relative to the price of services.[8] The real GDI to GDP ratio is calculated as the ratio of real investment to real GDP. We deflate nominal GDI[9] using the same *price of goods* used to construct the goods/services price ratio. Note that when using the investment deflator from NIPA tables to deflate investment, the trend observed in the investment/GDP ratio is similar and statistically significant, but less pronounced.[10] This is discussed further below because replicating a measure of the investment-output ratio deflated by the investment price requires a three-sector model.[11] Finally, real GDP is given by nominal GDP deflated by the GDP deflator.

Additionally, we present evidence on the evolution of the capital-GDP ratio. We are interested in the ratio between the real capital stock and real GDP, i.e. where each nominal measure is deflated by its own price. Note that this differs from the ratio of the two nominal measures as long as the relative price deflators for capital and GDP are different.

The measurement of capital is more controversial than that of investment. For this reason the estimates should be taken with caution. We use the measure coming from the BLS Multi Factor Productivity (MFP) project which calculates total capital services for

[7] In Appendix A we present a three-sector model and present data for the relative prices goods/services and investment/services. As we show there, the main message in the data and in the model is confirmed.

[8] NIPA Table 1.1.4 at http://www.bea.gov/iTable/index_nipa.cfm.

[9] NIPA Table 1.1.5.

[10] See Appendix A.

[11] The price of total goods including investment and consumption relative to services, displays a very similar trend to that of the price of consumption goods relative to services. The former falls at a rate of 1.57% per year between 1950 and 2015, and the latter at a rate of 1.61% per year.

the private business sector.[12] The measure uses a Jorgensonian perpetual-inventory method aggregating different types of capital according to their real user costs. As pointed out in Gourio and Klier (2015), BLS estimates are a more appropriate measure of factor inputs than BEA fixed assets accounts, as they use weights based on real user costs to aggregate capital stocks. For comparison, we also show the measure of Fernald (2012), which accounts for the total business sector and is adjusted for capital utilization. In practice, the trends displayed by these two measures are very similar, as they mostly differ only in terms of business cycle volatility.

Finally, the share of services in total consumption expenditure is calculated as the nominal share of personal consumption expenditure on services over total personal consumption expenditures (i.e. on services and goods). The data also come from NIPA (Table 1.1.5).

Figure 1 presents the data in logs (except for the consumption share of services) and a fitted trend line. The figure also contains the investment (GDI) to output (GDP) ratio in nominal terms from NIPA accounts for comparison. The price of consumption goods relative to services displays a very well defined negative trend implying a yearly growth of -1.57%. This is accompanied by an increase in the share of services in total private consumption expenditure from 40% in 1950 to 68.5% in 2015, which appears to be leveling off slightly during the last 15-20 years. The increase in the share of services in consumption and GDP is a well known fact in literature on the process of structural transformation (see Herrendorf, Rogerson, and Valentinyi (2014)). The data in figure 1 suggest that this process has been accompanied by a steady increase in the real measures of the investment to GDP ratio and capital to GDP ratio. The former increases at a rate of 0.92% per year and the latter at a rate of 0.46% per year (0.42% if using the measure by Fernald (2012) adjusted for capacity utilization). In contrast, the nominal investment-output ratio does not display any significant trend.[13]

While none of the facts presented in this section is new, the relationship between the growth facts discussed here and structural transformation has received little attention in the literature. We aim at investigating this relationship by using a model of structural transformation that displays a theoretical balanced growth path. When appropriately compared to the data, this model can account *jointly* for all the facts presented in this section.[14]

[12] We used the historical multifactor productivity dataset available at `https://www.bls.gov/mfp/special_requests/mfptablehis.xlsx` March 2016 release for the private sector. To calculate capital-output ratios we used the real value added measure provided in the same database and transformed the resulting series into an index number with base year 1950.

[13] Note that the capital service data are for the private business sector only, as BLS does not produce historical statistics for capital services for the overall economy. However, our investment data include the whole economy.

[14] It is well known that models of investment-specific technical change (ISTC) can also generate different

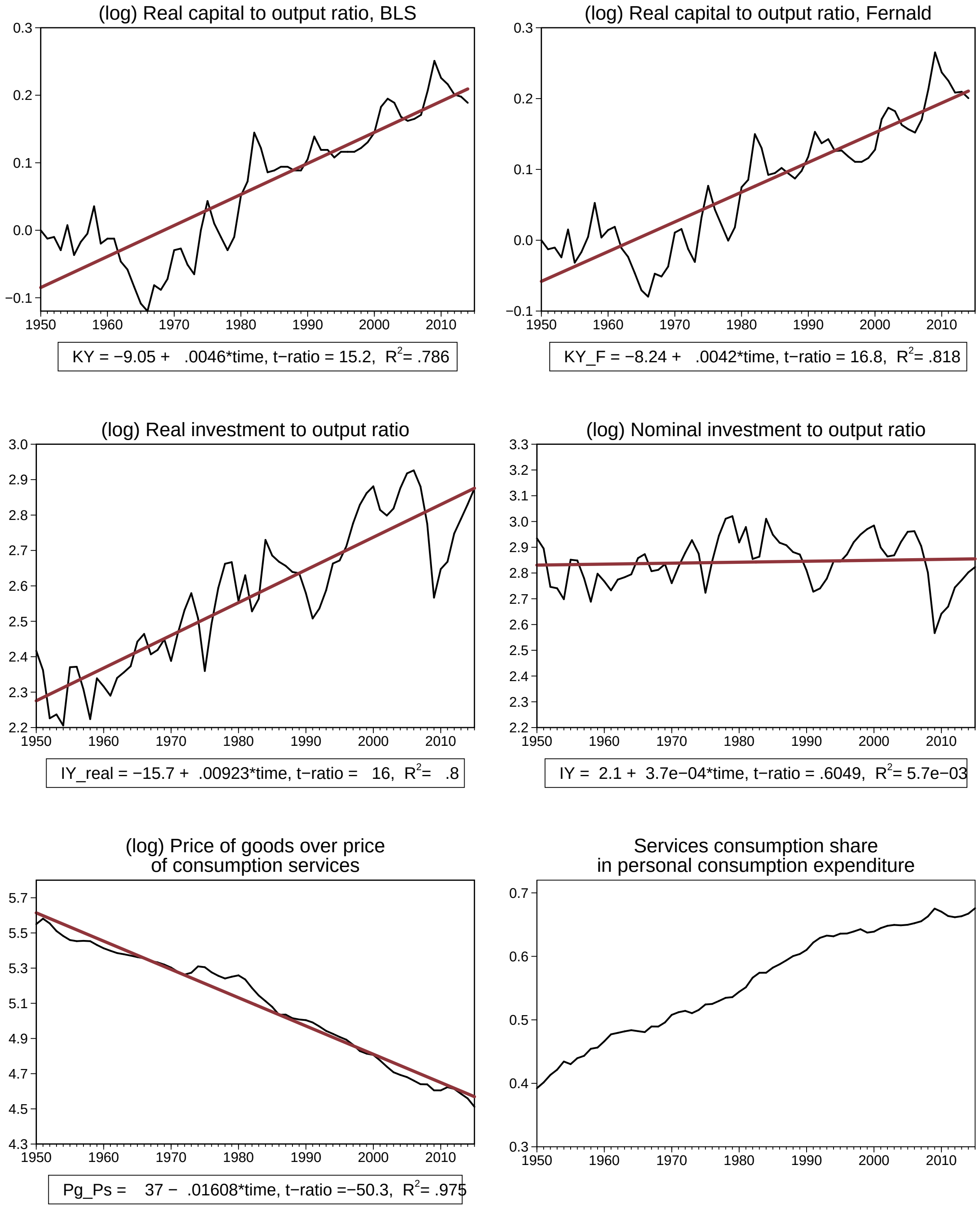

Figure 1: BLS capital-output ratio, Fernald capital-output ratio, real investment-output ratio, nominal investment-output ratio, price of goods relative to services consumption, and share of services consumption in total consumption expenditure. All variables in logs and with a fitted linear trend except for consumption shares.

3 Model

This section presents a two-sector model of structural change with balanced growth. The model is a simplified version of Boppart (2014), where we abstract from household heterogeneity and focus on features related to structural transformation between goods producing and services producing sectors, since we then use the model as a measurement tool.

3.1 Households

Time t is discrete. There are two types of goods in the economy: two consumption goods (manufacturing and services) and one investment good. The representative household in this economy has preferences given by

$$U = \sum_{t=0}^{\infty} \beta^t V(p_{st}, p_{gt}, E_t), \tag{1}$$

where β is the subjective discount factor, $V(p_{st}, p_{gt}, E_t)$ is an instantaneous indirect utility function of the household, p_{st} is the price of services, p_{gt} the price of manufacturing, and E_t is total nominal consumption expenditure. The explicit functional form for V is

$$V(p_s, p_g, E) = \frac{1}{\epsilon}\left[\frac{E}{p_s}\right]^{\epsilon} - \frac{\nu}{\xi}\left(\frac{p_s}{p_g}\right)^{-\xi} - \frac{1}{\epsilon} + \frac{\nu}{\xi}, \tag{2}$$

where $0 \leq \epsilon \leq \xi \leq 1$ and $\nu > 0$. These non-homothetic and non-Gorman type of preferences are the key to obtaining balanced growth in the original model by Boppart (2014). Within the indirect utility function $1 - \epsilon$ governs the exponential evolution of expenditure shares, both ϵ and ξ govern the elasticity of substitution between the two goods, and ν is a shift parameter.

The household owns the capital stock of the economy and rents it out to firms in the market. It also inelastically supplies a unit of labor to firms each period in exchange for a wage. The budget constraint is

$$E_t + p_{gt}K_{t+1} = w_t + p_{gt}K_t(1 + r_t - \delta), \tag{3}$$

where w_t is the wage rate, K_t is the amount of capital owned by the household, r_t is the (gross) return on capital and δ is the depreciation rate. Thus, the problem of the household is to maximize (1) subject to (2) and (3).

trends for real and nominal investment rates. In section 6 below we discuss the differences between ISTC models relative to models of structural transformation in terms of their consequences for the growth process.

