Does Home Production Drive Structural Transformation?*

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Abstract

Using new home production data for the U.S., we estimate a model of structural transformation with a home production sector, allowing for both non-homotheticity of preferences and differential productivity growth in each sector. We report two main findings. First, the data support a specification with different income elasticities of market and home services. Second, the slowdown in home labor productivity, started in the late 70s, is a key determinant of the late acceleration of market services. A counter-factual experiment shows that, without the slowdown, the share of market services would be lower by 6.9% in 2010.

JEL Classification: E20, E21, L16.

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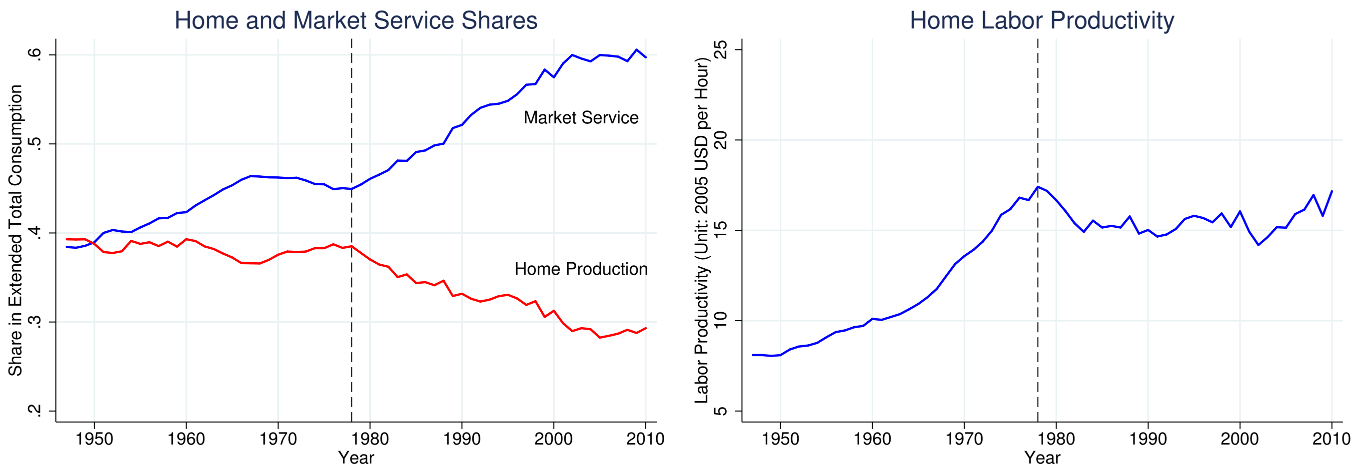

Figure 1: Home and Market Service Value Added Shares in Extended Total Consumption (Left) and Home Labor Productivity (Right)

Note: Data are from Bridgman (2013) and Herrendorf, Rogerson, and Valentinyi (2013).

1 Introduction

How important is the role of the home production sector for the process of structural transformation? In this paper, we address this issue by estimating a model of structural transformation using new home production data for the U.S. for the period 1947 to 2010. Our paper is motivated by the coincidence of the acceleration of the service sector growth, and the slowdown in home labor productivity. Figure 1 reports the shares of market and home services in *extended* total consumption and home labor productivity from Bridgman (2013).[1] The left panel shows that the growth rate of the share of market services accelerates around 1978, while the share of home production is flat until that year and it declines afterwards. The right panel shows that labor productivity at home maintains sustained growth (around 2.5% per-year on average) between 1947 and 1978, but undergoes a marked slowdown in the remaining part of the sample period.[2] These observations appear to suggest a role for home production in shaping structural change, something that has been noted in the previous literature.[3]

In this paper, we propose and estimate a model of structural transformation with a home production sector that can account for the movement of market and home services shares. We then assess whether the late acceleration of services can be explained by the

[1] We define extended total consumption as total consumption plus the value added of home production.

[2] The slowdown is statistically significant at 1% level according to the test proposed in Bai and Perron (1998, 2003) and break date is between 1978 and 1979.

[3] See for instance Rogerson (2008), and Ngai and Pissarides (2008) among others.

slowdown in home labor productivity through a counter-factual experiment. We start from a standard model of structural transformation with non-homotheticity of preferences and differential productivity growth in three market sectors as in Buera and Kaboski (2009). We then extend the model to include a home production sector, allowing for a different income elasticity between market and home services in household's demand. Since the inter-temporal and the intra-temporal problems can be solved independently in this model, we can re-write the latter as a static, consumption choice problem of the household, which depends on the prices of the three market goods, home labor productivity, extended total consumption, and extended total value added. This version of the model allows us to estimate the implied share equations, using the home production data from Bridgman (2013).

In the estimation, we allow for three different specifications of household preference. In the first specification, we consider the non-homothetic term for aggregate services to be *zero*, and also assume market and home services have the *same* income elasticity. In the literature, the non-homothetic term for aggregate services is interpreted as home production; so by having an explicit home sector in the model, it is natural to set it to zero.[4] In the second specification, we estimate the model by allowing the non-homothetic term for aggregate services to be *non-zero*, keeping the assumption that market and home services have the *same* income elasticity. The interpretation we give here is that the parameter simply reflects a non-homothetic nature of services, which cannot be explained by home production. Finally, in the third specification, we assume the non-homothetic term for aggregate services to be *zero*, but allow the income elasticity of services to be *different* between home and market.

We highlight two main results. First, in the estimation, the best fit of the data is given by the third specification, implying that the data support a different income elasticity between home and market services in household demand. Previous literature explained the movement of market and home service shares through their differences in the rates of technological progress.[5] On the other hand, our estimation results indicate that the model is not able to generate the movement of market and home service shares only through those differences in technologies. The second result is obtained by running a counter-factual experiment, in which we let home labor productivity grow at the constant rate of 2.5% after 1978, the average pace before the slowdown. We find that in this case the share of market services is 0.78 in 2010, compared to 0.84 in the data, which represents a 6.9% decrease. That is, without the slowdown in home labor productivity, the extent of structural change would be considerably lower than the actual data. This result indicates that the behavior of the home production sector can have quantitatively important implications for the structural change

[4]See Kongsamut, Rebelo, and Xie (2001).

[5]For example, see Ngai and Pissarides (2008) and Buera and Kaboski (2012b).

observed in market sectors.

Our paper relates to the literature that puts forth home production as a key determinant of the process of structural transformation, such as Rogerson (2008) and Ngai and Pissarides (2008). In particular, we focus on an aspect of the data which has not received extensive attention in the literature, namely the late acceleration of services. The empirical evidence for this fact is reported in Buera and Kaboski (2012a) for the U.S., and in Buera and Kaboski (2012b) and Eichengreen and Gupta (2013) for a large set of countries. Theories proposed to address this fact include those of Buera and Kaboski (2012a), who focus on human capital differences, and Buera and Kaboski (2012b), who study differences in production scale between the home and the market service sector. Our strategy here is instead to estimate a model that departs minimally from the standard model of structural change, and quantify the role of home production for the acceleration of market services through counter-factual experiments. In particular, we show that the marked slowdown of home labor productivity is largely responsible for the late rise of services in our model. This result calls for a cross-country investigation of the role of home production in generating structural change.

We also relate to the literature that estimates substitutability between market and home services. One set of studies uses fluctuations of aggregate home hours over the business cycles for estimation. For instance, McGrattan, Rogerson, and Wright (1997) find a value between 1.49 and 1.75 for the elasticity of substitution between market and home services, while Chang and Schorfheide (2003) estimate it as 2.3. Another set of works employs household micro data on home hours, instead. Rupert, Rogerson, and Wright (1995) find a value in the range between 1.60 and 2.00 while Aguiar and Hurst (2006) estimate it as 1.80. Our paper differs from these studies in that we estimate substitutability by exploiting variations in sectoral shares when prices change. In our most preferred specification, we estimate a value of 2.75, which is somewhat larger than the values obtained in the different approaches of the previous studies.

The remaining of the paper is as follows. Section 2 presents the model; Section 3 presents the estimation methodology and the data employed, while Section 4 reports the result and the counter-factual exercises. In Section 5 we present some robustness exercises and in Section 6 we conclude.

2 Model

This section presents a model of structural change with a home production sector.

2.1 Setup

Time is discrete. There is a representative household, whose objective is to maximize her utility. There are five types of good produced in this economy: four consumption goods (agriculture, manufacturing, market services, and home services) and one investment good. The household's preference is given by

$$u = \sum_{t=0}^{\infty} \beta^t \ln C_t,$$

where β is the subjective discount factor. The composite consumption index C_t is defined as

$$C_t = \left(\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \tag{1}$$

where c_t^i denotes consumption of good $i \in \{a, m, s\}$. In (1), the parameter ω^i determines the weight on each good in the household's preference; the parameter $\bar{c}^i$ controls non-homotheticity in preference; and the parameter σ governs the elasticity of substitution between three goods. Service consumption is a composite of market services, c_t^{sm}, and home produced services, c_t^{sh}, as

$$c_t^s = \left[\psi (c_t^{sm})^{\frac{\gamma-1}{\gamma}} + (1-\psi)(c_t^{sh} + \bar{c}^{sh})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}. \tag{2}$$

In (2), the parameter γ governs the elasticity of substitution between market and home services and ψ is the share parameter in the service aggregator. Note that we allow for a different income elasticity between market and home services through the parameter $\bar{c}^{sh}$. We provide a discussion on this parameter in Section 2.5 and in the estimation section.

