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 three main findings. First, the data support a specification with a different income elasticity of market and home services. Second, the non-homotheticity can account alone for the decline in the home services share, while price and income effects together are responsible for the rise of market services. Third, the slowdown in home labor productivity, started in the late 70s, is a key determinant of the late acceleration of the share of market services. We use the estimated model to run a counter-factual experiment and find that, by keeping the average growth rate of home labor productivity as before 1978, the model displays the consumption per capita of market services lowered by 26.1% in 2010.

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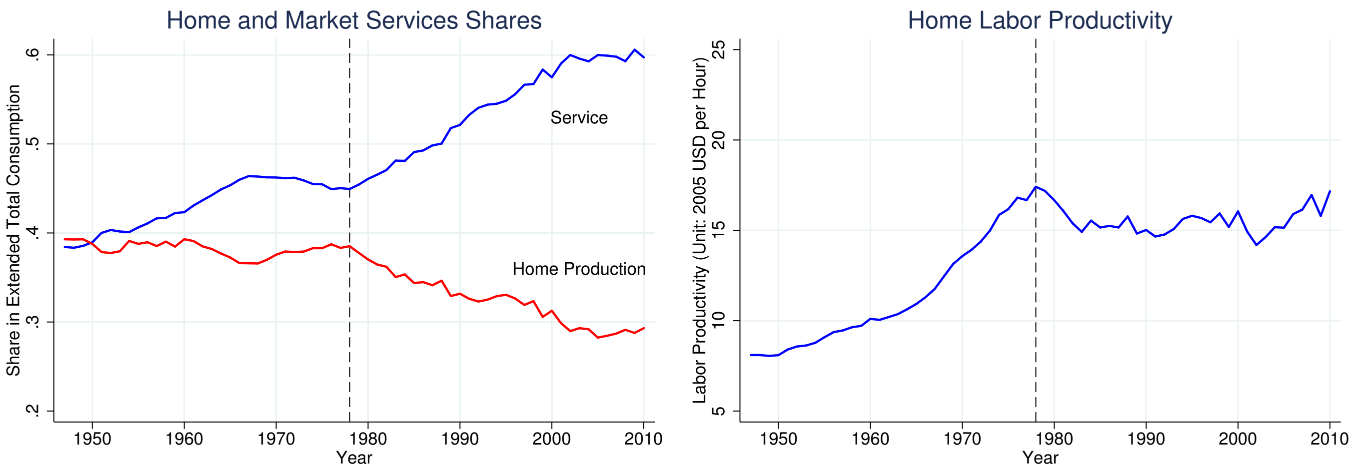

Figure 1: Home and Market Services Value Added Shares in Extended Total Consumption (Left) and Home Labor Productivity (Right)

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 change using new home production data for the U.S. for the period 1947 to 2010. Our paper is motivated by the timing 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*[1] and home labor productivity from Bridgman (2013). The left panel shows that the share of market services increases continuously but its growth rate 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 displays sustained growth (around 2.5% per-year on average) between 1947 to 1978, and a marked slowdown in the remaining part of the sample. These observations appear to suggest a role for home production in shaping structural change, something that has been noted in the previous literature.[2]

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 service shares, and then assess whether the late acceleration of services can be accounted for by the slowdown in home labor productivity. 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 extend the model to include a home production sector, allowing for a different income elasticity between market and home services in household's demand. We show that, after separating the inter-temporal choice problem from the main problem, such a model can be re-written as a

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

[2] See for instance Rogerson (2008), Ngai and Pissarides (2008), and Buera and Kaboski (2009) among others.

household's consumption choice problem which depends on the prices of the three market sectors, home labor productivity, extended total consumption, and extended total value added. The latter 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's preference. In the first specification, we consider the non-homothetic term on services to be *zero*, and also assume market and home services have the *same* income elasticity. In the literature, the non-homothetic term on services is interpreted as home production, so by having an explicit home sector in the model it is natural to set it to zero. In the second specification, we estimate the model by allowing the non-homothetic term on 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 is not fully measured by home production. Finally, in the third specification, we assume the non-homothetic term on services to be *zero*, but allow the income elasticity of services to be *different* between home and market. This specification is motivated by the empirical evidence suggesting that home and market services grow at different pace with rising income.[3]

There are three main results in estimation and subsequent counter-factual experiments. The first result is that, 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's demand. This is important, because the previous literature explains the movement of market and home service shares only by the changes in technologies.[4] Our result clearly indicates that the changes in technologies are not enough to generate the movement of market and home service shares. Second, we assess the role of price and income effects in generating structural change through counter-factual experiments. We find that the non-homotheticity alone can account for the whole decline in the share of the home good and for a part of the rise of market services. The remaining part of the increase in market services is due to relative prices effects. Finally, the third 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, that is, the average pace before the slowdown. We find that in this case the consumption per capita of market services would be lowered by 26.1% in 2010. That is, without the slowdown in home 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 observed in market sectors.