The indirect utility function $V(p_{st}, p_{gt,} E_t)$ encompasses the static problem in which the household decides, given the level of consumption expenditure E_t, how much to spend in goods and services such that instantaneous utility is maximized and

$$E_t = p_{st}C_{st} + p_{gt}C_{gt},$$

holds, where C_{st} and C_{gt} are the optimal consumption levels of services and manufacturing.

3.2 Firms and Market Clearing

There are two representative firms in the economy operating in perfect competition. The first firm produces the manufacturing good with technology

$$y_{gt} = k_{gt}^{\alpha}(n_{gt}A_{gt})^{1-\alpha}, \tag{4}$$

where k_{gt}, n_{gt} and $A_{gt}^{1-\alpha}$ are capital, labor and total factor productivity (TFP) of the goods producing firm. This output can be used to build the capital stock or as consumption of manufacturing.[15] The second firm produces services with technology

$$y_{st} = k_{st}^{\alpha}(n_{st}A_{st})^{1-\alpha}, \tag{5}$$

with k_{st}, n_{st} and $A_{st}^{1-\alpha}$ being capital, labor and TFP of the service producing firm. The output of this firm is used as services consumption.

The efficiency terms in the two sectors evolve according to

$$\frac{A_{st+1}}{A_{st}} = 1 + \gamma_s, \tag{6}$$

$$\frac{A_{gt+1}}{A_{gt}} = 1 + \gamma_g, \tag{7}$$

where γ_s and γ_g are exogenous constant growth rates, and we assume that $\gamma_s < \gamma_g$.

In equilibrium, all markets clear and the following must hold:

$$y_{gt} = C_{gt} + K_{t+1} - (1 - \delta)K_t,$$

$$y_{st} = C_{st},$$

$$k_{gt} + k_{st} = K_t,$$

[15] In Appendix A we consider the case in which consumption and investment goods are produced in different sectors.

and

$$n_{gt} + n_{st} = 1.$$

3.3 A model displaying both balanced and unbalanced growth

In this subsection we show how growth in the model can be balanced or unbalanced depending on the units it is measured in. To do this, we first consider the properties of the economy at time t in two extreme cases, one in which only manufacturing is produced, and the other in which only services are produced. Next, we use the production possibility frontier of the economy to study the case in which aggregate output is a composite of manufacturing and services.

At a point in time t, there are two possible aggregate production functions that can be defined, one mapping total capital and labor in the economy into the maximum amount of manufacturing that can be produced, and another mapping the same inputs into the maximum amount of services that can be produced. Boppart (2014) shows that the aggregate production function in manufacturing units is

$$Y_{gt} = K_t^{\alpha}(A_{gt})^{1-\alpha}. \tag{8}$$

Boppart (2014) also shows that there is a dynamic equilibrium which represents a balanced growth path (BGP). Along this BGP, aggregate capital, wages, consumption expenditure and output in terms of the numeraire (goods) grow at the same rate of A_{gt}, γ_g.

The Cobb-Douglas technologies in the two sectors determine a linear production possibility for this economy. This implies that, at any t, giving up production of a unit of manufacturing allows to produce p_{gt}/p_{st} units of services. It follows that the maximum amount of services that can be produced at t is:

$$Y_{st} = \frac{p_{gt}}{p_{st}} Y_{gt}, \tag{9}$$

where

$$\frac{p_{st}}{p_{gt}} = \frac{A_{gt}^{1-\alpha}}{A_{st}^{1-\alpha}}. \tag{10}$$

From (8), (9) and (10), we can then obtain the aggregate production function in services units, which is

$$Y_{st} = K_t^{\alpha}(A_{st})^{1-\alpha}. \tag{11}$$

Along the BGP in manufacturing units, K grows at rate γ_g and A_{st} grows at rate γ_s so Y_{st} grows at the constant rate $\gamma_{ys} = \alpha\gamma_g + (1-\alpha)\gamma_s$. Note, however, that if output is measured in services units, the capital output-ratio is non-constant over time, as the numerator grows at γ_g while the denominator at $\gamma_{ys} = \alpha\gamma_g + (1-\alpha)\gamma_s < \gamma_g$. Thus, the concept of balanced growth is tightly linked to the units in which aggregate variables are measured.

Consider now the aggregate marginal product of capital in the economy (MPK) in the two extreme production cases, which is obtained by deriving (8) and (11) with respect to K_t:

$$MPK_t^g = \alpha K_t^{\alpha-1}(n_t A_{gt})^{1-\alpha} = \alpha\frac{Y_{gt}}{K_t} = \alpha\frac{p_{gt}Y_{gt}}{p_{gt}K_t} = r_t - \delta = constant, \tag{12}$$

and

$$MPK_t^s = \alpha K_t^{\alpha-1}(n_t A_{st})^{1-\alpha} = \alpha\frac{Y_{st}}{K_t} = \alpha\frac{p_{st}Y_{st}}{p_{st}K_t} = \alpha\frac{Y_{gt}}{K_t}\frac{p_{gt}}{p_{st}} = \frac{p_{gt}}{p_{st}}MPK_t^g. \tag{13}$$

While MPK_t^g is constant along the BGP, as long as p_{gt}/p_{st} is non-constant over time, the marginal product of capital in services units is also non-constant in this model, confirming that one of the requirements for balanced growth does not hold. In fact, a time varying MKP implies that an additional unit of capital provides a different amount of output at two points in time, implying that the capital/output ratio is also time varying, which implies the violation of one of the Kaldor facts.

We now turn to the real interest rate in the two extreme production cases. To derive the real interest rate in the model we introduce a one period bond denominated in nominal terms (i.e. dollars) and then we create derivatives on that bond denominated in manufacturing and services units. The budget constraint of the consumer becomes:

$$E_t + p_{gt}K_{t+1} + B_{t+1} = w_t + p_{gt}K_t(1 + r_t - \delta) + (1 + r_t^b)B_t$$

where in addition to variables appearing in (3), B_{t+1} is the cost in dollars at t of a bond which gives $(1+r_{t+1}^b)B_{t+1}$ dollars at $t+1$. Consider now an arbitrageur who creates two derivatives from this bond denominated in dollars. One derivative is sold at a price in manufacturing units and provides a gross return in manufacturing units. The other derivative is sold at a price in services and provides a gross return in service units. By the no-arbitrage condition, the first derivative costs B_{t+1}/p_{gt} manufacturing units today and gives $(1 + r_{t+1}^b)B_{t+1}/p_{gt+1}$ manufacturing units tomorrow. For the same reason, the second derivative costs B_{t+1}/p_{st} services units today and gives $(1+r_{t+1}^b)B_{t+1}/p_{st+1}$ services units tomorrow. Using a standard asset pricing formula (see Cochrane (2009)) to compute the gross return of the three assets we obtain the return in dollars

$$R_{t+1}^b = \frac{(1 + r_{t+1}^b)B_{t+1}}{B_{t+1}} = (1 + r_{t+1}^b),$$

that in manufacturing units

$$R^g_{t+1} = \frac{(1 + r^b_{t+1})p_{gt}B_{t+1}}{p_{gt+1}B_{t+1}} = \frac{(1 + r^b_{t+1})p_{gt}}{p_{gt+1}},$$

and that in services units

$$R^s_{t+1} = \frac{(1 + r^b_{t+1})p_{st}B_{t+1}}{p_{st+1}B_{t+1}} = \frac{(1 + r^b_{t+1})p_{st}}{p_{st+1}}.$$

From utility maximization we have that

$$[1 + r_{t+1} - \delta] = [1 + r^b_{t+1}]\frac{p_{gt}}{p_{gt+1}} = R^g_{t+1}. \tag{14}$$

Consider manufacturing as the numeraire, $p_{gt+1} = p_{gt} = 1$. Hence

$$[1 + r_{t+1} - \delta] = R^g_{t+1} = constant_a, \tag{15}$$

where the last equality follows from the fact that real return on capital in units of manufacturing r_{t+1} is constant in equilibrium. Now consider the return in services units. The ratio p_{st+1}/p_{st} is given by

$$\frac{p_{st+1}}{p_{st}} = \left(\frac{A_{gt+1}/A_{gt}}{A_{st+1}/A_{st}}\right)^{1-\alpha} = \left(\frac{1+\gamma_g}{1+\gamma_s}\right)^{1-\alpha} = constant_b,$$

so the return in services units is also constant and given by

$$R^s_{t+1} = (1 + r^b_{t+1})\left(\frac{1+\gamma_s}{1+\gamma_g}\right)^{1-\alpha} = constant_c < R^g_{t+1} = constant_a. \tag{16}$$

Thus, in both cases the real interest rate is constant, but it is larger when the economy produces only manufacturing. Thus, as in the one-sector growth model, the larger the growth rate of aggregate TFP, the larger the real interest rate in the economy.

Note that in units of services the economy displays a *non-constant* MPK_s together with a *constant* R^s_t. To see why this is the case, it is useful to see MPK_s as the net payoff in services units of holding a unit of capital at $t+1$. This is given by

$$MPK^s_{t+1} = \frac{p_{gt+1}}{p_{st+1}}r_{t+1}, \tag{17}$$

which, as described above, is declining at the same rate as p_{gt+1}/p_{st+1}. How does the cost of obtaining a unit of capital evolve over time? To obtain one unit of capital at t, one has to give up p_{gt}/p_{st} units of services. This implies that both the price and the payoff of the investment are declining at the same rate, thus making the real return, which is the ratio of the two, constant over time.