In our setup, for each period, the household is endowed with $\bar{l} = 1$ unit of labor that she splits into working time in the market, l_t^{mk}, paid at wage w_t and working time at home, l_t^{sh}. Also, the household holds the capital stock k_t in the economy, and decides how much to rent in the market, k_t^{mk}, at rate r_t, and how much to use in home production, k_t^{sh}. Then, the household's constraints are given by

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + k_{t+1}^{mk} - (1-\delta) k_t^{mk} + k_{t+1}^{sh} - (1-\delta) k_t^{sh} = r_t k_t^{mk} + w_t l_t^{mk}, \tag{3}$$

$$l_t^{mk} + l_t^{sh} = \bar{l},$$

where p_t^j is the price of good $j \in \{a, m, sm\}$ and δ is the depreciation rate. We normalize the price of the investment goods to be equal to one. The total amount of capital is defined as

$$k_t \equiv k_t^{mk} + k_t^{sh}.$$

The household produces home services through the following technology,

$$c_t^{sh} = A_t^{sh} \left(k_t^{sh}\right)^{\alpha} \left(l_t^{sh}\right)^{1-\alpha}.$$

In this economy, there is a perfectly competitive firm in each market sector $j \in \{a, m, sm\}$ with technology,

$$Y_t^j = A_t^j \left(K_t^j\right)^{\alpha} \left(L_t^j\right)^{1-\alpha}.$$

Finally, there is also a perfectly competitive firm operating in the investment good sector with technology,

$$Y_t^x = A_t^x \left(K_t^x\right)^{\alpha} \left(L_t^x\right)^{1-\alpha}.$$

2.2 Household's Problem

Next, we re-write the previous setup by treating the home production sector as being operated by a perfectly competitive firm. This allows us to consider the home production sector as similar to the other sectors, which helps us to simplify the problem. We first define an implicit price index for the home good by

$$p_t^{sh} \equiv \frac{r_t^{\alpha} w_t^{1-\alpha}}{A_t^{sh} \alpha^{\alpha} (1-\alpha)^{1-\alpha}}. \tag{4}$$

Using the above price, we can show that

$$p_t^{sh} c_t^{sh} = w_t l_t^{sh} + r_t k_t^{sh}. \tag{5}$$

We now add up (5) to the budget constraint of the household, (3), and obtain

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} + k_{t+1} - (1-\delta) k_t = r_t k_t + w_t \bar{l}.$$

Thus, we rewrite the household problem as

$$\max \sum_{t=0}^{\infty} \beta^t \ln C_t \tag{P1}$$

subject to

$$C_t = \left(\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}},$$

$$c_t^s = \left[\psi (c_t^{sm})^{\frac{\gamma-1}{\gamma}} + (1-\psi)(c_t^{sh} + \bar{c}^{sh})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}},$$

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} + k_{t+1} - (1-\delta) k_t = r_t k_t + w_t \bar{l}.$$

Given the definition of the implicit price for home services, (4), it is straight-forward to show that the problem (P1) is equivalent to the original setup in Section 2.1.

2.3 Separating Inter-Temporal and Intra-Temporal Problems

As the final step toward the estimation, we separate the inter-temporal problem from the main problem. Specifically, we show (in the appendix) that the household's problem (P1) can be decomposed into the following two problems.

1. *Inter-Temporal Problem*: The household solves:

$$\max_{\{C_t, k_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \ln C_t \tag{P2}$$

   subject to

$$P_t C_t + k_{t+1} - (1-\delta) k_t = r_t k_t + w_t \bar{l} + p_t^{sh} \bar{c}^{sh} + \sum_{i=a,m,s} p_t^i \bar{c}^i,$$

   where $P_t \equiv \left[\sum_{i=a,m,s} \omega^i \left(p_t^i\right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$ and $p_t^s \equiv \left[\psi^\gamma \left(p_t^{sm}\right)^{1-\gamma} + (1-\psi)^\gamma \left(p_t^{sh}\right)^{1-\gamma} \right]^{\frac{1}{1-\gamma}}$.

2. *Intra-Temporal Problem*: The household solves:

$$\max_{\left\{c_t^a, c_t^m, c_t^{sm}, c_t^{sh}\right\}} \left(\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{P3}$$

   subject to

$$c_t^s = \left[\psi (c_t^{sm})^{\frac{\gamma-1}{\gamma}} + (1-\psi)(c_t^{sh} + \bar{c}^{sh})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}},$$

   and

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} = P_t C_t - \sum_{i=a,m,s} p_t^i \bar{c}^i - p_t^{sh} \bar{c}^{sh} \equiv E_t,$$

where E_t stands for the extended total expenditure on consumption - that is, total consumption plus home production.

The above decomposition indicates that the inter-temporal problem (P2) and the intra-temporal problem (P3) can be solved separately. Also, note that the intra-temporal problem (P3) is the one that causes sectoral transformation among four consumption good sectors in our setup.

In Section 3, we estimate the intra-temporal problem (P3) using time series data for prices $\{p_t^a, p_t^m, p_t^{sm}, p_t^{sh}\}$ and extended total consumption, E_t.[6] We choose to estimate (P3) instead of the full model (P1) for two reasons. First, we are interested in estimating preference parameters in a model of structural transformation with home production. Given the separation of the two problems shown in this section, it is sufficient to estimate (P3) to obtain consistent estimators of the relevant parameters. Second, to estimate the full model (P1), we would need to take a stand on how to bring the investment sector to the data. We know that, in the data, aggregate investment comes from the three market sectors (agriculture, manufacturing, and services) and that the composition has been changing over time. Given this feature of investment one needs to make some simplification assumptions to model the investment sector. However, depending on the modeling choice, estimates could be different. With this in mind, we avoid to make this choice in the inter-temporal problem, and focus only on the estimation of the intra-temporal problem (P3).

2.4 Alternative Preference Specifications

The model presented in the previous subsections encompasses the standard models of structural transformation, namely those of Kongsamut, Rebelo, and Xie (2001) and Ngai and Pissarides (2007), with the addition of home production. Since our purpose is to study the effect of home production on structural transformation, we estimate the following three different specifications, which imply different interaction mechanisms of the home and the market sectors.[7]

Model 1: We first impose $\bar{c}^s = \bar{c}^{sh} = 0$. As discussed in Kongsamut, Rebelo, and Xie (2001), the parameter $\bar{c}^s > 0$ can be interpreted as home production of services. Thus, when adding an explicit home production sector to the model, a natural restriction is to impose $\bar{c}^s = 0$. In this way we can asses whether the home sector can replicate the role played by the non-homothetic parameter in the standard model.

[6] Regarding the implicit price of home good, p_t^{sh}, we discuss how to link it to labor productivity data in Section 2.5.

[7] Note that in all specifications we restrict $\bar{c}^m$ to be zero as standard in the literature.

Model 2: In the second specification, we only impose $\bar{c}^{sh} = 0$. This implies that we are allowing for both an explicit home production sector and the standard non-homotheticity effect for services. One can consider that the parameter $\bar{c}^{s}$ simply reflects a non-homothetic nature of services, which is not fully explained by home production. This is the interpretation that we take in estimating this version of the model.

Model 3: Finally, we estimate the specification in which $\bar{c}^{s} = 0$. In this case we are allowing the non-homotheticity to be specific to the home services through $\bar{c}^{sh}$. Putting it differently, we are allowing the non-homotheticity to be different between market and home services.[8] This is done because the empirical evidence suggests that services categories can have different income elasticities. For instance, Eichengreen and Gupta (2013) show that the share of modern market services rises faster with income compared to that of the more traditional market services, which can also be produced at home. Although this evidence does not provide insights on the income elasticity of home services, it is reasonable to suppose that home and market services have different income elasticities. If the latter have a larger elasticity, we should expect a parameter $\bar{c}^{sh} < 0$. In this case, the parameter can be interpreted as a minimum requirement of home production that the household has to provide (for instance maintenance and cleaning) before enjoying the rest of home services produced.

2.5 Implicit Price for Home Services

In order to link the implicit price for home services, p_t^{sh}, to the home labor productivity, we consider the first order condition with respect to labor in the home sector:

$$p_t^{sh} = \frac{w_t}{(1-\alpha)\, A_t^{sh} \left(\frac{K_t^{sh}}{L_t^{sh}}\right)^{\alpha}} = \frac{w_t}{(1-\alpha)\left(\frac{Y_t^{sh}}{L_t^{sh}}\right)} = \frac{w_t}{(1-\alpha)\, A_t^{*sh}} \tag{6}$$

where A_t^{*sh} is the labor productivity of the home sector.[9] Thus, the implicit price for home production is a function of the wage rate and the home labor productivity. To find the wage rate, w_t, note that we have $L_t^a + L_t^m + L_t^{sm} + L_t^{sh} + L_t^x = \bar{l} = 1$. Then, we obtain

$$w_t = (1-\alpha) EGDP_t, \tag{7}$$

[8]Note that in a CES aggregator with two goods, the presence of a non-homothetic term associated with one of the goods implies that the other good will also display a non-homothetic behavior. This is the case here for home services and market services. On this point, see Moro (forthcoming).

[9]In Equation (6), K_t^{sh}, L_t^{sh}, and Y_t^{sh} denote capital, labor, and output, which the firm operating in the home sector uses and produces.

where $EGDP_t$ denotes the extended total value added, calculated by adding total value added in the market to value added at home, Y_t^{sh}. The above equation means that the wage rate is equal to the labor share in the extended total value added, given that the total amount of labor is normalized to one. From (6) and (7), we can derive[10]

$$p_t^{sh} = \frac{EGDP_t}{A_t^{*sh}}. \tag{8}$$

We use the above implicit price for home services to solve the problem (P3).

3 Estimation

This section explains how we estimate our model.

3.1 Procedure

To estimate the model, we first derive equations for the share of each sector in the extended total consumption. Given the implicit price for home services, (8), and the set of (pre-determined) variables

$$\mathbf{x}_t \equiv \left(p_t^a, p_t^m, p_t^{sm}, A_t^{*sh}, E_t, EGDP_t\right),$$

problem (P3) can be solved for four shares, $\frac{p_t^j c_t^j}{E_t}$, where $j \in \{a, m, sm, sh\}$. The set of parameters to be estimated in the model is

$$\boldsymbol{\theta} \equiv \left(\sigma, \bar{c}^a, \bar{c}^s, \bar{c}^{sh}, \omega^a, \omega^m, \omega^s, \psi, \gamma\right).$$

Since sectoral shares sum up to one, the error covariance matrix becomes singular with four share equations. Thus, we drop one share equation, and finally have the three non-linear equations to be estimated:

$$\frac{p_t^a c_t^a}{E_t} = f_1\left(\mathbf{x}_t; \boldsymbol{\theta}\right) + \epsilon_1,$$
$$\frac{p_t^m c_t^m}{E_t} = f_2\left(\mathbf{x}_t; \boldsymbol{\theta}\right) + \epsilon_2,$$
$$\frac{p_t^{sm} c_t^{sm}}{E_t} = f_3\left(\mathbf{x}_t; \boldsymbol{\theta}\right) + \epsilon_3.$$

In the appendix, we show the derivation of (f_1, f_2, f_3).[11]

[10] Here, we are using the assumption that the labor share parameter (α) is the same in the market sectors and the home sector. In Section 5.1, we relax this assumption.

[11] See Equations (19) through (21).

To estimate our demand system we closely follow previous works in the literature: Deaton (1986) and Herrendorf, Rogerson, and Valentinyi (2013). Specifically, we employ iterated feasible generalized nonlinear least square to estimate the share equations.[12] For the parameters with constraints ($\sigma \geq 0,\ \omega^a + \omega^m + \omega^s = 1,\ \omega^i \geq 0,\ 0 \leq \psi \leq 1,\ \gamma \geq 0$), we transform them into unconstrained parameters as follows;

$$\sigma = e^{b_1},\ \omega^a = \frac{1}{1+e^{b_2}+e^{b_3}},\ \omega^m = \frac{e^{b_2}}{1+e^{b_2}+e^{b_3}},\ \omega^s = \frac{e^{b_3}}{1+e^{b_2}+e^{b_3}},\ \psi = \frac{e^{b_4}}{1+e^{b_4}},\ \gamma = e^{b_5}.$$

After estimating the unconstrained parameters, we transform those back to compute point estimates and standard errors for the original parameters.