Our paper relates to the literature that put forth home production as a key determinant of the process of structural transformation. 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 reported in Buera and Kaboski (2012b) and Eichengreen and Gupta (2013) for a large set of countries and

[3]See Buera and Kaboski (2012a) and Eichengreen and Gupta (2013).
[4]For example, see Ngai and Pissarides (2008).

in Buera and Kaboski (2012a) for the U.S. With respect to Buera and Kaboski (2012a), who focus on human capital differences between the home and the market services sectors, and Buera and Kaboski (2012b), who study the effect of minimum production scale, we estimate a model that departs minimally from the standard model of structural change and focus on the quantitative role of home production for the acceleration of market services. In particular, we show that the marked slowdown of home productivity is responsible for the late rise of services in our model. This result calls for a cross-country investigation of the role of home production for structural change.

We also relate to the literature that estimates parameters that can be used to calibrate structural change models with home production. Regarding the elasticity of substitution between broad categories (agriculture, manufacturing and services), our estimates are close to those reported in Herrendorf, Rogerson, and Valentinyi (2013), with values ranging from 0.0006 to 0.0015 in the specification providing the best fit of the data. For the elasticity of substitution between market and home services, we obtain a value of 2.75 in our preferred specification. This is somewhat larger than previous estimates such as McGrattan, Rogerson, and Wright (1997), who find a value between 1.66 and 1.82 and Chang and Schorfheide (2003), who estimate a range of 2.22 to 2.5. Other estimates based on micro data such as Rupert, Rogerson, and Wright (1995) and Aguiar and Hurst (2006) also report similar estimates.

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 explains the 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; agriculture, manufacturing, market services, home services, and 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 C_t is defined as

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

where c_t^i denotes consumption of each good $i \in \{a, m, s\}$. In (1), the parameter ω^i (≥ 0) 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 (≥ 0) 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 (≥ 0), governs the elasticity of substitution between market and home services. 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 Subsection 2.5 and in the estimation section.

In our setup, the household is endowed with 1 unit of labor every period. She determines the time into hours worked in the market, l_t, (paid at wage w_t), and hours worked for home production, l_t^{sh}. The household holds capital stock k_t in this economy. She determines 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}, every period. Then, the household's constraints are given by

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

$$l_t + l_t^{sh} = 1,$$

where p_t^j is the price of good $j \in \{a, m, sm\}$. In this economy the price of the investment goods is normalized to one. The total amount of capital is defined as

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

The household produces home services by using the following technology,

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

There is a competitive firm in each market sector $j \in \{a, m, ms\}$ with technology,

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

There is also another competitive firm operating in the investment good sector with technology,

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

2.2 Household's Problem

Next, we re-write the previous setup by introducing an artificial firm into the home production sector as if the firm produces home good, and the household purchase it from the firm. By doing so, we can treat 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

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

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

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

Thus, we rewrite the household problem as

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

subject to

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

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

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

Given the definition of the implicit home price, (4), it is straight-forward to show that the problem (P1) is equivalent to the original household's problem.

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 which can be solved sequentially.

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

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

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*: Given C_t, the household solves:

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

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 consumption, that is total consumption plus home production.

In the rest of this paper, we try to estimate the problem (P3).

2.4 Alternative Preference Specifications

The model presented in the previous subsections encompasses the standard models of structural transformation, namely Kongsamut, Rebelo, and Xie (2001) and Ngai and Pissarides (2007), with the addition of home production. By setting $\psi = 1$ the model becomes the one estimated in Herrendorf, Rogerson, and Valentinyi (2013). Our purpose is to study the effect of home production on structural transformation and given that home production is a substitute for market services in the model, in section 3 we estimate three different specifications, which imply different mechanics of the home and the market services sectors.

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 test whether the home sector can replicate the role played by the non-homothetic parameter in the standard model. [5]

Model 2: In the second specification we impose $\bar{c}^{sh} = 0$. This implies that we are allowing both for an explicit home production sector and for the standard non-homotheticity effect for services. As discussed in Herrendorf, Rogerson, and Valentinyi (2013), one can interpret the non-homotheticity parameter $\bar{c}^s$ in the standard model as capturing both the presence of home production and a non-homotheticity in the preferences for services. This is the interpretation that we take in estimating this version of the model.