Finally, we conclude this section by discussing the theoretical concept of GDP in a multisector model. Figure 2 shows the evolution of the production possibility frontier over time, under the assumption that $\gamma_g > \gamma_s$. When the economy produces only one product, the definition of aggregate output (i.e. GDP) is straightforward and maximum growth at any time t is attained if the economy produces only manufacturing, while minimum growth is given if the economy produces only services. To measure growth in all other intermediate cases, one has to take a stand on what aggregate output (i.e. GDP) is when the economy produces both goods. This choice is typically avoided in multisector models and GDP is represented output in units of one of the goods in the economy. To define GDP growth in the multisector case, note that in the two extreme cases in Figure 2 GDP growth is given by the Euclidean distance between the corresponding two points on the frontiers (for instance between $Y_{s,t}$ and $Y_{s,t+n}$). We can extend this measure to all intermediate cases and define GDP growth between two periods as the Euclidean norm between two points on two different frontiers. Note that this measure depends on both the quantities of the two products and the relative prices (which determine the change in the slope of the frontier) in the two periods considered. Figure 2 reports two possible paths for GDP between t and $t + n$, suggesting that the more the economy is intensive in services, the smaller GDP growth will be.[16]

4 Measuring the model with NIPA methodology

In this section we describe how we use NIPA methodology to measure the model's outcome. In Appendix B we report in detail the formulas from NIPA that we use to construct real GDP and the GDP deflator. We show there that GDP as measured by the chain-weighted Fisher index also depends on the quantities of the two products and the relative price of the two products in the two periods, in the same way as the Euclidean norm discussed in the previous section. Here we focus on the measurement of the marginal product of capital (MPK) and the real interest rate when NIPA methodology is used.

[16]Note that the solid lines in the figure are stylized GDP trajectories, and not the Euclidean norm measuring GDP growth, which is linear by definition.

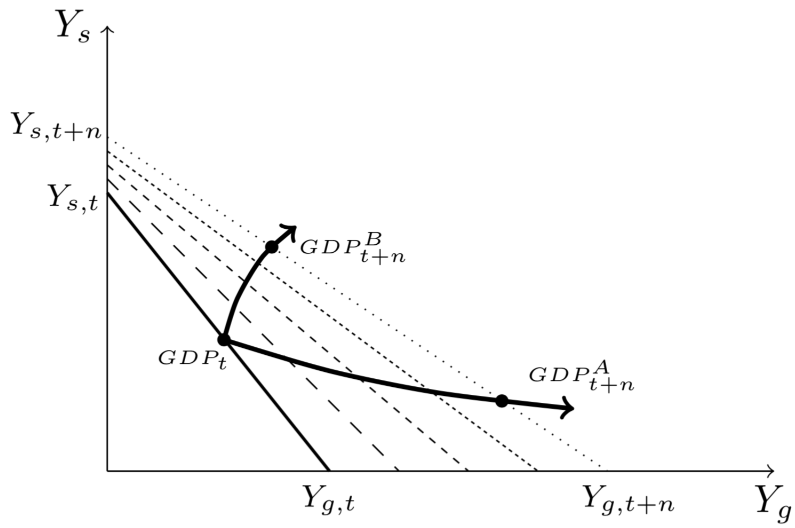

Figure 2: Evolution of the production possibility frontier and two possible GDP trajectories.

4.1 The MPK

Equations (12) and (13) suggest that the MPK can be expressed in different units by simply dividing the MPK in manufacturing by a relative price. The question that naturally arises then is which is the appropriate deflator in multi-sector models when confronting them with the data. In one-sector models, this issue does not arise as all goods are produced with the same technology and output, investment, and consumption share the same price, commonly assumed to be the numeraire. In multi-sector models, instead, the common practice is to express aggregate variables such as total output (GDP) and aggregate consumption in terms of the numeraire of the economy, usually the investment good. However, this is in contrast with standard aggregate measures in national accounts, that are used to contrast the model with the data.

In the U.S., the NIPA construct real GDP using a chain-weighted Fisher index of sectoral value added. This is similar to a Divisia index, in which the growth of the various components of GDP is weighted by their shares in nominal GDP. As the shares change over time, the weights of the various components also change. Thus, if GDP is constructed in the model as it is in the data, even if all its individual components (consumption of manufacturing and services and investment in the model in the context of our model) grow at constant rates over time, structural transformation implies a non-constant growth of GDP over time.[17] Equally, to construct measures of the economy-level MPK one needs to decide in terms of which

[17] Moro (2015) for instance, shows that in a model calibrated to the U.S., structural transformation from manufacturing to services implies a decline in the growth rate of GDP as measured with a Fisher index.

units this is expressed. In fact, the aggregate MPK is given by the ratio between the new aggregate output produced by some additional capital, and the amount of that additional capital. The natural measure of the MPK in the data is then the additional amount of GDP that is generated by an additional unit of capital.

Thus, to obtain the MPK in the data from the model's outcome, we measure what is the extra output in terms of GDP, of an extra unit of capital used in production in the economy.[18] This requires to construct GDP from the model's equilibrium path as it is constructed in the data. Hence, we take the following steps:

1. We find the solution of the model;

2. We use the solution of the model to construct real GDP through a Fisher index ($GDPreal_t$);

3. By using this measure of real GDP and GDP in terms of the numeraire in the model (Y_{gt}) we construct a measure of the GDP deflator ($P_{GDP,t}$):

$$P_{GDP,t} = \frac{Y_{gt}}{GDPreal_t}.$$

4. Since the marginal revenue product of capital is equalized across sectors, we can write $p_g MPK_g = P_{GDP,t} MPK_{GDP,t}$, where MPK_g is the physical marginal product of capital in the goods sector, and $MPK_{GDP,t}$ the marginal product of capital in GDP units. We thus find $MPK_{GDP,t}$ as

$$MPK_{GDP,t} = \frac{p_g MPK_g}{P_{GDP,t}}.$$

5. We repeat steps 2, 3 and 4 by substituting GDP with aggregate consumption to obtain a measure of the MPK in consumption units.

4.2 The real interest rate

The discussion in section 3.3 suggests that in an economy experiencing structural transformation the real interest rate is bounded from above by $R_t^g - 1$ and converges asymptotically to the lower bound $R_t^s - 1$ as the economy transfers resources from manufacturing to services. Thus, in a context of structural transformation, the real interest rate in GDP or consumption units is non-constant. To show this, we derive the real interest rate as the return of an

[18] Or, equivalently, the MPK in terms of aggregate consumption is the extra units of aggregate consumption obtained from an extra unit of capital in production.

investment opportunity of an investor holding a unit of GDP at t. This investment opportunity then measures the units of GDP that the investor can buy at $t+1$ if she gives up a unit of GDP at t and invest it in capital. A similar reasoning holds for aggregate consumption.

At time t, the investor uses an amount of GDP, say $\bar{y} = 1$ units, whose price is $P_{GDP,t}$, to purchase some capital such that $P_{GDP,t}\bar{y} = p_{gt}K_t$ holds. The real return to capital at $t+1$ is $\bar{r}_{t+1} = r_{t+1} - \delta$, so the investor has, in that period, $p_{gt+1}K_t(1+\bar{r}_{t+1})$ or, by using the previous equality, $p_{gt+1}\frac{P_{GDP,t}\bar{y}}{p_{gt}}(1+\bar{r}_{t+1})$. This return on investment can be used to purchase GDP at $t+1$ at price $P_{GDP,t+1}$, so the real return on investment is $\frac{p_{gt+1}}{p_{gt}}\frac{P_{GDP,t}}{P_{GDP,t+1}}\bar{y}(1+\bar{r}_{t+1})$. As $\bar{y} = 1$, and the price of capital is the numeraire in each period, then the gross return in GDP units is given by

$$R_{t+1} = \frac{1+\bar{r}_{t+1}}{1+\pi^y_{t+1}}, \tag{18}$$

where π^y_t is the inflation rate of the GDP deflator, while the net return, i.e. the real interest rate $\tilde{r}_t$, by

$$\tilde{r}_{t+1} = \frac{1+\bar{r}_{t+1}}{1+\pi^y_{t+1}} - 1, \tag{19}$$

which is the gross return in GDP units minus the initial unit of GDP invested.[19] The real interest rate reflects the fact that a unit of GDP tomorrow costs $P_{GDP,t+1}$ while a unit of GDP today costs $P_{GDP,t}$, so the real return has to be adjusted for the change in the relative price $1+\pi^y_t = P_{Y,t+1}/P_{Y,t}$.[20] This change in the price of GDP, however, is not constant when we measure the model's outcome as in the data. This is because structural change modifies the weight of different consumption components. Since the share of services in consumption increases along the growth path, and since the price of services grows faster than the price of goods, π^y_t also increases along the balanced growth path, and hence the real interest rate falls. The real interest rate in GDP units in the data is then computed using the inflation rate of the GDP deflator as measured in section 4.1 and formula (18). A similar methodology is used to compute the real interest rate in consumption units.

[19] We could have derived the real interest rate in GDP and consumption units using the bond introduced in section 3.3 and the standard asset prices formula used in (15) and (16). In that case we would have a gross return at t+1

$$R_{t+1} = \frac{(1+r^b_{t+1})P_{GDP,t}B_{t+1}}{P_{GDP,t+1}B_{t+1}} = \frac{1+\bar{r}_{t+1}}{1+\pi^y_{t+1}}.$$

A similar formula applies to aggregate consumption.

[20] An equivalent reasoning is made when measuring the real return in units of consumption. In that case, we would use the relative inflation rate for the consumption price index as constructed in the previous section.

Table 1: Parameter Values

β	α	δ	ϵ	ξ	ν	A_{g1}	A_{s1}	γ_g	γ_s
0.95	0.34	0.06	0.20	0.50	0.63	1	1	2.78%	0.40%

Table 2: Data targets

Target	GDPpc Growth	Initial share of services	Final share of services	Real I/Y growth	Growth of p_g/p_s
Data	2.12%	0.393	0.685	0.92%	-1.57%
Model	2.09%	0.392	0.687	0.68%	-1.57%

5 Quantitative analysis

In this section we calibrate the model to aggregate targets of the U.S. economy to measure the effect of structural transformation on the process of growth. We set some parameters to standard values in the literature. Thus we have β= 0.95, α= 0.34, and δ= 0.06 as in Caselli and Feyrer (2007).

By normalizing TFP levels in the two sectors in the first period to 1, we then need to calibrate three preference parameters ϵ, ξ and ν, and two growth rates of TFP, γ_g and γ_s. To calibrate these we choose the following targets in the data: 1) the average growth rate of GDP per capita over the period considered (1950-2015); 2) the share of services in the initial period (1950); 3) the share of services in the final period (2015); 4) the average growth rate of the real investment to output ratio during the period considered; and 5) the average growth in the relative price goods/services. In the model, we assume that the manufacturing sector produces both investment and consumption goods. Thus, as explained in section 2, to construct our target 5 we compute a Fisher index from the price of investment and the price of goods in the data, and take the ratio of this index and the price of services. Table 1 reports all parameter values while table 2 shows the fit of the calibrated model.