3.2 Data

One of the contributions of this paper is to estimate the structural change model using newly-created home production data for the U.S. by Bridgman (2013).[13] Since the construction of home production values in his paper is based on the value-added method, we focus on consumption value added shares for our estimation. Here, we list the set of the data we use for our estimation:

- *Value Added Consumption* and *Price Index*: The data for value added consumption and consistent price index for agriculture, manufacturing, and services is from Herrendorf, Rogerson, and Valentinyi (2013). The advantage of using their data is that they compute value-added consumption from final consumption expenditure by using an input-output matrix, in order to avoid investment components included in consumption value-added data.[14]

- *Total Value Added*: We need the total value added data for the calculation of the implicit home price equation, (8). We obtain the data from BEA.

- *Value Added* and *Labor Productivity in the Home Sector*: We use the value added of the home sector and home labor productivity data from Bridgman (2013).

[12] This methodology has also been recently used in the estimation of supply systems. See León-Ledesma, McAdam, and Willman (2010).

[13] Bridgman (2013) constructed home production data by using the equation, $Y_t^{sh} = w_t L_t^{sh} + \sum_j \left(r_t^j + \delta^j\right) Q_t^j$, where Q_t^j is the value of capital good j at home.

[14] Other previous works in this literature assume investments are all made from manufacturing goods, creating a problem because investment exceeds manufacturing from 1999 onward in BEA's data.

In our estimation, we focus on the time period between 1947 and 2010, due to the availability of the data listed above.[15] In order to calculate four sector shares (agriculture, manufacturing, services, and home) in extended consumption value added, we combine consumption value added data with value added of the home sector. One important assumption made here is that goods produced at home are not used for investments. To derive the implicit home price, (8), we use the extended total value added and home labor productivity. The extended total value added is obtained by combining the total value added with value added of the home sector.

4 Results

In this section, we describe our estimation results.

4.1 Estimates

Table 1 summarizes all the estimation results for our three specifications of the model. In columns (1) to (3), Model 1 ($\bar{c}^s = \bar{c}^{sh} = 0$) is estimated for different types of restrictions on γ. In column (1) we set no restrictions on γ. In column (2) we set γ to 1.5, the smallest value used in the literature, while in column (3) γ is equal to 2.3, the largest value in the literature.[16] Similarly, we estimate Model 2 ((4) no restriction, (5) $\gamma = 1.5$, and (6) $\gamma = 2.3$), and also Model 3 ($\bar{c}^s = 0$) ((7) no restriction, (8) $\gamma = 1.5$, and (9) $\gamma = 2.3$).

From the perspectives of the Akaike and Bayesian Information Criteria (AIC and BIC henceforth) reported in Table 1, it is evident that neither of the specifications of Model 1 and 2 (the column (1) through (6)) has better performance than Model 3a (column (7)), which has lower values of the AIC and the BIC. The failures of the fit of Model 1a and 2a are also visually presented in Figure 2, indicating that neither models can correctly capture the increasing trend of market services and the decreasing trend of home services. These facts imply that the common specification in the literature, which assumes the same income elasticity of market and home services (i.e. $\bar{c}^{sh} = 0$), cannot explain why the demand for market services has increased relative to home services over the period. Also, from the estimation of Model 2, it is clear that the non-homotheticity term on aggregate services ($\bar{c}^s$) doesn't help to solve the issue.

[15]Our data for the estimation starts from 1947 because we cannot construct value-added consumption from final consumption expenditure before the period due to the unavailability of an input-output matrix . Our data ends in 2010, because the data for value added and labor productivity in the home sector is not released after the time.

[16]We take 1.5 from McGrattan, Rogerson, and Wright (1997) and 2.3 from Chang and Schorfheide (2003).

Table 1: Sectoral Share Estimation Result

	(1) 1a	(2) 1b	(3) 1c	(4) 2a	(5) 2b	(6) 2c	(7) 3a	(8) 3b	(9) 3c	(10) 3d
σ	0.2212**	0.3787**	0.1985**	0.1781**	0.2940**	0.1876**	0.0015	0.0006	0.0010	
	(0.0265)	(0.0280)	(0.0212)	(0.0276)	(0.0249)	(0.0243)	(0.0009)	(0.0012)	(0.0009)	
$\bar{c}^a$	-174.0990**	-175.1083**	-162.1058**	-171.9554**	-176.4608**	-169.5443**	-111.0453**	-134.5039**	-127.7640**	-107.6523**
	(4.0798)	(4.0280)	(5.7545)	(3.3737)	(3.6396)	(3.4175)	(4.8018)	(11.7211)	(9.5673)	(6.2414)
$\bar{c}^s$				562.9095**	1248.9178**	34.3515				
				(117.2384)	(179.4126)	(25.7063)				
$\bar{c}^{sh}$							-5462.3142**	-5016.4150**	-5497.1630**	-5374.0798**
							(102.6465)	(386.9034)	(156.6820)	(86.5952)
ω^a	0.0001	0.0001	0.0008	0.0000	0.0000	0.0001	0.0039**	0.0028**	0.0030**	0.0041**
	(0.0001)	(0.0001)	(0.0005)	(0.0001)	(0.0000)	(0.0001)	(0.0005)	(0.0010)	(0.0009)	(0.0006)
ω^m	0.1714**	0.1662**	0.1711**	0.1670**	0.1579**	0.1714**	0.1997**	0.1989**	0.2004**	0.1991**
	(0.0014)	(0.0019)	(0.0013)	(0.0017)	(0.0022)	(0.0014)	(0.0021)	(0.0024)	(0.0022)	(0.0021)
ω^s	0.8285**	0.8337**	0.8281**	0.8329**	0.8420**	0.8284**	0.7964**	0.7983**	0.7966**	0.7968**
	(0.0014)	(0.0019)	(0.0013)	(0.0017)	(0.0022)	(0.0014)	(0.0024)	(0.0030)	(0.0026)	(0.0024)
ψ	0.5712**	0.5735**	0.5716**	0.5710**	0.5722**	0.5708**	0.6107**	0.6366**	0.6179**	0.6099**
	(0.0020)	(0.0023)	(0.0018)	(0.0016)	(0.0024)	(0.0015)	(0.0011)	(0.0072)	(0.0019)	(0.0010)
γ	2.1180**			1.9992**			2.7357**			2.7450**
	(0.0763)			(0.0828)			(0.0331)			(0.0318)
N	64	64	64	64	64	64	64	64	64	64
AIC	-1272.7	-1262.1	-1274.5	-1266.7	-1263.1	-1271.8	-1438.1	-1268.5	-1374.1	-1440.7
BIC	-1234.8	-1230.5	-1242.9	-1222.5	-1225.2	-1233.9	-1393.9	-1230.6	-1336.2	-1402.8
$RMSE^a$	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
$RMSE^m$	0.009	0.011	0.009	0.008	0.008	0.009	0.011	0.011	0.011	0.011
$RMSE^s$	0.033	0.042	0.032	0.032	0.037	0.032	0.015	0.025	0.014	0.015
$RMSE^h$	0.029	0.037	0.027	0.030	0.035	0.027	0.005	0.027	0.011	0.005

Robust standard errors in parentheses
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Note: N stands for the number of the sample in the estimation. AIC is Akaike Information Criterion. BIC is Bayesian information Criterion. $RMSE^j$ is the Root Mean Squared Error for j-sector's share equation.

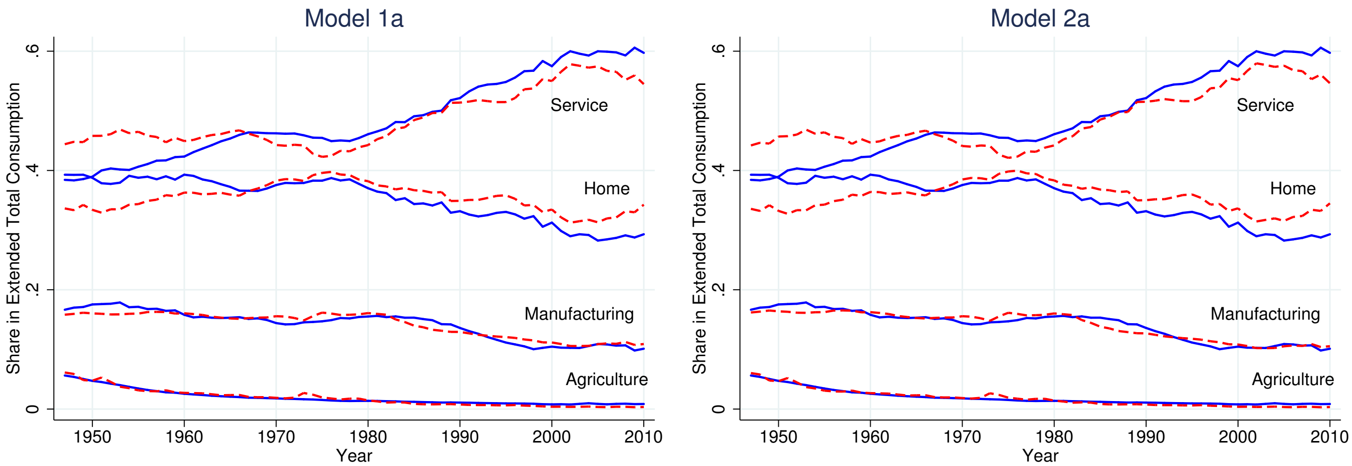

Figure 2: Fitted Sectoral Shares in Extended Total Consumption for Model 1a ($\bar{c}^s = \bar{c}^{sh} = 0$) and Model 2a ($\bar{c}^{sh} = 0$)

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

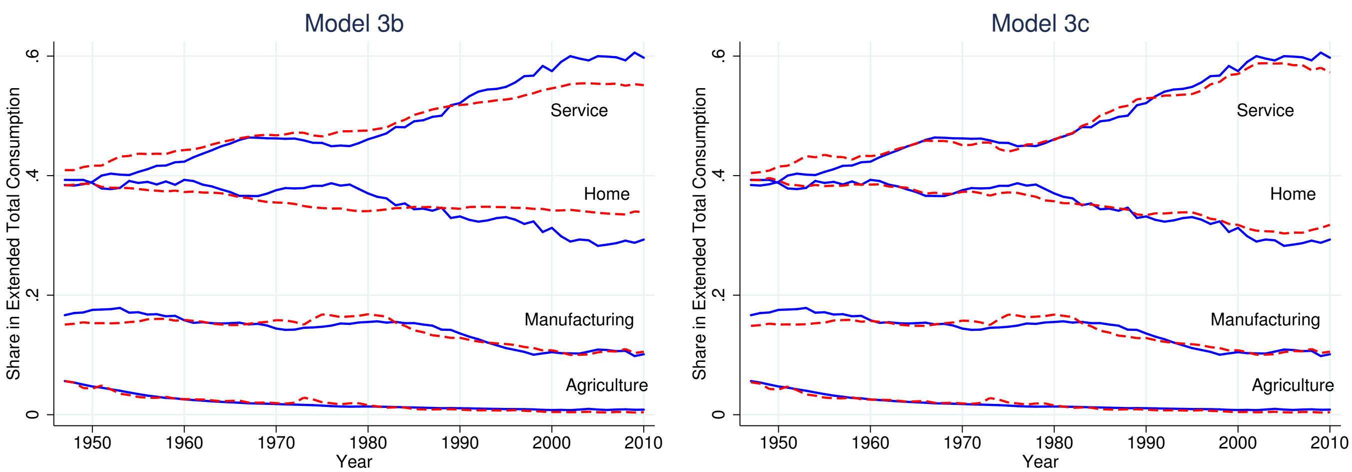

Figure 3: Fitted Sectoral Shares in Extended Total Consumption for Model 3b ($\gamma = 1.5$) and Model 3c ($\gamma = 2.3$)