[5] Herrendorf, Rogerson, and Valentinyi (2013) estimate $\bar{c}^s > 0$ in all specifications.

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 $\bar{c}^{sh}$. Put it differently, we are allowing the non-homotheticity to be different between market and home services.[6] 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 with respect to the share of 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, as suggested in Eichengreen and Gupta (2013), 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 home price, p_t^{sh}, to the home labor productivity, we consider the first order condition in terms of home services;

$$p_t^{sh} = \frac{w_t}{A_t^{sh}\left(1-\alpha\right)\left(\frac{K_t^{sh}}{L_t^{sh}}\right)^{\alpha}} = \frac{w_t}{\left(1-\alpha\right)\hat{A}_t^{sh}}$$

where $\hat{A}_t^{sh}$ is the labor productivity of the home sector. From the above equation, we obtain

$$\left(1-\alpha\right)p_t^{sh}Y_t^{sh} = w_t L_t^{sh}.$$

The last condition holds for every industry assuming that the labor share parameter is same across industries. By summing up those, we obtain

$$\left(1-\alpha\right)\left(p_t^a Y_t^a + p_t^m Y_t^m + p_t^{sm} Y_t^{sm} + p_t^{sh} Y_t^{sh} + Y_t^x\right) = w_t\left(L_t^a + L_t^m + L_t^{sm} + L_t^{sh} + L_t^x\right).$$

Note that $L_t^a + L_t^m + L_t^{sm} + L_t^{sh} = 1$. Then,

$$w_t = (1-\alpha)EGDP_t.$$

Therefore, we obtain

$$p_t^{sh} = \frac{EGDP_t}{\hat{A}_t^{sh}}. \tag{6}$$

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

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 home price equation, (6), and the set of (pre-determined) variables,

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

problem (P3) can be solved for four shares, $\frac{p_t^i c_t^i}{E_t}$, where $i \in \{a, m, sm, sh\}$. 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 equation, and finally have the three non-linear equations to be estimated;

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

In the appendix, we show the derivation of $f_1,\ f_2,\ f_3$.

For the estimation procedure, 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. For the parameters with constraints ($\sigma \geq 0,\ \omega^a + \omega^m + \omega^s = 1,\ 0 \leq \psi \leq 1,\ \gamma \geq 0$), 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). 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 input-output matrix, in order to avoid investment components included in consumption value-added data.[7]

- Total Value Added: We need the total value added data for the calculation of the implicit home price, (6). We obtain the data from BEA.

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

In our estimation, we focus on the time period between 1947 and 2010, due to the availability of the data listed above.[8] 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, (6), 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 result.

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 it to 1.5, the smallest value used in the literature. In column (3), we set the value equal to 2.3, the largest value in the literature. 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 Akaike and Beynsian information criteria (AIC and BIC) 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 3-a (the column (7), which has lower values of the AIC

[7]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.

[8]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 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.

Table 1: Sectoral Share Estimation Result

	(1) 1-a	(2) 1-b	(3) 1-c	(4) 2-a	(5) 2-b	(6) 2-c	(7) 3-a	(8) 3-b	(9) 3-c	(10) 3-d
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)				
$\bar{c}^h$							-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
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