Figure 3 reports the visual fit of the model for GDP, the share of services and the investment-output ratio. The model does a good job at replicating the long run evolution of GDP and the services share. The evolution of the investment-output ratio is also reproduced fairly well, although this series in the data displays high volatility. The model produces a 0.68% average growth compared to a 0.92% in the data. Figure 4 compares the behavior of the model versus that of a linear trend in predicting the evolution of log-GDP. Note that, in the calibration, we target an average growth of real GDP per capita of 2.12% per year, the one measured in the U.S. in the 1950-2015 period. However, the model predicts

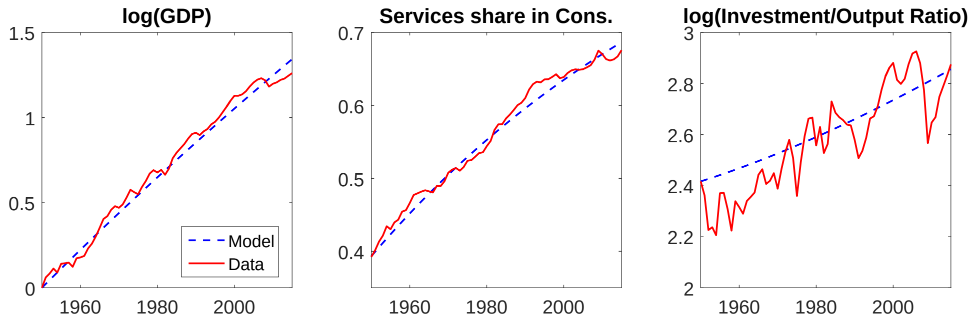

Figure 3: Model versus Data.

a declining growth rate of GDP, due to structural transformation between manufacturing and services. The growth rate of GDP in the model goes from 2.29% in the first period to 1.93% in the last period of the simulation. This is a decline of 16% in the rate of growth. Such concavity in the evolution of GDP in the model helps to fit better the data. We find that the sum of squared residuals of the log deviations of the model from actual GDP is 31% lower than the corresponding measure of the log deviations from a linear trend. The second panel of Figure 3 plots the percentage difference between the model and a linear trend.

Thus, even if GDP appears to grow at a constant rate in the data, the model suggests that the rate of growth declines over time. Given the size of the U.S. business cycle, which displays a standard deviation of GDP growth of 2.3% over the period considered, it is difficult to detect such trend decline in the data. Using state space models allowing for a change in the long-run growth rate of GDP, however, Antolín-Díaz, Drechsel, and Petrella (2017) find that there is a slow moving fall in the growth rate of real GDP in the U.S.[21] They report a fall from an estimated long-run growth from 3.5% in the 1950s to 2% in recent years (a decline of almost 43%). Their estimates correspond to real GDP growth and are not in per-capita terms. Given the decline in the rate of population growth of about 1 percentage point (1.7% in the 1950s to 0.7% in the current decade) this implies a decline in the rate of growth of per capita GDP of around 22%.

Figure 5 reports the effect of structural transformation on the growth facts we focus on, i.e. the MPK, the real interest rate and GDP growth. The left panel of Figure 5 shows that the MPK declines by 36% over the period considered (0.6448 in 2015) in units of GDP and by 43% in units of aggregate consumption (0.5720 in 2015). Thus, if an additional unit of capital in 1950 provides an additional unit of GDP, in 2015 this additional unit of capital

[21] Previous evidence in Bai, Lumsdaine, and Stock (1998) and Eo and Morley (2015), also suggests that there is a fall in the growth rate of real GDP in the U.S. In these papers, the fall takes the form of abrupt structural breaks. Antolín-Díaz, Drechsel, and Petrella (2017), instead, allow for the growth rate to drift gradually over time. Consistent with our model, their evidence points to a gradual decline in the growth rate.

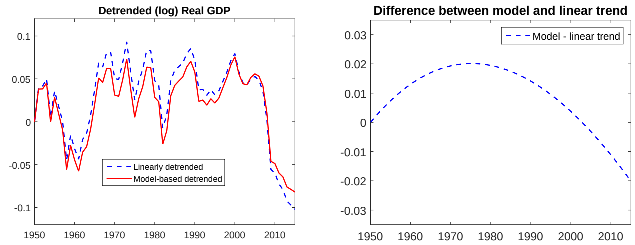

Figure 4: GDP: Model versus linear trend.

provides only 0.64 units of GDP. The difference between 1950 and 2015 in terms of units of consumption is even more striking. Note that this is consistent with the findings in Caselli and Feyrer (2007) using a cross-country comparison of MPKs. Their results suggest that the MPK is equalized across countries, regardless of the income level. However, if measured in units of GDP, the MPK would display a different value across countries, depending on the level of income (i.e. depending on the share of services in GDP). This, as pointed out in Caselli and Feyrer (2007), is due to the different relative price of capital across countries.[22] A related argument for cross-country comparisons is made in the next section.

The middle panel of Figure 5 shows that while the effect on the MPK is striking in magnitude, the corresponding effect on the real interest rate is more contained. It goes from 7.42% to 7.04% in GDP units and from 7.27% to 6.80% in consumption units. The difference between the decline in the MPK and the real interest rate lies in the fact that, while the units of GDP obtained from an additional unit of capital decline strongly, the cost of buying that unit of capital in GDP terms also falls substantially. Finally, the third panel of Figure 5 shows the comparison between the decline in the real interest rate and the growth rate of GDP, when both are normalized to one in 1950. The growth rate of GDP declines faster than the real interest rate, regardless of the units the latter is measured in (i.e. GDP or consumption).

6 Cross country evidence

The previous section shows that the model of structural transformation measured with NIPA methodology fits well the growth experience of the U.S. both qualitatively and quantitatively. However, ST is a phenomenon that can also be observed across countries and, thus, we want to know whether its consequences for the growth process are also consistent with cross-

[22] Note that this trend in the MPK and the capital-output ratio generated by structural change could potentially relate to the recent decline in the labor share if the elasticity of capital-labor substitution were larger than one, as argued by Karabarbounis and Neiman (2014).

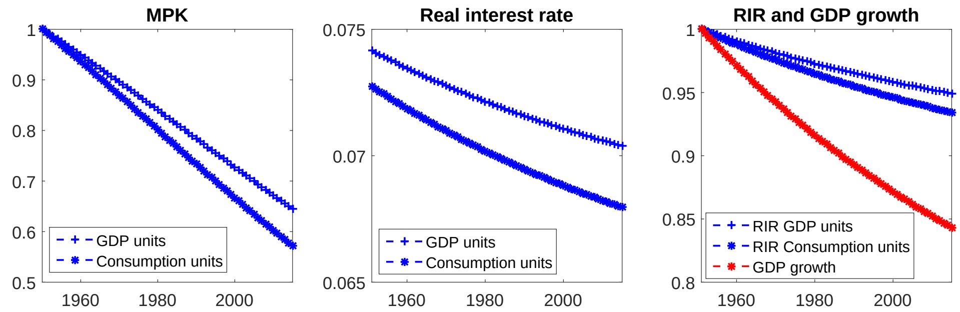

Figure 5: Model versus Data.

country data. In addition to this, as in the structural change model, a standard theory of investment specific-technological change (ISTC) also predicts the following cross-country growth facts: i) the positive relationship of real investment rates with income levels (Barro (1991)); ii) the absence of correlation between nominal investment rates and income levels (Hsieh and Klenow (2007)); and iii) the absence of correlation between the MPK in units of capital and income levels (Caselli and Feyrer (2007)).

For the above reasons, we devote this section to evaluating the performance of the structural transformation model in predicting cross-country facts. We focus on the positive relationship between real investment rates and income levels (and the absence of a relationship between nominal investment rates and income). We do this in three steps. We first show that modeling structural transformation provides additional predictions on the growth process with respect to a standard theory of ISTC, and that these predictions are *qualitatively* in line with the cross-country evidence.

Second, we test the ability of the model in providing out of sample *quantitative* predictions. We show that the model calibrated for the U.S. can account well for the relationship between real investment rates and the share of services in consumption that we document in the data. This result has at least two important implications. On the one hand, it suggests that the processes structural transformation by itself has the potential to determine the evolution of real investment rates along the growth path, as no inefficiencies are present in the model. On the other hand, it suggests that the growth and structural transformation experience observed in cross-country data is remarkably consistent with that of the U.S.

Finally, we ask whether the predictions of the ST model calibrated for the U.S. regarding the evolution of real investment rates are comparable to those displayed by a standard model of ISTC, also calibrated to the U.S. By contrasting the two models with the cross-country data, we find that the ST model substantially outperforms the ISTC model along this metric. This result suggests that explicitly modeling structural transformation does not only provides additional predictions on the growth process with respect a model of ISCT, but also provide a quantitatively better performance in terms of the predictions shared by the two models.

6.1 A standard model of ISTC

We first modify our benchmark model to be a standard theory of ISTC. To do this, we reduce the model to one consumption sector and one investment sector by setting $\nu = 0$. In this way, preferences depend only on services consumption. Thus, the services sector produces the only consumption good (i.e. the only one that enters utility) and manufacturing produces the investment good (i.e. the only one used to build capital). We then drop the terminology services and manufacturing in this model to refer to *consumption* and *investment* sectors.

The utility function becomes

$$V(p, E) = \frac{1}{\epsilon}\left[\frac{E}{p}\right]^{\epsilon} - \frac{1}{\epsilon}, \tag{20}$$

where p is the price of consumption relative to investment (i.e. the investment good is the numeraire) and E is again nominal consumption expenditure.

The consumption good is produced with a Cobb-Douglas technology

$$y_{ct} = k_{ct}^{\alpha}(n_{ct}A_{ct})^{1-\alpha}, \tag{21}$$

and the investment firm produces with technology

$$y_{It} = k_{It}^{\alpha}(n_{It}A_{It})^{1-\alpha}. \tag{22}$$

This two-sector representation implies that the relative price of consumption is

$$p_t = \frac{(A_{It})^{(1-\alpha)}}{(A_{ct})^{(1-\alpha)}},$$

and assuming that $\gamma_I > \gamma_c$ the relative price consumption/investment increases over time, so there is ISTC, which is given by $1/p_t$. Thus, as in a typical ISTC model, the growth rate of ISTC is constant.