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

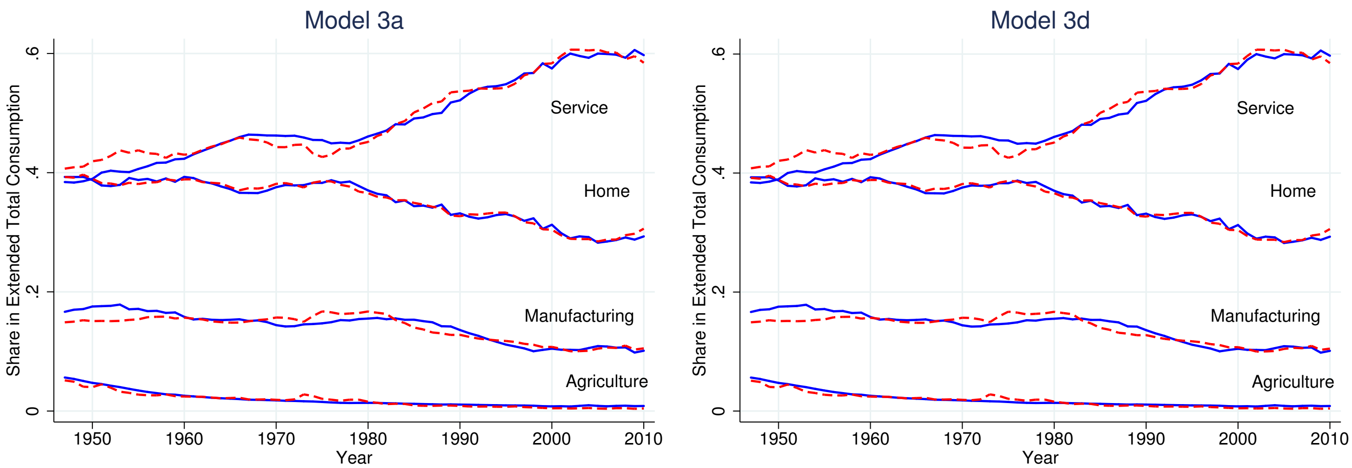

Figure 4: Fitted Sectoral Shares in Extended Total Consumption for Model 3a (σ unrestricted) and Model 3d ($\sigma = 0$)

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

We now turn to discuss Model 3. There are two points which are worth emphasizing here. First, by comparing the performance of 3a, 3b, and 3c, we note that the substitutability parameter (γ) plays an important role in determining the model's fit. This is also visually shown in Figure 3. When the substitutability parameter (γ) is set to 1.5 (Model 3b), the model cannot account for the slowdown in the growth of the service share in 1970s, and its rapid growth thereafter. The model's performance improves when the value of the substitutability parameter (γ) becomes larger (see Model 3c in Figure 3). When the value is unrestricted, we estimate it to be 2.75 (Model 3a in the column (7) of Table 1), which is somewhat larger than those in the previous studies.[17]

Second, once the non-homothetic term for home service is introduced, the value of σ is no longer statistically significantly different from zero. The point estimator of σ is 0.0015, and the value of the heteroscedasticity-robust standard error is 0.0009. This implies that the utility function takes a Leontief specification in terms of agricultural, manufacturing, and aggregate services. Notably, this result for σ is similar to that of Buera and Kaboski (2009) and of Herrendorf, Rogerson, and Valentinyi (2013). Given that the point estimator of σ is not statistically significantly different from zero, we restrict the value of σ to zero, and run the estimation of Model 3d (column (10) in Table 1). The result shows that, while the

[17] As we noted before, the value of the substitutability parameter (γ) ranges between 1.5 and 2.3 according to McGrattan, Rogerson, and Wright (1997), Chang and Schorfheide (2003), Rupert, Rogerson, and Wright (1995) and Aguiar and Hurst (2006). Note also that the estimated value for the share parameter in the services aggregator (ψ) is within the range obtained in previous work. For instance, McGrattan, Rogerson, and Wright (1997), Rogerson (2008) and Rendall (2011) report values between 0.4 and 0.6.

root mean squared errors are unchanged, the AIC and the BIC decrease, implying that this specification is the most preferable in terms of those measures. Therefore, we use Model 3d for our counter-factual experiments in the subsequent subsections.[18]

4.2 Properties of the Estimated Model

In this subsection, we study how the estimated model behaves when there is a change in relative prices or in the level of income. We start by presenting a partial equilibrium exercise in which there is a change in the price of either manufacturing or market services. We compare our model with the standard model of structural transformation in Herrendorf, Rogerson, and Valentinyi (2013), in which there are only three consumption good sectors, and no home production sector. These results are shown in Figures 5 and 6.

Comparing the responses of the two models to price shocks, first note that, in both models, σ is zero, meaning that the utility function takes a Leontief specification in terms of agriculture, manufacturing, and aggregate services. This, in the model without home production, implies that quantities in equilibrium are little affected by changes in prices, so that the share of manufacturing (or services) increases and the other shares decline after the rise in the price of manufacturing (or services) (see HRV in Figures 5 and 6). This is also the same for the model with home production, when the shock is on the manufacturing price (Model 3d in Figure 5). However, when the shock is on the services price (Model 3d in Figure 6), the result is different. The rise in the share of market services becomes smaller, because the household substitutes market services with home services. This substitution effect is also reflected in the decline of total consumption expenditure in the market (last panel in Figure 6). As a result, the variation of all market shares is smaller, compared to the case with no home production. In summary, when there is a shock to the price of services, substitution between market and home services occurs. Therefore, our model exhibits a share movement which is substantially different from the one in the previous literature. This substitution effect also plays a central role for the movement of market services shares when there is a slowdown in home labor productivity, which we study in Section 4.3.

Next, we perform a counter-factual exercise in which we shut down price and income effects one at a time, and compare the evolution of the shares as implied by the model with those in the data. The results of this exercise are reported in Figure 7. The lesson we can draw is that both income and price effects are important to account for actual shares also

[18] To interpret the estimated non-homothetic terms $\bar{c}^a$ and $\bar{c}^{sh}$ for Model 3d, we compute their values relative to the consumption level of each good in 1947. The value of $(-\bar{c}^a/c^a)$ in 1947 is 0.67, while that of $(-\bar{c}^{sh}/c^{sh})$ in 1947 is 0.49.

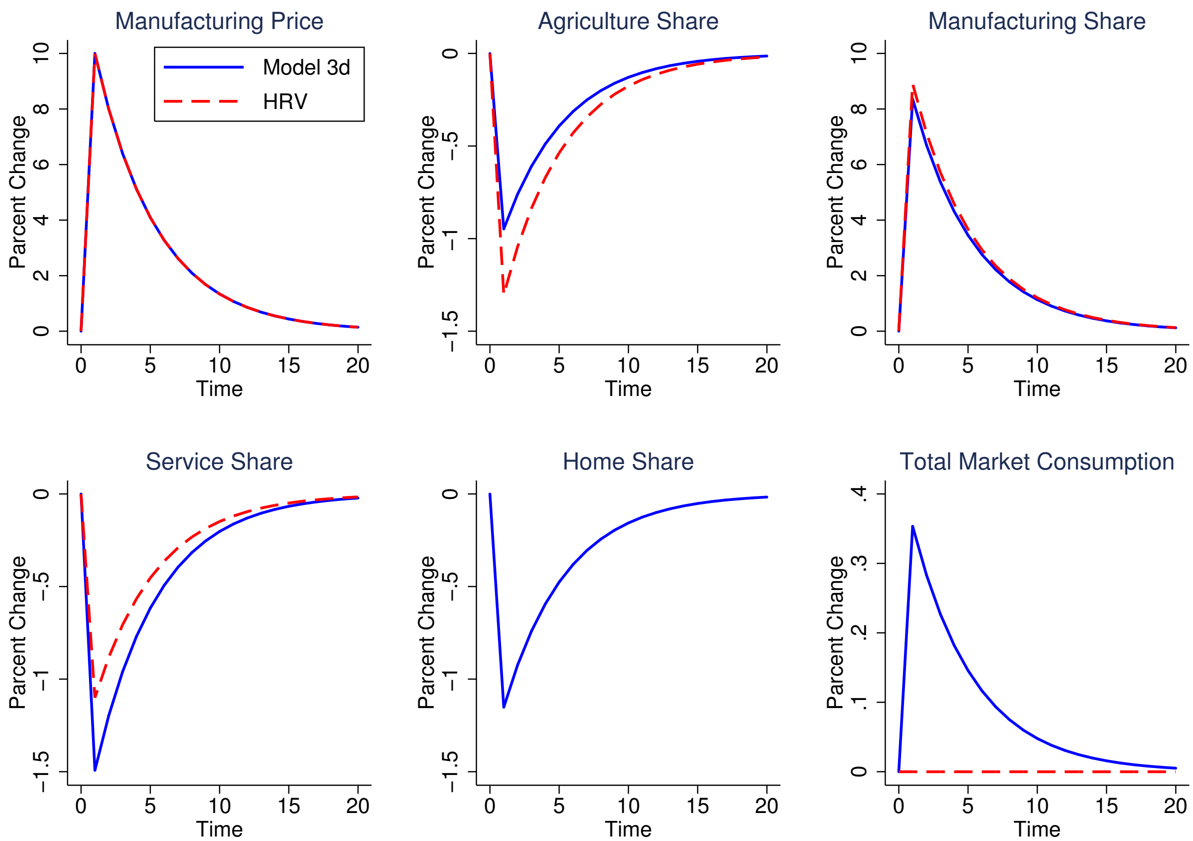

Figure 5: Effect of an Increase in Manufacturing Price on Sectoral Shares, Comparison with HRV (2013)

Note: For the purposes of comparison, we replicate the results of the specification "(2)" in Table 3 in HRV (2013). All the shares are calculated relative to total market consumption, in order to make the results in our model and HRV (2013) comparable.