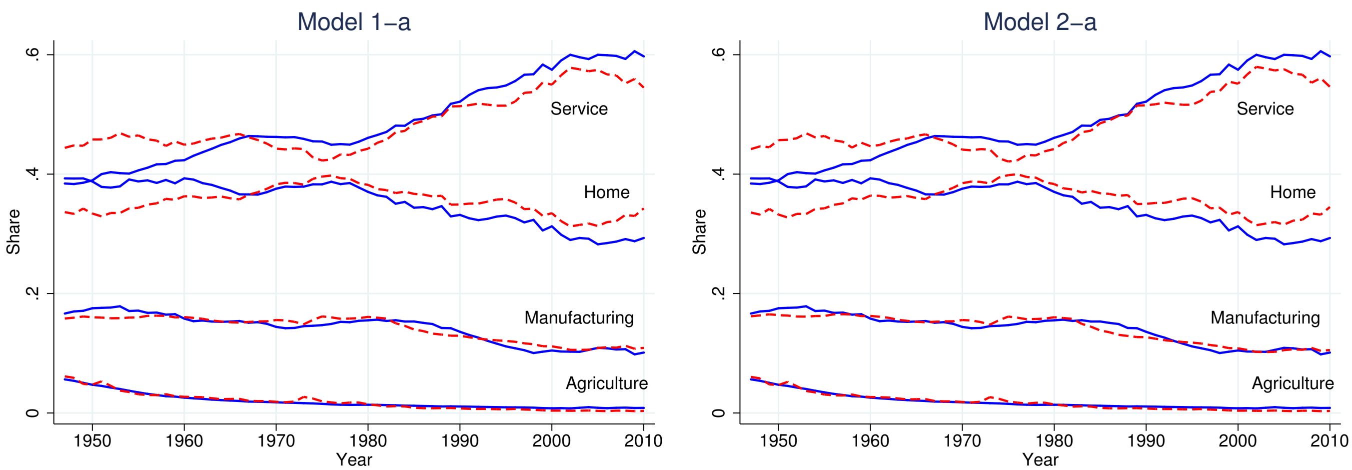

Figure 2: Fitted Sectoral Shares in Extended Consumption Value-Added for Model 1-a and 2-a

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

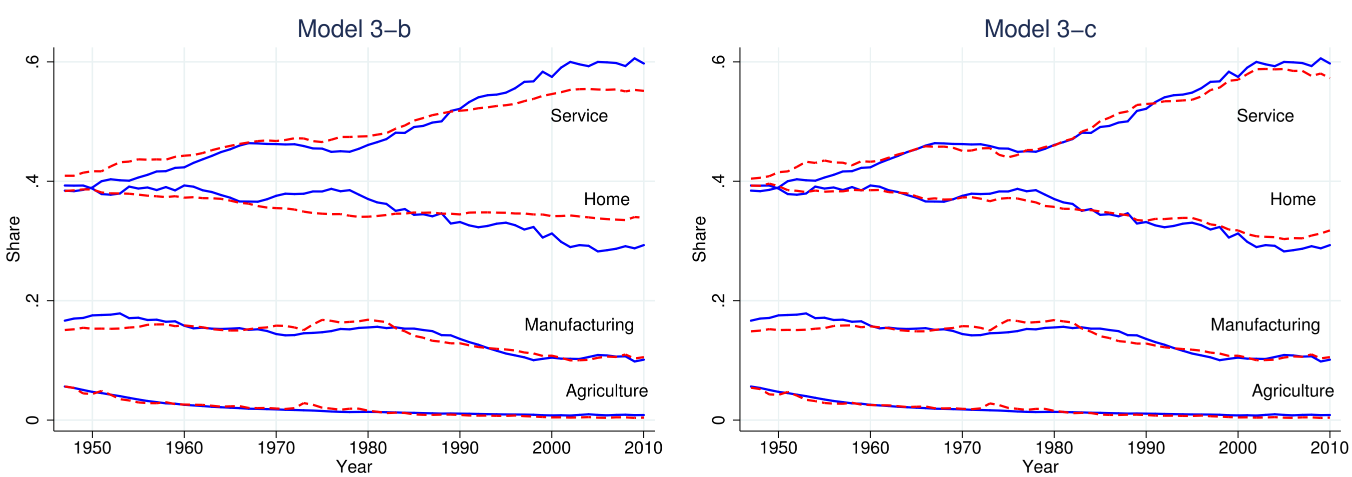

Figure 3: Fitted Sectoral Shares in Extended Consumption Value-Added for Model 3-b and 3-c