Note that this technology specification is isomorphic to explicitly assuming that the investment-good producer uses a linear technology that turns x units of consumption good into qx units of investment good with technology

$$I_t = q_t x_t. \tag{23}$$

In this case the current state of ISTC is q_t which, as above, is equal to $1/p_t$ in equilibrium.

As the structural transformation model (ST hereafter) this ISTC model predicts a positive relationship between the real investment rate and the income level, a constant nominal investment rate and the absence of correlation between the MPK in units of capital and the level of income.

6.2 ISCT or Structural Transformation?

As a starting point to compare the two models, we note that the model of structural change endogenously produces ISTC, as the price of investment relative to aggregate consumption (and to GDP) declines as income grows. This decline is due to the changing composition of consumption, which becomes more intensive in services relative to goods.[23] Thus, the ST model can be also interpreted as an endogenous theory of ISCT. A clear advantage of this modeling choice is that the ST model provides additional predictions with respect to a standard theory of exogenous ISTC, which can be contrasted with cross-country growth facts. These are: 1) the rise of the services share in GDP as income grows; 2) the decline in the growth rate of GDP as the share of services grows; 3) a declining real interest rate as income grows; 4) an acceleration of ISTC as income grows. The first fact is well established (Herrendorf, Rogerson, and Valentinyi (2014)). The second relates to Baumol's disease and has been documented in cross-country data in Echevarria (1997) and, recently, Moro (2015) who also shows that structural transformation can account for the bulk of differences in per-capita GDP growth between middle income and high income economies. The third fact is more controversial due to difficulties in constructing real interest rates that are comparable across countries, but the evidence discussed in Barro and Sala-i-Martín (2004, p. 13) leads the authors to claim that "*it seems likely that Kaldor's hypothesis of a roughly stable real rate of return should be replaced by a tendency for returns to fall over some range as an economy develops*".

The fourth fact has been recently documented by Samaniego and Sun (2016), and represents a key dimension to evaluate whether the endogenous theory of ISTC performs better than the exogenous theory. We reproduce this evidence in Figure 6, in which we use the Penn World Table 7.1 to regress the average yearly growth rate of the inverse of the relative price investment/consumption (i.e., the average growth rate of ISTC) over the period 1970-2010, against the log of average GDP per capita in the same period.[24] We find a positive

[23]Structural transformation would generate ISTC even if the investment good were made up of both goods and services as long as the proportion of goods in investment is larger than that in consumption. See García-Santana, Pijoan-Mas, and Villacorta (2016) on this point.

[24]We use version 7.1 as in Samaniego and Sun (2016) because, as discussed in that paper, in later versions of the PWT, the sampling method focuses on goods that are comparable across countries instead of being

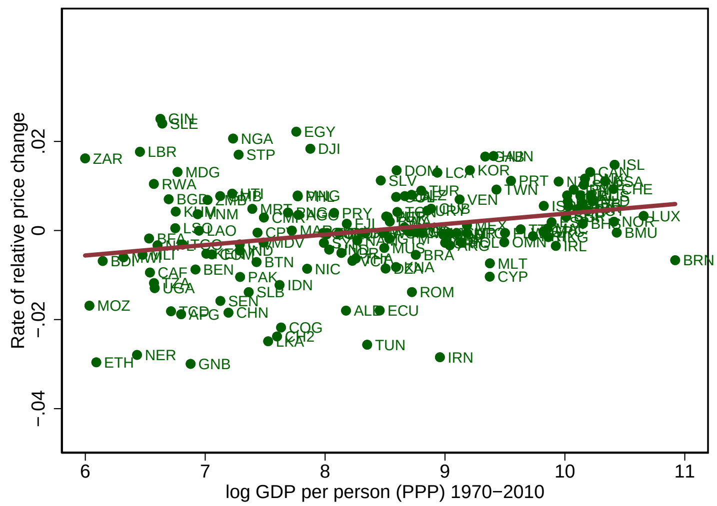

Figure 6: Investment-specific technological change by income level. Own calculations following the methodology in Samaniego and Sun (2016).

coefficient of 0.0023 (s.e. 0.00073) which is statistically significant at the 1% level.[25] The ST model produces an acceleration of ISTC as income grows because the share of services in consumption increases over time, thus making the relative price of investment decline faster at higher income levels.[26] Thus, as for the growth rate of GDP, the marginal product of capital, and the real interest rate, the key variable in determining the pace of ISTC in the model is the share of services. To test whether this prediction of the model is also confirmed in the data, we regress the growth of the rate of ISTC between 1970 and 2010 on the log consumption share of services using using the Penn World Table 7.1. As discussed in the next section and Appendix C, the consumption share is only available for benchmark years, so we use the first and the last of these (1980 and 2011). For 1980 there are 55 countries after matching services share and ISTC data while for 2011 there are 119.[27] Figure 7 reports the results. The coefficient for 1980 is 0.013, while that in 2011 is 0.006. In both cases, the coefficients are significant at the 5% statistical level. We note that using the 1980 data, the coefficient is twice as large as for the 2011 data while the dispersion is smaller. The

representative of goods purchased in any given country as was the case in PWT versions 7.1 and earlier. Since the focus here on the growth rate of the relative price of investment goods, the PWT 7.1. definition is the appropriate one for our purposes.

[25] Samaniego and Sun (2016) show that a similar relationship holds when considering the 1950-2010 period. In that case, however, the number of countries for which data are available covering that period is substantially reduced. For this reason we report here the regression for the 1970-2010 period.

[26] Comparisons between models are made by measuring both with NIPA methodology, so the differences that we highlight do not depend on measurement issues.

[27] We trimmed the sample for countries with implausibly large or low rates of ISTC above 3% or below -3%. As mentioned below, we also used robust regressions to control for the effect of outliers.

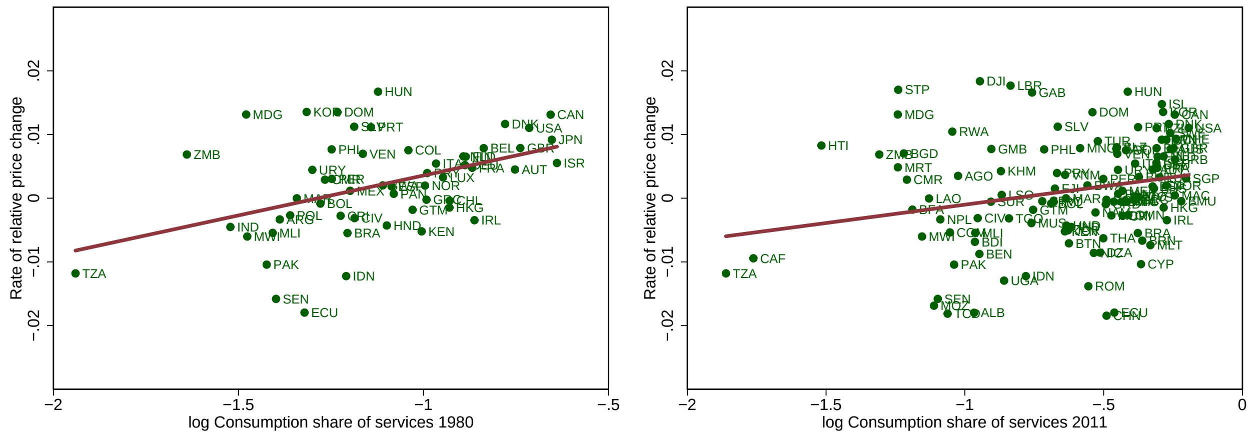

Figure 7: Investment-specific technological change against services share. Left panel: 1980. Right panel: 2011.

difference between the two cases is due to the fact that the 1980 sample of 55 observations mainly contains developed economies while the 2011 sample includes more countries at lower income level and smaller share of services. As ISTC appears to accelerate with income level, the correlation coefficient between ISTC and share of services is larger when only higher income countries are considered.[28]

The evidence discussed in this section suggests that structural transformation affects the growth process along several dimensions which hold in cross-country data, and that are absent in a standard theory of ISTC. In addition, the ST model represents a theory of endogenous ISTC that is consistent with the cross-country evidence on this type of technological change.

6.3 Out of sample predictions of the ST model

Given the qualitative predictions of the model discussed in the previous subsection, we now ask how well the model can account *quantitatively* for the cross-country evidence on real investment rates. We choose real investment rates since the positive trend with the level of income appears to be one of the most robust cross-country observations regarding the growth process. To test the model's predictive power we focus on the share of services in consumption. We choose this variable because, in the model, given the constant growth of TFP in the two sectors, the evolution of the share of services is the key variable which

[28]Lower income countries also display higher variability, which suggests that the significance of the regression might be due to outliers. To exclude this possibility, we run robust regressions to control for the effect of outliers in both years. The results remain significant, and the effect is stronger than in the original regressions. For the 1980 regression the coefficient increases to 0.014 significant at the 1% level, and for 2011 it increases to 0.007 also significant at the 1% level. The robust regression results remain significant when we do not trim the sample.

determines the magnitude of the change in the relative price of investment. A faster pace of structural transformation implies that the relative price of investment declines faster, implying a higher rate of ISTC and a faster increase in the real investment rate. Thus, if the model is a good predictor of the cross-country growth process, it should provide an elasticity of the real investment rate to the share of services comparable to that observed in the data.

To report the empirical evidence on the relationship between the share of services in consumption and real investment rates we use data from the International Comparisons Program (ICP) used to construct the Penn World Tables for the years 1980, 1985, 1996, 2005 and 2011. We focus on these years as they contain the benchmark data with details on expenditure components measured in local currency (nominal) and in purchasing power parity (PPP) dollars (real). Appendix C describes in detail data sources and methodology. We construct data for the cross-section of countries for the real and nominal shares of investment in GDP, and the share of services in private consumption expenditures. In table 3 and figure 4 we report, for each year, the estimated elasticity of the real and nominal investment rates with respect to the share of services in private consumption.[29] Similar to the results in Hsieh and Klenow (2007), who use the income level as a proxy of development, we find a positive and significant relationship between the real investment rates and the share of services in consumption, with an average elasticity across years of 0.61.[30] Also, consistent with Hsieh and Klenow (2007), nominal investment rates do not correlate or correlate very mildly with development indicators. As discussed above, the two-sector model employed in this paper is qualitatively consistent with both observations.