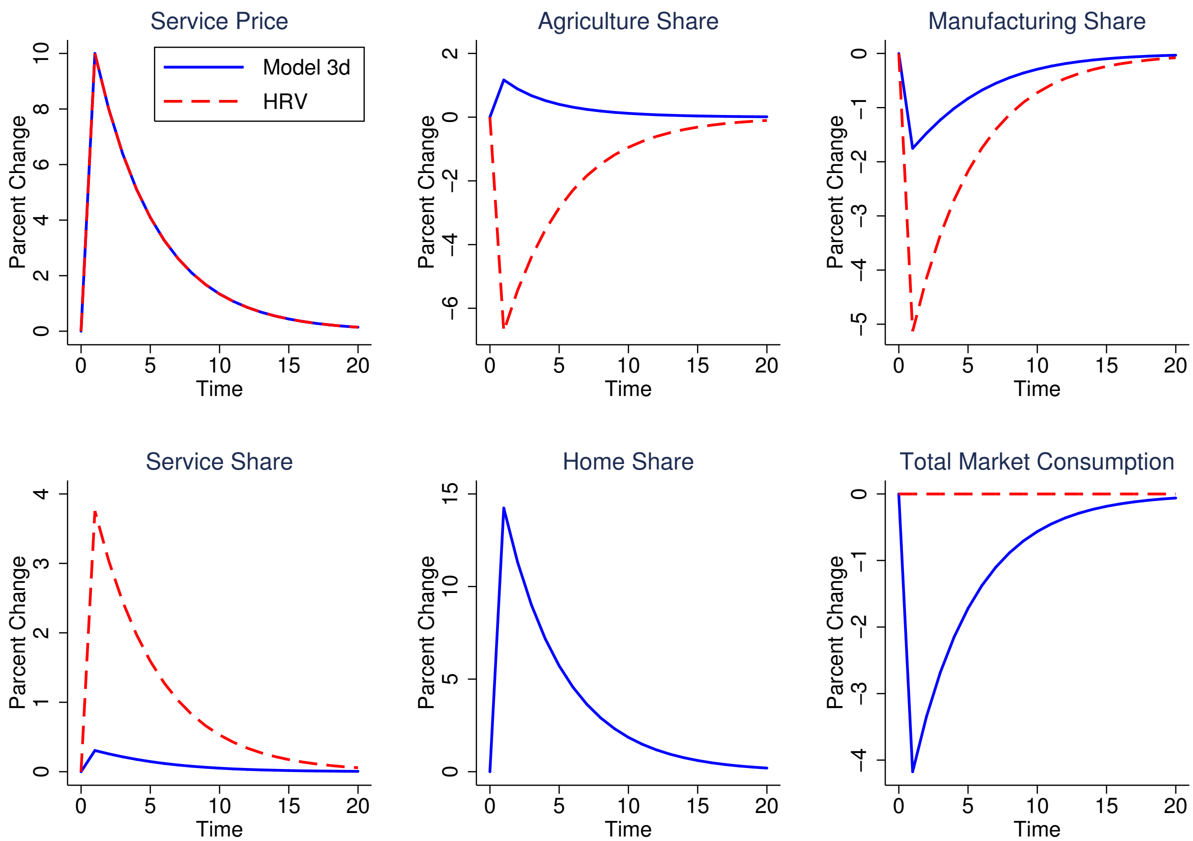

Figure 6: Effect of an Increase in Service Price on Sectoral Shares, Comparison with HRV (2013)

Note: For the purposes of comparison, we replicate the results of the specification "(2)" in Table 3 in HRV (2013). All the shares are calculated relative to total market consumption, in order to make the results in our model and HRV (2013) comparable.

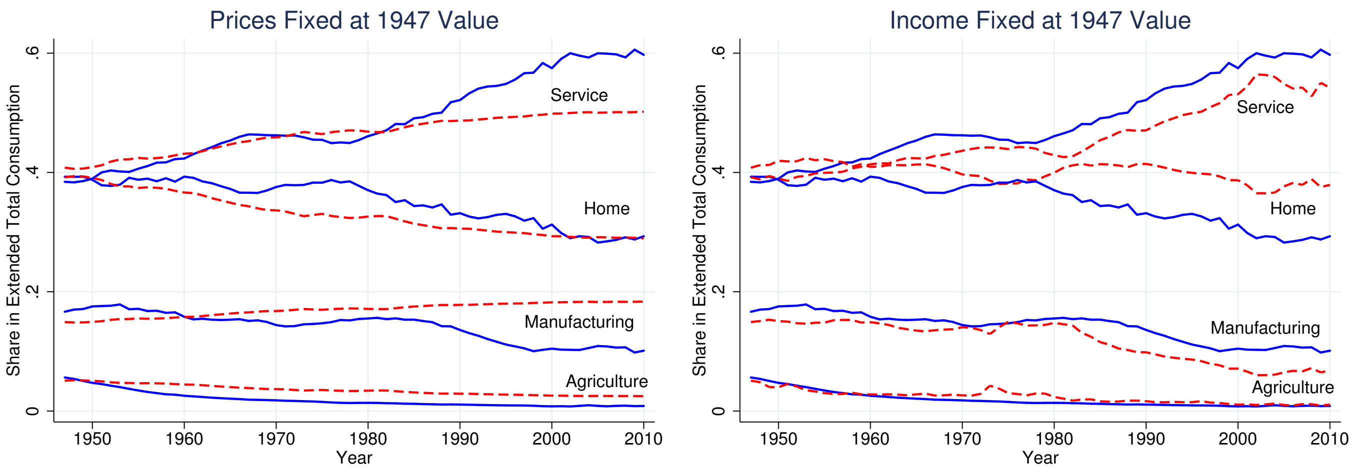

Figure 7: Sectoral Share Movements when Prices are Fixed at 1947 Value (Left) and Income is Fixed at 1947 Value (Right)

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

in the model with home production.[19] However, there seems to be a key difference between market and home services. With income effects only, the model is able to account for the entire decline of the home share over the period, while it cannot explain the entire rise of market services (left panel). The rest of the changes in market services are generated by the price changes (right panel). To sum up, the decline of the home sector is explained by the difference in degrees of non-homotheticity between home and market services, while the rise of market services is the result of both non-homotheticity and price effects.

4.3 Slowdown in Home Labor Productivity after 1978

As documented in Bridgman (2013), the growth rate of home labor productivity out-paces that of the market economy during the 1948-1977 period (2.5% versus 2.1%). After that period, the growth rate of labor productivity fluctuates around zero (see Figure 8, left panel). To precisely date the slowdown, we test for multiple structural breaks using the approach proposed by Bai and Perron (1998, 2003). We find that, at 1% significance level, there is a unique break between 1978 and 1979, after which the mean growth rate of home labor productivity decreases by 2.5%.[20] This is a remarkable slowdown, both for magnitude and for its long lasting behavior. As home services could be substitutes for services in the market,

[19] Boppart (2014) estimates income and substitution effects in a structural change model featuring non-Gorman preferences. He finds that each effect accounts for roughly 50% of the structural change between goods and services in the U.S.

[20] See the appendix for details.

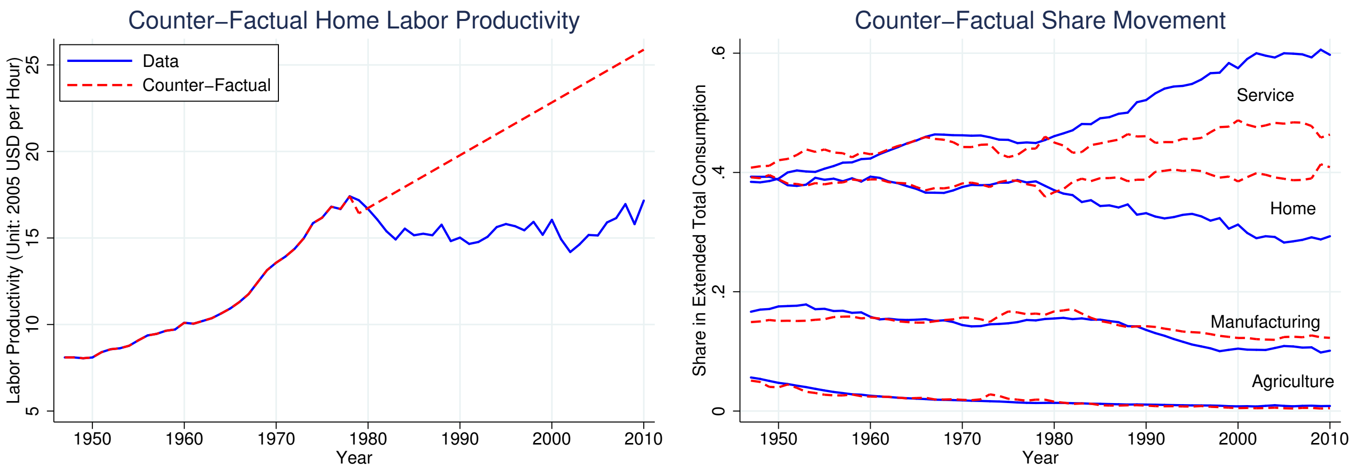

Figure 8: Counter-Factual Experiment: No Slow-Down in Home Labor Productivity after 1978: Labor Productivity (Left), Movement of Shares (Right)

it is reasonable to ask how large the quantitative effect of this slowdown is for the process of structural transformation. We address this question by running a counter-factual experiment in which, other conditions equal, home labor productivity keeps growing at a constant rate from 1978 to 2010. More precisely, we assume that in the household problem, all market prices and total expenditure evolve as in the data, while the price of the home good, given by (8), evolves now in a different fashion due to the counter-factual evolution of home labor productivity A_t^{*sh}. To run the counter-factual we use model 3d, which provides the best fit of the data. The outcome of the exercise is displayed in the right panel of Figure 8.

Without the slowdown in home productivity there is almost no divergence between the market services share and the home share in the extended total consumption over the period. The exercise thus suggests that, holding other conditions equal, the slowdown in home labor productivity is crucial to account for the late acceleration of the market services share. Models that do not display an explicit home production sector might overlook an important factor which determines the rise of the market services sector.

Table 2 reports the level of shares in the fitted value in the benchmark estimation and in the counter-factual for the year 2010. Regarding the extended consumption shares, the market services share is 0.58 in the benchmark and 0.46 in the counter-factual experiment. For the most part, this difference is compensated for by the home share, which is 0.31 in the benchmark and 0.41 in the counter-factual. A similar result holds for the services share when considering market consumption shares (i.e. consumption shares which appear in GDP): services is 0.84 in the benchmark and 0.78 in the counter-factual.