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

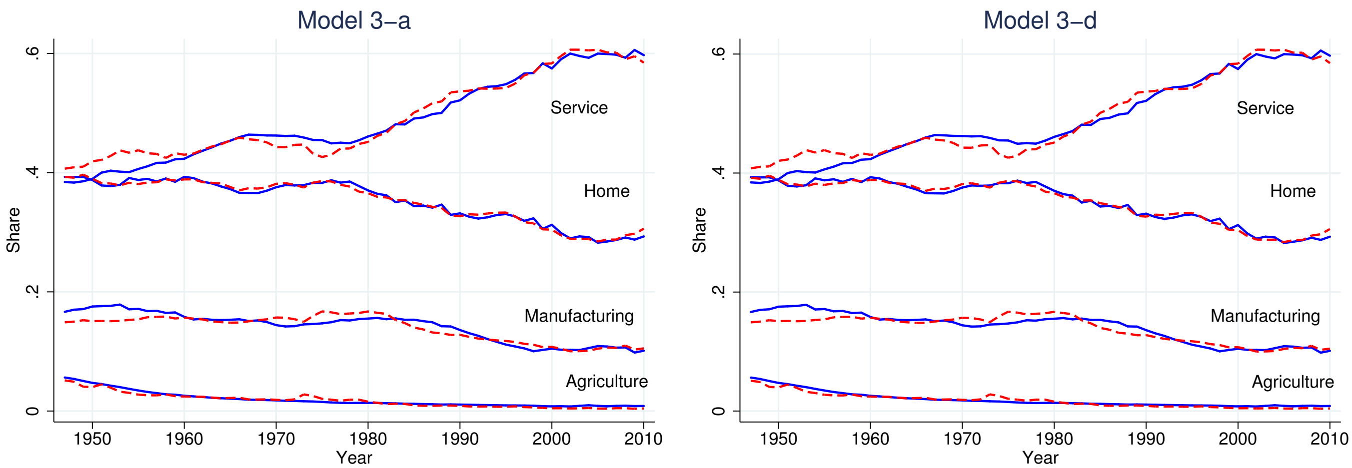

Figure 4: Fitted Sectoral Shares in Extended Consumption Value-Added for Model 3-a and 3-d
Note: Data (Blue and Solid Line) and Model (Red and Dashed Line)

and the BIC). The failures of the fit of Model 1-a and 2-a are also visually presented in Figure 2, indicating that either models cannot 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 constant elasticity of substitution between market and home services (Model 1 and 2), 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 in the aggregated service ($\bar{c}^s$) doesn't help to solve the issue.

We now turn to discuss Model 3. There are two points which are worth emphasizing here. First, by comparing the performance of 3-a, 3-b, and 3-c, 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 3-b), 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 3-c in Figure 3). When the value is unrestricted, we estimate its value to be 2.75, which is somewhat larger than other estimates in the literature.[9]

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 Leontief specification in terms of agricultural, manufacturing, and aggregate services. Notably, this result for σ is similar to what Herrendorf, Rogerson, and Valentinyi (2013) obtain in their estimation using value added consumption data. Given that the point estimator of σ is not statistically significantly different from zero, we restrict the value of σ to be zero, and run the estimation of

[9]See McGrattan, Rogerson, and Wright (1997), Chang and Schorfheide (2003), Rupert, Rogerson, and Wright (1995) and Aguiar and Hurst (2006).