To contrast the model with cross-country data, we need to calibrate the model independently from such data. To do this, we tie our hands by using the calibration of the previous section for the U.S. growth path. This exercise amounts to assuming that the U.S. path of structural transformation is a representative one, and to asking whether such experience produces an evolution of the real investment to GDP ratio that resembles the cross-country evidence. Technically, we proceed as follows. Starting from period 1 of the simulation in the previous section, we discount TFP levels in each sector using the constant growth rates of TFP in the two sectors reported in table 1 for a number of periods. This way we are able to reconstruct, along the theoretical balanced growth path, the equilibrium of the model at earlier stages of development in which the share of services is smaller. The number of periods backwards is pinned down by the minimum level of the share of services we want to achieve,

[29] We also provide estimates for all countries and years pooled. To account for different intercepts, in that particular regression we take the dependent and independent variables relative to the value for the U.S. for the corresponding year, hence normalizing all values to make them comparable.

[30] We also estimate robust regressions to account for the potential impact of outliers. The results do not change significantly any of the elasticities.

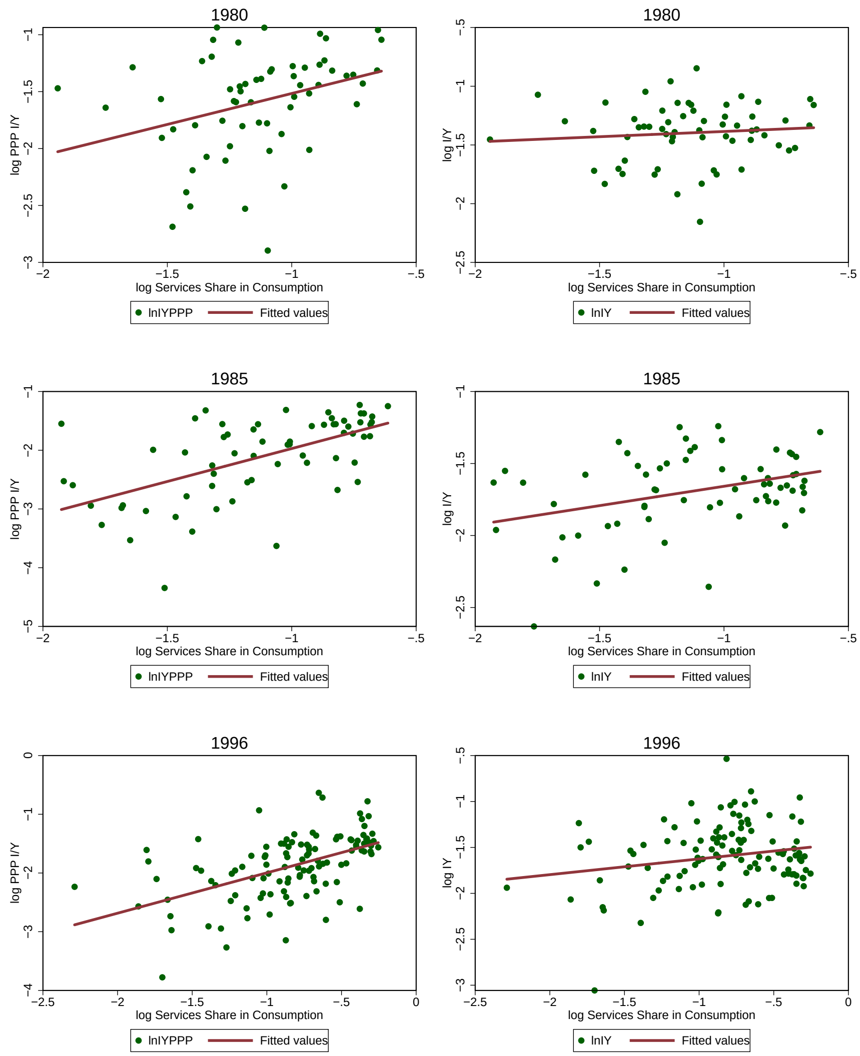

Figure 8: Investment to GDP ratio measured in PPP dollars (left column) and in nominal terms (right column) versus consumption share of services. Data from the International Comparisons Program, 1980, 1985, 1996, 2005, 2011. See Appendix C for construction.

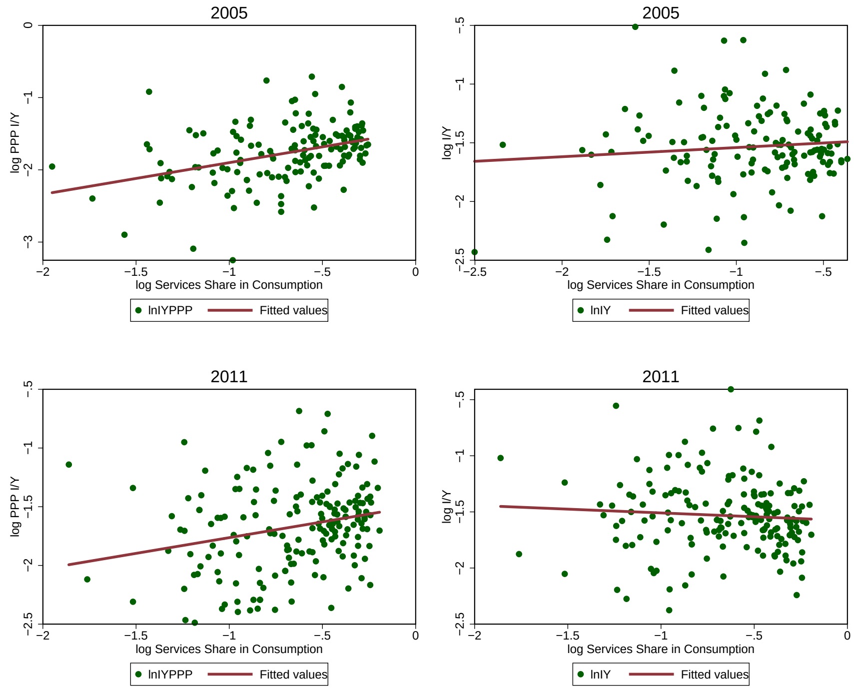

Figure 8: Continued

Table 3: Coefficient of PPP investment rates and domestic prices investment rates regressed on consumption share of services. All variables in logs.

year	PPP I/Y	Nominal I/Y	No. Observations
1980	**0.544**	0.089	N=61
	(0.193)	(0.100)	
	R^2=0.11	R^2=0.01	
1985	**1.122**	**0.268**	N=64
	(0.218)	(0.097)	
	R^2=0.34	R^2=0.13	
1996	**0.688**	0.171	N=115
	(0.123)	(0.087)	
	R^2=0.28	R^2=0.04	
2005	**0.437**	0.092	N=145
	(0.098)	(0.096)	
	R^2=0.14	R^2=0.01	
2011	**0.269**	-0.068	N=180
	(0.091)	(0.078)	
	R^2=0.06	R^2=0.01	
All years	**0.560**	0.075	N=565
	(0.064)	(0.043)	
	R^2=0.15	R^2=0.01	

Notes: robust standard errors in parentheses. Bold indicates significant at the 5% level.

which we choose to be the minimum value across countries and years in the data (0.10 for Tanzania in 1996). This implies that, given the growth rates of TFP in table 1 and starting from period 1 of the U.S. simulation, we need to project the model back by 38 periods. This exercise leaves us with 104 years of data for the artificial economy with the same parameter values as the U.S. economy between 1950 and 2015. We then calculate the real investment to GDP ratio of this artificial economy for the 104 periods and the corresponding average elasticity with respect to the consumption share of services.[31] This yields a model elasticity of 0.63. The average elasticity in table 3 for the five benchmark years considered is 0.61. The elasticity obtained by pooling the data for all years is 0.56 (row "all years" in table 3). Figure 9 shows the scatter plot for all country-years and the log-linear fit together with the model-implied log-linear fit.[32] The two lines are virtually indistinguishable, showing a striking resemblance between the model and the cross-country elasticity of the real investment to GDP ratio with respect to the services share in consumption. Thus, even without resorting to transitional dynamics, the behavior of the structural transformation model, measured with NIPA conventions, can account well for the international evidence on real investment rates.[33] This suggests that most countries experience a growth process that resembles the one of the U.S.

6.4 ISCT vs ST out of sample predictions

In this subsection we compare the quantitative performance of the ISTC and the ST model in the out of sample predictions. We address the following question: if both the ST and the ISTC models are calibrated to U.S. data, which model provides a more accurate prediction of the cross-country variability in real investment rates? To answer this, we first note that, in the ST model, the key variable affecting the growth process is the share of services. In the ISTC model, absent this variable, we focus on the growth of per-capita GDP to compare the model calibrated to the U.S. with cross-country data.

In contrast with the ST model, in the ISTC model there are only three parameters that we need to calibrate, ϵ, γ_g and γ_s. Note, however, that for our purposes the calibration of ϵ is irrelevant, as it only determines the value of the nominal share of investment, which is constant in the dynamic equilibrium. Instead, the key parameters determining the quantitative

[31]The elasticity of the real investment rate to the share of services in consumption is given, period by period, by the percentage change in the first variable divided by the percentage change in the second variable.

[32]The intercept of the model implied log-linear fit in Figure 9 is chosen such that it crosses the data fit line at the average value of the services shares.

[33]Note that the empirical relationship between real investment rates and proxies for development is unlikely to be driven by transitional dynamics. If it were, countries that are far away from steady state and hence grow faster, would display higher investment-output ratios. In our data, we could not find a systematic relationship between growth and real investment rates. Results available on request.