The last two columns of Table 2 show the difference between per capita consumption

Table 2: Counter-Factual Experiment: No Slowdown in Home Labor Productivity

	Extended Consumption Share		Consumption Share		Consumption per Capita	
	Bench	Counter-Factual	Bench	Counter-Factual	Bench	Counter-Factual
Agriculture	0.0044	0.0048 (9.1%)	0.0063	0.0081 (28.6%)	255	279 (9.4%)
Manufacturing	0.1049	0.1228 (17.1%)	0.1511	0.2077 (37.5%)	6097	7138 (17.1%)
Service	0.5848	0.4636 (-20.7%)	0.8425	0.7842 (-6.9%)	33992	26946 (-26.1%)
Home	0.3059	0.4089 (33.7%)	-	-	17783	23766 (33.6%)

Note: Consumption per capita is in 2005 U.S. dollars. The numbers in brackets are percent changes from the benchmark fitted value of Model 3d.

in the benchmark and in the counter-factual experiment. Without the slowdown in home productivity, agriculture and manufacturing consumption is larger than in the benchmark, while market services are at a substantially lower level than in the benchmark. This is due to the large amount of home production in the counter-factual experiment with respect to the benchmark, which depends on the sustained growth of home labor productivity. This result suggests that the slowdown in home productivity is also crucial for the evolution of real shares of GDP.

5 Robustness

Here, we discuss the robustness of the results in Section 4.

5.1 Different Labor Shares between Market and Home

When we derive the implicit price for home services in Section 2.5, we assume that the share parameter (α) is the same between the market sectors and the home sector. During the period 1947 to 2010, the mean labor share in GDP, $(1-\alpha^{mk})$, is 0.702, while the mean labor share in the home sector, $(1-\alpha^{sh})$, is 0.632, showing a difference of 7% points. Therefore, in this subsection, we relax the assumption that the market and the home have the same share parameter (α), and check whether the results in Section 4 change or not.

When the share parameters are different between the market sectors and the home sector, we can calculate the wage rate as

$$w_t = \left(1-\alpha^{mk}\right) GDP_t + \left(1-\alpha^{sh}\right) Y_t^{sh}.$$

where GDP_t and Y_t^{sh} denote value added in the market and at home, respectively. Then,

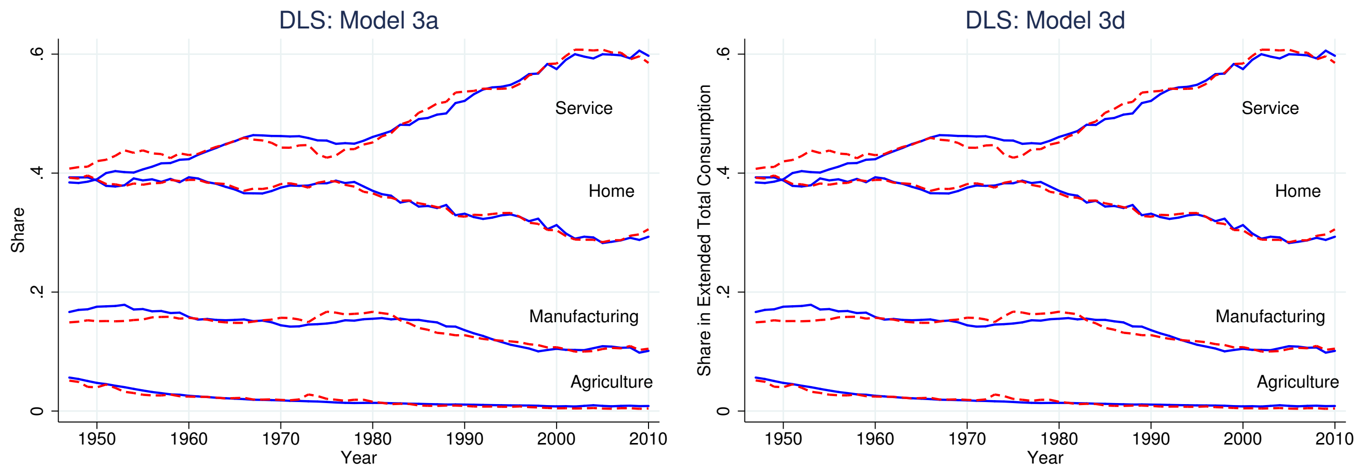

Figure 9: Fitted Sectoral Shares in Extended Total Consumption for Model 3a and Model 3d with New Implicit Home Price Definition

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

the implicit price for home services is defined as:

$$p_t^{sh} = \frac{\left(1-\alpha^{mk}\right) GDP_t + \left(1-\alpha^{sh}\right) Y_t^{sh}}{\left(1-\alpha^{sh}\right) A_t^{*sh}}.$$

Using the above implicit price for home services, we run the estimation and counter-factual experiment again.

Estimation results are reported in the first four columns of Table 3, while Figure 9 displays the fitted values. The results indicate that the estimated parameter values for all four specifications, 1a, 2a, 3a, and 3d, are not significantly different from those in Table 1. Again, note that Model 3a and 3d perform better than Model 1a and 2a in terms of the AIC and the BIC statistics, implying a different income elasticity in market and home services.

In the middle section of Table 4, we report the results for the counter-factual experiment for the model with different labor shares, in which home labor productivity keeps growing at a constant rate from 1978 to 2010. Note that the majority of quantitative results only show small differences with respect to the benchmark case. Therefore, we conclude that the difference in the labor share observed in the data doesn't really affect the results in the counter-factual experiment.

5.2 Excluding Government Consumption

In this subsection we perform the estimation of the model by subtracting government value added from the three market sectors. Government consumption is externally imposed on the

Table 3: Sectoral Share Estimation Result for Robustness

	(1) DLS: 1a	(2) DLS: 2a	(3) DLS: 3a	(4) DLS: 3d	(5) NG: 1a	(6) NG: 2a	(7) NG: 3a	(8) NG: 3d
σ	0.1872**	0.1434**	0.0003		0.3661**	0.4834**	0.1052**	
	(0.0306)	(0.0320)	(0.0007)		(0.0277)	(0.0229)	(0.0190)	
$\bar{c}^a$	-170.9923**	-166.6319**	-109.5263**	-111.7382**	-152.8351**	-92.9442**	-101.4814**	-107.8409**
	(3.4615)	(6.3239)	(7.8216)	(6.0989)	(2.7966)	(7.1123)	(6.0650)	(6.8808)
$\bar{c}^s$		783.5226**				2774.3874**		
		(141.9526)				(277.3434)		
$\bar{c}^{sh}$			-5410.6116**	-5425.7228**			-5566.9336**	-5703.8864**
			(97.2150)	(95.8840)			(166.1311)	(138.8104)
ω^a	0.0002	0.0003	0.0040**	0.0038**	0.0000	0.0053**	0.0042**	0.0034**
	(0.0002)	(0.0004)	(0.0007)	(0.0006)	(0.0000)	(0.0006)	(0.0007)	(0.0007)
ω^m	0.1716**	0.1653**	0.1989**	0.1991**	0.1587**	0.1332**	0.1883**	0.1921**
	(0.0015)	(0.0020)	(0.0021)	(0.0022)	(0.0019)	(0.0022)	(0.0021)	(0.0023)
ω^s	0.8282**	0.8344**	0.7972**	0.7970**	0.8413**	0.8615**	0.8075**	0.8044**
	(0.0015)	(0.0020)	(0.0025)	(0.0026)	(0.0019)	(0.0020)	(0.0023)	(0.0027)
ψ	0.5717**	0.5711**	0.6107**	0.6108**	0.5561**	0.5632**	0.5992**	0.6003**
	(0.0015)	(0.0013)	(0.0010)	(0.0010)	(0.0014)	(0.0012)	(0.0012)	(0.0012)
γ	2.1528**	2.0192**	2.7351**	2.7376**	2.2717**	1.7492**	2.5670**	2.5869**
	(0.0827)	(0.0965)	(0.0331)	(0.0297)	(0.0590)	(0.0600)	(0.0174)	(0.0198)
N	64	64	64	64	64	64	64	64
AIC	-1272.7	-1264.3	-1439.8	-1441.7	-1312.7	-1379.2	-1467.3	-1463.2
BIC	-1234.8	-1220.0	-1395.6	-1403.8	-1274.8	-1334.9	-1423.1	-1425.3
$RMSE^a$	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
$RMSE^m$	0.009	0.008	0.011	0.011	0.008	0.006	0.011	0.012
$RMSE^s$	0.032	0.031	0.015	0.015	0.027	0.023	0.014	0.014
$RMSE^h$	0.028	0.029	0.005	0.005	0.021	0.017	0.005	0.005

Robust standard errors in parentheses
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Note: N stands for the number of the sample in the estimation. AIC is Akaike Information Criterion. BIC is Bayesian information Criterion. $RMSE^j$ is the Root Mean Squared Error for j-sector's share equation.

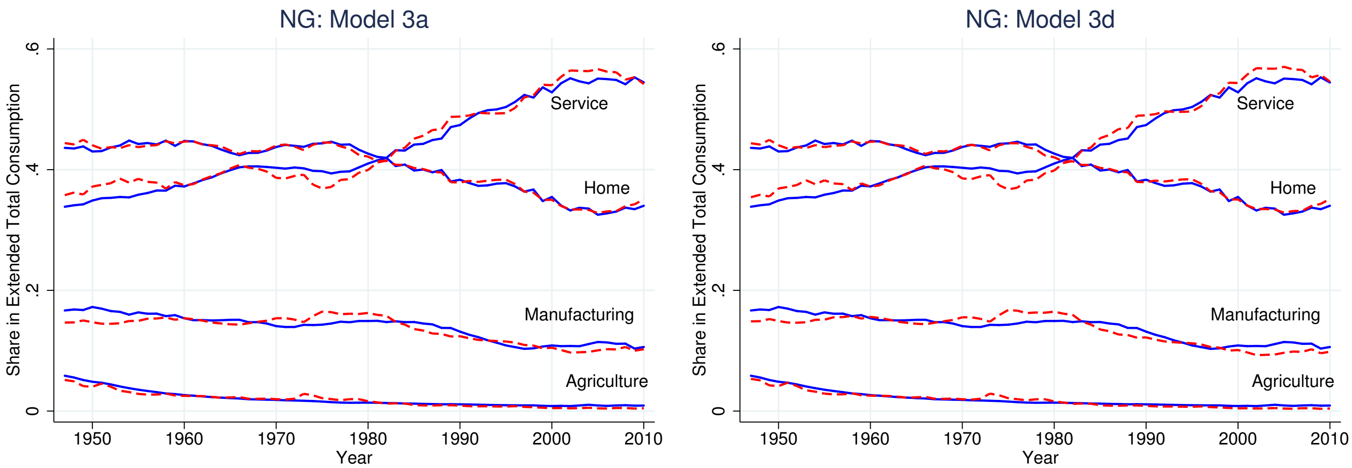

Figure 10: Fitted Sectoral Shares in Extended Total Consumption for Model 3a and 3d with No Government Consumption

Note: Data (Solid Blue Line) and Model (Dashed Red Line)

Table 4: Counter-Factual Experiment for Robustness: No Slowdown in Home Labor Productivity