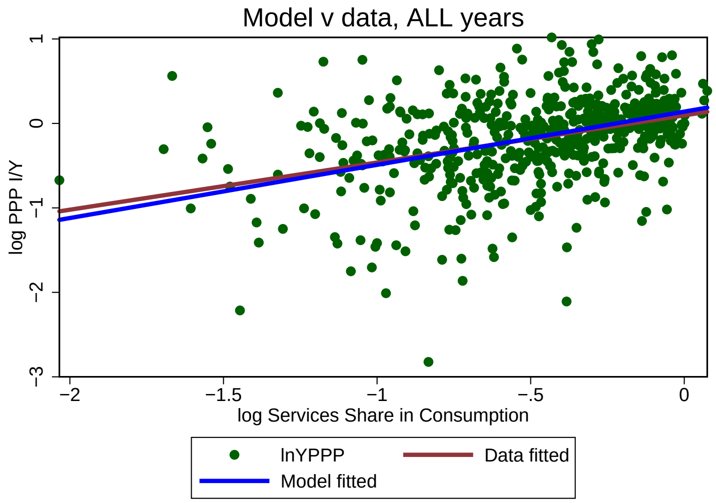

Figure 9: Cross country investment to GDP ratio in PPP dollars for all years v consumption share of services. The red line is the linear data fit, and the blue line the fit arising from the model calibration.

performance of the ISTC model in predicting the evolution of the relative price of investment are γ_I and γ_c.[34] As the nominal share of investment is constant, they also determine the evolution of the real investment rate. To assess the performance of the ISTC model it is then sufficient to calibrate γ_I and γ_c and we choose the following targets in the data: 1) the average growth rate of GDP per capita over the period considered (1950-2015); 2) the average growth rate of the real investment to output ratio during the period considered.

With an average GDP growth of 2.12%, real investment needs to grow at 3.04% to obtain a growth in I/Y of 3.04%-2.12%= 0.92% per year. The calibration then gives $\gamma_I = 3.04\%$ and $\gamma_c = 1.24$. The ISTC model thus accounts perfectly for the income elasticity of the real investment rate in the U.S., which is $0.92/2.12 = 0.43$. The income elasticity of the real investment rate computed using cross-country data for our 5 benchmark years and using the same specification as in Hsieh and Klenow (2007) is 0.19. In contrast with the ST model, the ISTC model predicts an elasticity that is more than double the one obtained using cross-country data.[35]

[34]That is, we can calibrate γ_I and γ_c independently of ϵ, and then pick ϵ to match the nominal share of investment.

[35]It is worth noting that a possible reason why the ST model performs better than the ISTC model, is that the former cannot as accurately account for the growth in the real investment rate in the U.S. The ST model predicts a value of 0.68% compared to 0.92% in the data. We can then ask what would the performance of the ISTC model be if it reproduced a growth of the real investment rate of 0.68%. In this case, we would have $0.68\%/2.12\% = 0.32$, which is still 68% larger than in the data.

7 Conclusions

We study the consequences of structural transformation for the growth process. While the extant literature has mainly focused on productivity growth effects (i.e. Baumol's "cost disease") here we study the effects on growth, real interest rates, the marginal product of capital, and the real investment to output ratio. We argue that, because of its effects on growth, structural transformation has the potential for generating "unbalanced" growth when variables are measured using NIPA conventions. We analyze the consequences of structural transformation for both the U.S. time-series and a cross-section of countries.

In the post-war U.S. economy we observe that the *real* investment-output and capital-output ratios display significant upward trends, whereas the rate of growth of per capita GDP displays a mild decline. We show how structural transformation can affect these variables using a two sector model of structural change from manufacturing to services displaying "balanced" growth. In this model, balanced growth occurs when variables are measured in terms of a numeraire (the price of manufacturing goods). When taken to the data, however, we need to measure the aggregate variables in the model using the same NIPA conventions that are used to construct national accounts. Our quantitative results suggest that structural transformation has a non-negligible effect on the growth process in the U.S. during the past 65 years. In particular, while accounting for the increasing share of services and the increasing real investment/output ratios, the model displays a mild decrease in the growth rate of GDP per-capita of 16%, a fall in the marginal product of capital of 36% when measured in units of GDP and of 43% in units of aggregate consumption and a decline in the real interest rate of 5%.

From an international perspective, the model implies that countries at a more advanced stage of structural transformation should display higher real investment to output ratios. Using the parameter calibration arising from the model for the U.S. economy, we then ask how much of the cross-country variability in investment rates can be accounted for by structural transformation alone. The elasticity of the real investment-output ratio with respect to the share of services in consumption is 0.61 in the data. The elasticity arising from the model is 0.63. That is, we can interpret the well known fact that real investment-output ratios increase as economies develop as a consequence of economies being at different stages of structural transformation along the same growth path. It follows that the two-sector model of structural transformation represents a simple and very tractable tool that can be used to study the process of economic growth. In particular, to explain the long run evolution of real investment rates and capital-output ratios it is not necessary to assume that different countries are on transitional dynamics converging asymptotically to a balanced growth path. The model does not even require to assume differences in preferences, taxation, or other deep parameters to explain cross-country differences in investment rates. The key assumption to generate these differences is a constant differential TFP growth between the goods and the services sector along the growth path, something that is motivated by the well established constant decline of the relative price goods/services in U.S. data.We also compare the performance of the structural transformation model with that of a standard investment-specific technical change model and conclude that the former outperforms the latter in terms of its predictions for cross-country real investment rates.

Thus, our results suggest that a growth model of structural transformation, when appropriately taken to the data, can account well for the time series evidence for the U.S. and for the international evidence on investment-output ratios. The measurement of the model with NIPA conventions is a key aspect of our approach, which is overlooked in most applications comparing multi-sector models to the data.

References

Antolín-Díaz, J., T. Drechsel, and I. Petrella (2017): "Tracking the Slowdown in Long-Run GDP Growth," *The Review of Economics and Statistics*, forthcoming.

Bai, J., R. L. Lumsdaine, and J. H. Stock (1998): "Testing For and Dating Common Breaks in Multivariate Time Series," *Review of Economic Studies*, 65(3), 395–432.

Barro, R., and X. Sala-i-Martín (2004): *Economic Growth*. McGraw-Hill.

Barro, R. J. (1991): "Economic Growth in a Cross Section of Countries," *The Quarterly Journal of Economics*, 106(2), 407–443.

Baumol, W. J. (1967): "Macroeconomics of unbalanced growth: the anatomy of urban crisis," *The American economic review*, pp. 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. Kaboski (2012a): "The Rise of the Service Economy," *American Economic Review*, 102(6), 2540–69.

Buera, F. J., and J. P. Kaboski (2012b): "Scale and the Origins of Structural Change," *Journal of Economic Theory*, 147(2), 684–712.

Caselli, F., and J. Feyrer (2007): "The Marginal Product of Capital," *The Quarterly Journal of Economics*, 122(2), 535–568.

Cochrane, J. H. (2009): *Asset pricing: Revised edition*. Princeton university press.

Duernecker, G., B. Herrendorf, and A. Valentinyi (2017): "Structural Change within the Service Sector and the Future of Baumol's Disease," Mimeo.

——— (2018): "Quantity Measurement and Balanced Growth in Multi-sector Growth Models," Mimeo.

Echevarria, C. (1997): "Changes in Sectoral Composition Associated with Economic Growth," *International Economic Review*, 38(2), 431–452.

Eo, Y., and J. Morley (2015): "Likelihood-ratio-based confidence sets for the timing of structural breaks," *Quantitative Economics*, 6(2), 463–497.

Fernald, J. G. (2012): “A quarterly, utilization-adjusted series on total factor productivity,” Working Paper Series 2012-19, Federal Reserve Bank of San Francisco.

García-Santana, M., J. Pijoan-Mas, and L. Villacorta (2016): “Investment Demand and Structural Change,” Mimeo.

Gourio, F., and T. H. Klier (2015): “Recent Trends in Capital Accumulation and Implications for Investment,” *Chicago Fed Letter*, (344).

Herrendorf, B., R. Rogerson, and A. Valentinyi (2014): “Growth and Structural Transformation,” *Handbook of Economic Growth*.

Hsieh, C.-T., and P. J. Klenow (2007): “Relative Prices and Relative Prosperity,” *American Economic Review*, 97(3), 562–585.

IMF (2018): *World Economic Outlook, April 2018*. International Monetary Fund.

Karabarbounis, L., and B. Neiman (2014): “The Global Decline of the Labor Share,” *The Quarterly Journal of Economics*, 129(1), 61–103.

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

Moro, A. (2015): “Structural Change, Growth, and Volatility,” *American Economic Journal: Macroeconomics*, 7(3), 259–94.

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

Nordhaus, W. D. (2008): “Baumol’s diseases: a macroeconomic perspective,” *The BE Journal of Macroeconomics*, 8(1).

Samaniego, R. M., and J. Y. Sun (2016): “Investment-Specific Technical Change and Growth around the World,” Mimeo.

Appendix

A A three sector model

In this appendix we extend the model to three sectors: a consumption good sector, a services sector and an investment sector. There are now three representative firms in the economy operating in perfect competition. The first firm produces the manufacturing consumption good with technology

$$y_{gt} = k_{gt}^{\alpha}(n_{gt}A_{gt})^{1-\alpha}, \tag{24}$$

where k_{gt}, n_{gt} and $A_{gt}^{1-\alpha}$ are capital, labor and total factor productivity (TFP) of the firm. The second firm produces services with technology

$$y_{st} = k_{st}^{\alpha}(n_{st}A_{st})^{1-\alpha}, \tag{25}$$

with k_{st}, n_{st} and $A_{st}^{1-\alpha}$ being capital, labor and TFP. The output of this firm is used as services consumption. Finally, the third firm produces the investment good with technology

$$y_{It} = k_{It}^{\alpha}(n_{It}A_{It})^{1-\alpha}, \tag{26}$$

with k_{It}, n_{It} and $A_{It}^{1-\alpha}$ being capital, labor and TFP.

TFP in the three sectors evolves according to

$$\frac{A_{st+1}}{A_{st}} = 1 + \gamma_s, \tag{27}$$

$$\frac{A_{gt+1}}{A_{gt}} = 1 + \gamma_g, \tag{28}$$

$$\frac{A_{It+1}}{A_{It}} = 1 + \gamma_I, \tag{29}$$

where γ_s , γ_g and γ_I are exogenous constant growth rates.

In equilibrium all markets clear and the following must hold

$$y_{gt} = C_{gt},$$

$$y_{st} = C_{st},$$

$$y_{It} = K_{t+1} - (1-\delta)K_t$$

$$k_{gt} + k_{st} + k_{It} = K_t,$$

Table 4: Parameter Values

β	α	δ	ϵ	ξ	ν	A_{g1}	A_{s1}	A_{I1}	γ_g	γ_s	γ_I
0.95	0.34	0.06	0.17	0.50	0.63	1	1	1	3.05%	0.62%	2.60%

Table 5: Data targets

Target	(1)	(2)	(3)	(4)	(5)	(6)
Data	2.12%	0.393	0.685	0.67%	-1.61%	-1.31%
Model	2.13%	0.390	0.685	0.46%	-1.61%	-1.31%

and

$$n_{gt} + n_{st} + n_{It} = 1.$$

By normalizing TFP levels in the three sectors in the first period to 1, we then need to calibrate three preference parameters ϵ, ξ and ν, and three growth rates of TFP, γ_s, γ_g and γ_I. Thus we need an additional target with respect to the two-sector model. Also, in the two-sector model, target 5) uses a Fisher index of the price of consumption goods and investment, because we assume that manufacturing goods and investment are produced in the same sector. Instead, here we target 5) the average growth in the relative price goods/services (-1.61%, where now we use the price of consumption goods as the numerator); and 6) the average growth in the relative price investment/services (-1.31%). Table 4 reports all parameter values while table 5 and figure 10 show the fit of the calibrated model.

In the two-sector model, we deflated the nominal investment-output ratio by the relative price manufacturing/GDP. To compare model and data, the price of goods in that case is a Fisher index of the price of consumption goods and investment. In the data in Figure 10 instead, the nominal investment-output is deflated by the price of investment over the price of GDP. In this case, the real investment-GDP ratio increases by 0.67% per year, compared to the 0.92% figure in section 3. The three sector model performs well in fitting GDP growth and the evolution of the share of services. As in the two-sector model, it reproduces a growth of the investment-GDP ratio smaller than in the data (0.46% versus 0.67%). The decline in the MPK in this case is 25% in terms of GDP and 32% in terms of aggregate consumption.

B Fisher Index

The Laspeyres and Paasche quantity indices as computed by NIPA are given by

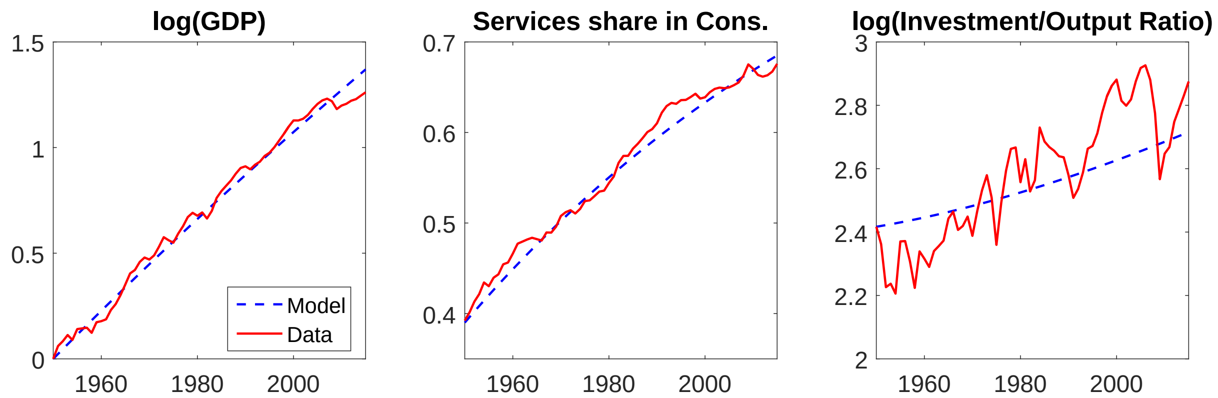

Figure 10: Three-sector model versus Data.

$$Q_t^L = \frac{\sum p_{t-1} q_t}{\sum p_{t-1} q_{t-1}},$$

$$Q_t^P = \frac{\sum p_t q_t}{\sum p_t q_{t-1}},$$

where the sum is over all the goods and services included in the bundle, p represents prices, and q quantities. The Fisher quantity index is then given by a weighted average of Laspeyres and Paasche

$$Q_t^F = \sqrt{Q_t^L Q_t^P}.$$

Consider the case of two goods. The Laspeyres is

$$Q_t^L = \frac{p_{1,t-1} q_{1,t} + p_{2,t-1} q_{2,t}}{p_{1,t-1} q_{1,t-1} + p_{2,t-1} q_{2,t-1}}.$$

Note that the Laspeyres quantity index is independent of the numeraire chosen. This is because it is a function of *relative prices*. To see this, divide numerator and denominator by the same price at $t-1:$

$$Q_t^L = \frac{q_{1,t} + \frac{p_{2,t-1}}{p_{1,t-1}} q_{2,t}}{q_{1,t-1} + \frac{p_{2,t-1}}{p_{1,t-1}} q_{2,t-1}},$$

thus implicitly choosing good 1 as the numeraire, or

$$Q_t^L = \frac{\frac{p_{1,t-1}}{p_{2,t-1}} q_{1,t} + q_{2,t}}{\frac{p_{1,t-1}}{p_{2,t-1}} q_{1,t-1} + q_{2,t-1}},$$

implicitly choosing good 2 as the numeraire. The same argument can be made for the Paasche index. This implies that the same argument extends to the Fisher index, which is a weighted average of the two. The bottom line is that the Fisher quantity index is *independent of the numeraire.*

The Fisher price index instead, is *not independent of the numeraire.* To see this we can proceed in two different ways, a direct one and an indirect one. The direct one requires constructing the Fisher price index using the NIPA formula. This is a weighted average of a Laspeyres and a Paasche price indices:

$$P_t^L = \frac{\sum p_t q_{t-1}}{\sum p_{t-1} q_{t-1}}$$

$$P_t^P = \frac{\sum p_t q_t}{\sum p_{t-1} q_t},$$

where again the sum is over the goods and services included in the bundle. The Fisher index is then given by a weighted average of Laspeyres and Paasche

$$P_t^F = \sqrt{P_t^L P_t^P}.$$

Consider the case of two goods. The Laspeyres is:

$$P_t^L = \frac{p_{1,t} q_{1,t-1} + p_{2,t} q_{2,t-1}}{p_{1,t-1} q_{1,t-1} + p_{2,t-1} q_{2,t-1}}. \tag{30}$$

It should be clear that this formula is not independent of the numeraire. To see this, consider that in (30) the numeraire each period is current dollars, as prices are expressed in dollar units. If instead, the numeraire each period is the price of good 1, equation (30) becomes

$$\widetilde{P}_t^L = \frac{q_{1,t-1} + \frac{p_{2,t}}{p_{1,t}} q_{2,t-1}}{q_{1,t-1} + \frac{p_{2,t-1}}{p_{1,t-1}} q_{2,t-1}}. \tag{31}$$

Clearly

$$P_t^L \neq \widetilde{P}_t^L.$$

The same argument can be made for the Paasche price index.

The other way to see this is to use the indirect method to construct the Fisher price index, that is dividing nominal GDP (i.e. in current dollars) by the Fisher index of real GDP computed above. Then

$$P_t^F = \frac{GDP_t}{Q_t^F}.$$

While real GDP Q_t^F is independent of the numeraire, nominal GDP, given by GDP_t in the formula, is not. For instance, if we express nominal GDP in units of apples instead of dollars, the Fisher price index that we obtain is different. The result should not be surprising, as a price is always an *exchange rate* of some units of one good for a unit of another good.

C Cross country data sources

The data used to construct cross-country series for investment to output ratios and the share of services in final household consumption come from four waves of the benchmark years of the International Comparisons Program used to construct the PWT dataset. We obtained data for benchmark years 1980, 1985, 1996, 2005, and 2011.[36] We collected data in purchasing power parity (PPP) dollars and in local currency. The series for real (PPP) investment to GDP ratios are ratios of investment to GDP in PPP dollars. The series for nominal investment to GDP ratios are ratios of investment to GDP in local currency. Investment consists of gross investment in fixed assets (excluding inventories). For the services consumption share, we summed the (nominal) expenditures on services and divided them by (nominal) household consumption. Because different benchmark years contain different detail of information on expenditure items, we list below the items considered as services consumption. We follow Herrendorf, Rogerson, and Valentinyi (2014) whenever possible as they suggest a sector assignment for years 1985 and 1996. The following are considered services consumption:

- 1980: services correspond to items 55, 59–62, 67, 79-80, 84–90, 94, 98–102, 109–111, 114–118, 123–125.
- 1985: services correspond to items 48, 52, 53-55, 62, 69, 73, 74, 78-81, 85, 88-93, 98-100, 102-104, 108-111.
- 1996: services correspond to gross rent and water charges, medical and health services, operation of transportation equipment, purchased transport services, communication, recreation and culture, education, restaurants, cafes and hotels, other goods and services.
- 2005: services correspond to miscellaneous goods and services, restaurants and hotels, education, recreation and culture, communication, transport, health. because the 2005 data contains an intem called housing, water, electricity, gas and other fuels, it does not distinguish between rents and the consumption of housing goods such as fuel. To

[36]Benchmark data for 1985 and 1996 can be obtained from http://www.rug.nl/ggdc/productivity/pwt/, for 2005 from http://databank.worldbank.org/data/reports.aspx?source=international-comparison-program-2005, and for 2011 from http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html.

separate rents out, we imputed rents according to the proportion of rents in total housing costs in 1996. The results without this imputation remain very similar and are available on request.

- 2011: services include health, transport, communication, recreation and culture, education, restaurants and hotels, miscellaneous goods and services. Housing expenditure is obtained as the difference between "individual consumption expenditure by households" and "individual consumption expenditure by households without housing".