	Extended Consumption Share		Consumption Share		Consumption per Capita	
	Bench	Counter-Factual	Bench	Counter-Factual	Bench	Counter-Factual
Baseline Result						
Agriculture	0.0044	0.0048 (9.1%)	0.0063	0.0081 (28.6%)	255	279 (9.4%)
Manufacturing	0.1049	0.1228 (17.1%)	0.1511	0.2077 (37.5%)	6097	7138 (17.1%)
Service	0.5848	0.4636 (-20.7%)	0.8425	0.7842 (-6.9%)	33992	26946 (-26.1%)
Home	0.3059	0.4089 (33.7%)	-	-	17783	23766 (33.6%)
Different Labor Share						
Agriculture	0.0043	0.0047 (9.3%)	0.0062	0.0079 (27.4%)	250	271 (8.4%)
Manufacturing	0.1049	0.1228 (17.1%)	0.1510	0.2071 (37.2%)	6097	7135 (17.0%)
Service	0.5853	0.4652 (-20.5%)	0.8427	0.7850 (-6.8%)	34020	27043 (-20.5%)
Home	0.3055	0.4073 (33.3%)	-	-	17759	23677 (33.3%)
No Government						
Agriculture	0.0043	0.0047 (8.4%)	0.0066	0.0084 (27.3%)	216	233 (7.9%)
Manufacturing	0.0984	0.1176 (20.4%)	0.1517	0.2109 (39.0%)	4927	5890 (19.5%)
Service	0.5459	0.4355 (-20.1%)	0.8416	0.7808 (-7.2%)	27334	21809 (-20.2%)
Home	0.3514	0.4422 (25.9%)	-	-	17598	22142 (25.8%)

Note: Consumption per capita is in 2005 U.S. dollars. The numbers in brackets are percent changes from the benchmark fitted value of Model 3d.

household, and there is not a price at which households decide how much quantity to purchase. For this reason, we re-estimate the model by removing the government spending from both consumption and expenditure data. By doing this we are assuming that the household is taxed by the government to run a balanced budget, and that government spending does not provide utility to the household.

Estimation results are reported in the last four columns of Table 3, while Figure 10 displays the fitted values. Note that the share of market services is now lower in Figure 4. As for the estimation including government, the best fit is provided by Models 3a and 3d, which show the lowest values of the AIC and the BIC statistics. Interestingly, the estimated value for σ in Model 3a is 0.1, which is larger that in the benchmark estimation, but still close to zero, which implies Leontief preferences. As before, in Model 3d, we impose $\sigma = 0$. In contrast with the benchmark estimation, the AIC and the BIC now provide contrasting results on the best model. The first criterion favors Model 3a, while the second favors Model 3d.

The lowest section of Table 4 reports the results for the counter-factual experiment in which home labor productivity keeps growing at a constant rate from 1978 to 2010, when we exclude the government sector. Quantitative results are similar to baseline ones. One notable difference is observed in the consumption per capita of market services, which decreases by 20.2%, compared to the fall of 26.1% in the baseline experiment, when including government. Also, consumption per-capita of the home good displays a smaller increase with respect to the baseline experiment, 25.8% versus 33.3%. Despite those differences from the baseline case, the slowdown of home labor productivity appears to have a large impact on the structural transformation of the U.S. economy even after we exclude the government spending from the data and re-estimate the model.

6 Conclusion

In this paper we present a model of structural transformation with home production and estimate it by using U.S. data. We find that the specification of the model with a different degree of non-homotheticity between home and market services provides the best fit of the data. In particular, the estimation provides an income elasticity of home services lower than that of market services. This is in line with recent empirical evidence suggesting that the share of market services that can be produced also at home, grows slower with income compared to that of market services which don't have home counterparts.

The estimated model is then used to run a counter-factual experiment. In particular, we measure the contribution of the slowdown in home productivity growth to the late acceleration of the market services share in the U.S. We find that without the slowdown, the model does not produce a quantitatively significant structural change. This result suggests that home productivity represents an important source of structural change. As the observed late acceleration of services appears to be a feature common to most high income countries, our result calls for a cross-country analysis of the role of home productivity for structural change.

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Appendix

A. Separating Inter-Temporal and Intra-Temporal Problem

In this appendix, we show how to separate the inter-temporal problem, in which the household decides aggregate consumption and investment across time, from the intra-temporal one, in which the household decides consumption levels of the four goods, given resources allocated to consumption in that period. We re-write here the household equivalent problem (P1):

$$\max \sum_{t=0}^{\infty} \beta^t \ln C_t$$

subject to

$$C_t = \left(\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}},$$

$$c_t^s = \left[\psi (c_t^{sm})^{\frac{\gamma-1}{\gamma}} + (1-\psi)(c_t^{sh} + \bar{c}^{sh})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}},$$

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} + k_{t+1} - (1-\delta) k_t = r_t k_t + w_t \bar{l},$$

The first order conditions for the four consumption goods are

$$\frac{\partial \mathcal{L}}{\partial c_t^a} = 0 \Longrightarrow \frac{\beta^t \left(\omega^a\right)^{1/\sigma} \left(c_t^a + \bar{c}^a\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^a \tag{9}$$

$$\frac{\partial \mathcal{L}}{\partial c_t^m} = 0 \Longrightarrow \frac{\beta^t \left(\omega^m\right)^{1/\sigma} \left(c_t^m + \bar{c}^m\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^m \tag{10}$$

$$\frac{\partial \mathcal{L}}{\partial c_t^{sm}} = 0 \Longrightarrow \frac{\beta^t \left(\omega^s\right)^{1/\sigma} \psi \left(c_t^{sm}\right)^{\frac{-1}{\gamma}} \left(c_t^s\right)^{\frac{1}{\gamma}} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^{sm} \tag{11}$$

$$\frac{\partial \mathcal{L}}{\partial c_t^{sh}} = 0 \Longrightarrow \frac{\beta^t \left(\omega^s\right)^{1/\sigma} (1-\psi) \left(c_t^{sh} + \bar{c}^{sh}\right)^{\frac{-1}{\gamma}} \left(c_t^s\right)^{\frac{1}{\gamma}} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^{sh} \tag{12}$$

Raise (11) and (12) to $1-\gamma$, sum them and raise to $\frac{1}{1-\gamma}$ to obtain

$$\frac{\beta^t \left(\omega^s\right)^{1/\sigma} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t \left[\left(p_t^{sm}\right)^{1-\gamma} \psi^\gamma + \left(p_t^{sh}\right)^{1-\gamma} (1-\psi)^\gamma \right]^{\frac{1}{1-\gamma}}. \tag{13}$$

As λ_t is the marginal utility of one additional unit of good i divided by the price of that good, we can define

$$p_t^s \equiv \left[\psi^\gamma \left(p_t^{sm}\right)^{1-\gamma} + (1-\psi)^\gamma \left(p_t^{sh}\right)^{1-\gamma} \right]^{\frac{1}{1-\gamma}}, \tag{14}$$

that is, one unit of the services consumption bundle costs p_t^s. Note that by using (14) we can write

$$\frac{\beta^t \left(\omega^s\right)^{1/\sigma} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^s. \tag{15}$$

Now sum FOCs (9) and (10) and use the definition of p_t^s to obtain

$$\frac{\beta^t \left(\omega^s\right)^{1/\sigma} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{C_t} c_t^s = \lambda_t \left[p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} + p_t^{sh} \bar{c}^{sh}\right] \tag{16}$$

Recall now from (15) that

$$\frac{\beta^t \left(\omega^s\right)^{1/\sigma} \left(c_t^s + \bar{c}^s\right)^{\frac{-1}{\sigma}} \left(C_t\right)^{\frac{1}{\sigma}}}{p_t^s C_t} = \lambda_t,$$

so we can use the last expression in (16) to obtain

$$p_t^s c_t^s - p_t^{sh} \bar{c}^{sh} = p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh}. \tag{17}$$

Now raise each condition (9), (10) and (15) to $1 - \sigma$ and sum across conditions

$$\frac{\beta^{t(1-\sigma)} C_t^{\frac{1-\sigma}{\sigma}}}{C_t^{1-\sigma}} \left[\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}}\right] = \lambda_t^{1-\sigma} \left[\sum_{i=a,m,s} \omega^i \left(p_t^i\right)^{1-\sigma}\right],$$

raise to $\frac{1}{1-\sigma}$ and simplify to obtain

$$\frac{\beta^t}{C_t} = \lambda_t \left[\sum_{i=a,m,s} \omega^i \left(p_t^i\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}.$$

As λ_t is the marginal utility of one additional unit of the consumption aggregator C_t in units of that good, and $\frac{\beta^t}{C_t}$ is the marginal utility of consumption, we can define the implicit price index P_t as

$$P_t \equiv \left[\sum_{i=a,m,s} \omega^i \left(p_t^i\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}.$$

Now sum across conditions (9), (10) and (15) to obtain

$$P_t C_t = \sum_{i=a,m,s} p_t^i c_t^i + \sum_{i=a,m,s} p_t^i \bar{c}^i. \tag{18}$$

Use (17) to substitute for $p_t^{sm}c_t^{sm} + p_t^{sh}c_t^{sh}$ in the budget constraint of the household to obtain

$$p_t^a c_t^a + p_t^m c_t^m + p_t^s c_t^s + k_{t+1} - (1-\delta)\,k_t = r_t k_t + w_t \bar{l} + p_t^{sh}\bar{c}^{sh}$$

and use (18) to substitute for $p_t^a c_t^a + p_t^m c_t^m + p_t^s c_t^s$ to obtain

$$P_t C_t + k_{t+1} - (1-\delta)\,k_t = r_t k_t + w_t \bar{l} + p_t^{sh}\bar{c}^{sh} + \sum_{i=a,m,s} p_t^i \bar{c}^i.$$

We are now equipped to state the inter-temporal and the intra-temporal problems:

1. *Inter-Temporal Problem*: The household solves:

$$\max_{\{C_t, k_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \ln C_t$$

subject to

$$P_t C_t + k_{t+1} - (1-\delta)\,k_t = r_t k_t + w_t \bar{l} + p_t^{sh}\bar{c}^{sh} + \sum_{i=a,m,s} p_t^i \bar{c}^i.$$

2. *Intra-Temporal Problem*: The household solves:

$$\max_{\left\{c_t^a, c_t^m, c_t^{sm}, c_t^{sh}\right\}} \left(\sum_{i=a,m,s} \left(\omega^i\right)^{\frac{1}{\sigma}} \left(c_t^i + \bar{c}^i\right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

subject to

$$c_t^s = \left[\psi (c_t^{sm})^{\frac{\gamma-1}{\gamma}} + (1-\psi)(c_t^{sh} + \bar{c}^{sh})^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}},$$

and

$$p_t^a c_t^a + p_t^m c_t^m + p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} = P_t C_t - \sum_{i=a,m,s} p_t^i \bar{c}^i - p_t^{sh}\bar{c}^{sh}.$$

B. Derivation of Sectoral Share Equations

The Lagrangian for household's maximization problem (P3) is written as;

$$\begin{aligned}\mathcal{L} &= \left((\omega^a)^{1/\sigma}\left(c_t^a+\bar{c}^a\right)^{\frac{\sigma-1}{\sigma}}+(\omega^m)^{1/\sigma}\left(c_t^m+\bar{c}^m\right)^{\frac{\sigma-1}{\sigma}}+(\omega^s)^{1/\sigma}\left(c_t^s+\bar{c}^s\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \\ &\quad +\lambda_t\left[E_t-p_t^a c_t^a-p_t^m c_t^m-p_t^{sm}c_t^{sm}-p_t^{sh}c_t^{sh}\right],\end{aligned}$$

where

$$c_t^s=\left[\psi(c_t^{sm})^{\frac{\gamma-1}{\gamma}}+(1-\psi)(c_t^{sh}+\bar{c}^{sh})^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}.$$

The first order conditions are;

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial c_t^a}&=0\Longrightarrow(\omega^a)^{1/\sigma}\left(c_t^a+\bar{c}^a\right)^{\frac{-1}{\sigma}}\left(\Psi_t\right)^{\frac{1}{\sigma-1}}=\lambda_t p_t^a,\\ \frac{\partial\mathcal{L}}{\partial c_t^m}&=0\Longrightarrow(\omega^m)^{1/\sigma}\left(c_t^m+\bar{c}^m\right)^{\frac{-1}{\sigma}}\left(\Psi_t\right)^{\frac{1}{\sigma-1}}=\lambda_t p_t^m,\\ \frac{\partial\mathcal{L}}{\partial c_t^{sm}}&=0\Longrightarrow(\omega^s)^{1/\sigma}\psi\left(c_t^{sm}\right)^{\frac{-1}{\gamma}}\left(c_t^s\right)^{\frac{1}{\gamma}}\left(c_t^s+\bar{c}^s\right)^{\frac{-1}{\sigma}}\left(\Psi_t\right)^{\frac{1}{\sigma-1}}=\lambda_t p_t^{sm},\\ \frac{\partial\mathcal{L}}{\partial c_t^{sh}}&=0\Longrightarrow(\omega^s)^{1/\sigma}(1-\psi)\left(c_t^{sh}+\bar{c}^{sh}\right)^{\frac{-1}{\gamma}}\left(c_t^s\right)^{\frac{1}{\gamma}}\left(c_t^s+\bar{c}^s\right)^{\frac{-1}{\sigma}}\left(\Psi_t\right)^{\frac{1}{\sigma-1}}=\lambda_t p_t^{sh},\end{aligned}$$

where

$$\Psi_t\equiv(\omega^a)^{1/\sigma}\left(c_t^a+\bar{c}^a\right)^{\frac{\sigma-1}{\sigma}}+(\omega^m)^{1/\sigma}\left(c_t^m+\bar{c}^m\right)^{\frac{\sigma-1}{\sigma}}+(\omega^s)^{1/\sigma}\left(c_t^s+\bar{c}^s\right)^{\frac{\sigma-1}{\sigma}}.$$

From the first order conditions, we can derive the following share equations;

$$\frac{p_t^a c_t^a}{E_t}=f_1\equiv\frac{\left(p_t^a\right)^{1-\sigma}\omega^a\Phi_{t,1}}{\Phi_{t,2}}-\frac{p_t^a\bar{c}_t^a}{E_t} \tag{19}$$

$$\frac{p_t^m c_t^m}{E_t}=f_2\equiv\frac{\left(p_t^m\right)^{1-\sigma}\omega^m\Phi_{t,1}}{\Phi_{t,2}}-\frac{p_t^m\bar{c}_t{}^m}{E_t} \tag{20}$$

$$\frac{p_t^{sm}c_t^{sm}}{E_t}=f_3\equiv\frac{\left(p_t^{sm}\right)^{1-\sigma}\omega^s\psi^\sigma\Omega_{t,1}^{\frac{\sigma}{\gamma}-1}\Phi_{t,1}}{\Phi_{t,2}}-\frac{p_t^{sm}\Omega_{t,1}^{-1}\bar{c}^s}{E_t} \tag{21}$$

where

$$\begin{aligned}\Phi_{t,1}&\equiv\left(1+\frac{p_t^a\bar{c}^a+p_t^m\bar{c}^m+p_t^{sh}\bar{c}^{sh}+p_t^{sm}\Omega_{t,1}^{-1}\bar{c}^s+p_t^{sh}\Omega_{t,2}^{-1}\bar{c}^s}{E}\right),\\ \Phi_{t,2}&\equiv\left(p_t^a\right)^{1-\sigma}\omega^a+\left(p_t^m\right)^{1-\sigma}\omega^m+\left(p_t^{sm}\right)^{1-\sigma}\omega^s\psi^\sigma\Omega_{t,1}^{\frac{\sigma}{\gamma}-1}+\left(p_t^{sh}\right)^{1-\sigma}\omega^s(1-\psi)^\sigma\Omega_{t,2}^{\frac{\sigma}{\gamma}-1},\end{aligned}$$

and where

$$\Omega_{t,1} \equiv \left[\psi + (1-\psi) \left(\frac{1-\psi}{\psi} \right)^{\gamma-1} \left(\frac{p_t^{sm}}{p_t^{sh}} \right)^{\gamma-1} \right]^{\frac{\gamma}{\gamma-1}},$$

$$\Omega_{t,2} \equiv \left[\psi \left(\frac{\psi}{1-\psi} \right)^{\gamma-1} \left(\frac{p_t^{sh}}{p_t^{sm}} \right)^{\gamma-1} + (1-\psi) \right]^{\frac{\gamma}{\gamma-1}}.$$

The share equations, (19), (20), and (21), are used for estimation.

C. Estimating Structural Breaks in Home Labor Productivity

In this appendix, we discuss the estimation of structural breaks in home labor productivity, which we use in the counter-factual experiment in Section 4.3. We follow the standard approach developed by Bai and Perron (1998, 2003), which allows us to estimate multiple structural breaks in a linear model estimated by least squares.[21]

More specifically, we estimate the following home labor productivity process with m breaks ($m+1$ regimes) for the period 1947 to 2010:

$$\ln A_t^{*sh} - \ln A_{t-1}^{*sh} = \delta_j + u_t, \qquad t = T_{j-1}+1, \dots, T_j$$

for $j = 1, \dots, m+1$. Our concern centers on the number of regime switches (m), the date of regime switches ($T_1, \dots, T_m$), and how the mean growth rate of labor productivity varies (δ_j) across the different regimes. When applying the Bai and Perron (1998, 2003) method, we allow up to 5 breaks, and use a trimming $\epsilon = 0.10$ (meaning that each regime has at least 10 observations).[22] We also allow serial correlations in the error terms and different variance of the residuals across the regimes.

Table 5: Estimation Results: Structural Breaks in Home Labor Productivity Series

			Tests			
$\sup F_T(1)$	$\sup F_T(2)$	$\sup F_T(3)$	$\sup F_T(4)$	$\sup F_T(5)$	$UDmax$	$WDmax$
15.21**	12.18**	12.21**	9.40**	7.84**	15.21**	15.21**
$\sup F(2 \mid 1)$	$\sup F(3 \mid 2)$	$\sup F(4 \mid 3)$	$\sup F(5 \mid 4)$			
13.13*	12.04*	1.42	2.00			
			Number of Breaks Selected			
Sequential 1%	Sequential 5%	LWZ	BIC			
1	3	0	1			
			Estimates with One Break			
$\hat{\delta}_1$	$\hat{\delta}_2$			$\hat{T}_1$		
0.0246	-0.0004	-	-	31	-	-
(0.0037)	(0.0051)			(16,39)		
			Estimates with Three Breaks			
$\hat{\delta}_1$	$\hat{\delta}_2$	$\hat{\delta}_3$	$\hat{\delta}_4$	$\hat{T}_1$	$\hat{T}_2$	$\hat{T}_3$
0.0154	0.0345	-0.0085	0.0237	16	31	55
(0.0033)	(0.0042)	(0.0056)	(0.0065)	(8,24)	(26,34)	(52.65)

Note: $*p < 0.05$, $**p < 0.01$. In parentheses are the standard errors (robust to serial correlation) for $\hat{\delta}_i$, and the 95% confidence intervals for $\hat{T}_i$.

[21] For the general survey on the estimation of a structural break, see Hansen (2001).

[22] Parameter values are standard in this framework. See Bai and Perron (2003).

Table 5 reports the results. As for the number of breaks, first, we note that $\sup F_T(k)$ ($k = 1, \ldots, 5$) tests are all significant at 1% level. Here, $\sup F_T(k)$ is a test statistic of no structural break ($m = 0$) versus a fixed number of breaks ($m = k$). Also, $UDmax$ and $WDmax$ are tests of no structural breaks versus unknown number of breaks given some upper bound on the number of breaks (here, $M = 5$), both of which are significant at 1% level.[23] Therefore, we conclude that at least one break is present. Next, we note that both the $\sup F_T(2 \mid 1)$ and the $\sup F_T(3 \mid 2)$ tests are significant at 5% level, while the $\sup F_T(4 \mid 3)$ is not significant. The statistic, $\sup F_T(l+1 \mid l)$, tests l breaks versus $l+1$ breaks. Therefore, given the values of $\sup F_T(k)$ and $\sup F_T(l+1 \mid l)$, the sequential procedure, selects one break at 1% significance level, and three breaks at 5% significance level. While the BIC and the LWZ information criteria select one and zero breaks, respectively, those information criteria are known to be downward biased.[24]

In conclusion, the estimation results indicate that, at 1% significance level, there is a unique break between 1978 and 1979 ($\hat{T}_1 = 31$), at which the mean growth rate of home labor productivity decreases by 2.5%. At 5% significance level, there are three breaks, one between 1953 and 1954 ($\hat{T}_1 = 16$), one between 1978 and 1979 ($\hat{T}_1 = 31$), and one between 2002 and 2003 ($\hat{T}_1 = 55$). In this case, the switch of regimes first increased the mean growth rate, from 1.5% to 3.5% between 1953 and 1954. Then, there happened a large drop from 3.5% to -0.9% between 1978 and 1979. Finally, the growth rate recovered from -0.9% to 2.4% between 2002 and 2003.

In our counter-factual experiment in Section 4.3 we focus on the break that occurred between 1978 and 1979. We do this for two reasons: first, the existence of this unique break is statistically significant at 1% level, while for the three breaks, significance is only at 5%; second, the change in the growth rate of labor productivity is the most dramatic in magnitude among the three breaks and has long lasting effects (even in the case with three breaks the next change after 1978 occurs in 2002).

[23] The value of those two test statistics are exactly same because of our model's specification, where there is only one variable that changes its value across regimes. See Bai and Perron (1998) for the definition of the test statistics.

[24] See Bai and Perron (2003).