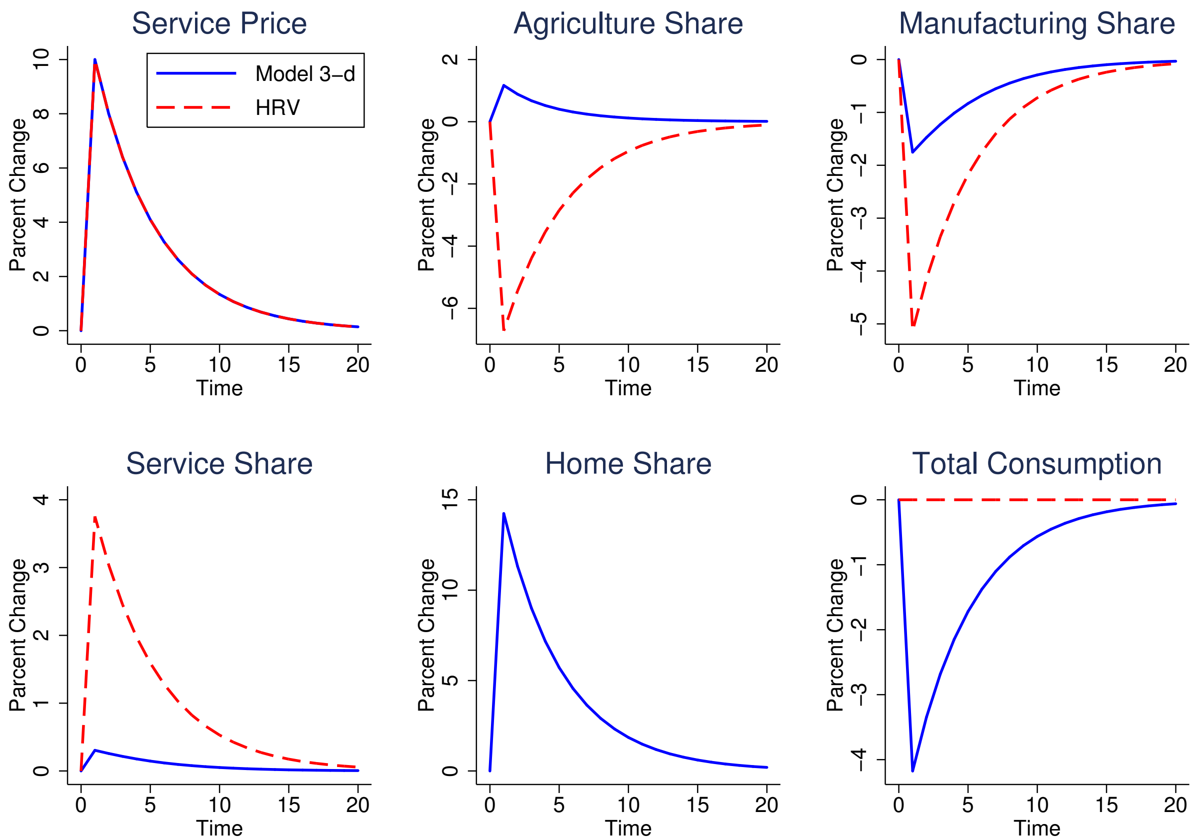

Figure 5: Effect of an Increase in Service Price on Sectoral Shares. Comparison with Herrendorf, Rogerson, and Valentinyi (2013)

Model 3-d (column (10) in Table 1). The result shows that, while the 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 3-d for our counter-factual experiments in the subsequent subsections.

4.2 Price and Income Effects

In this section we analyze price and income effects in our model. We start by presenting a partial equilibrium exercise in which there is a change in the price of market services. We work in partial equilibrium because we want to analyze the variation in shares due to the reaction of the household to the change in price, other conditions equal. We compare our model with the standard model of structural transformation in Herrendorf, Rogerson, and Valentinyi (2013), in which the problem is that of a household maximizing utility given prices and total expenditure. Figure 5 shows the results.

In both models, the estimated σ is set to zero. This, in the model without home production,

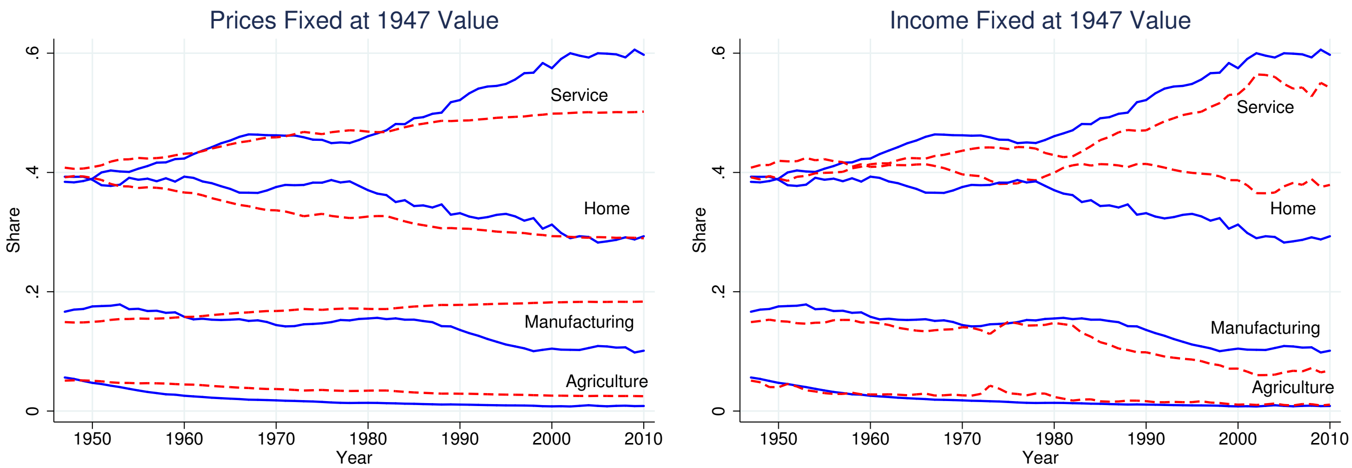

Figure 6: Sectoral Share Movements when Prices are Fixed at 1947 Value (Left) and Income is Fixed at 1947 Value (Right)

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

implies that quantities in equilibrium are little affected by changes in prices, so that the share of services increases and the shares of manufacturing and agriculture decline after the raise in the price of services. In the model with home production instead, the rise in the share of market services is smaller, because the household substitutes market services with home services. This is reflected by the decline in total expenditure in the market. As a result, the variation of all market shares is smaller, in percentage terms, with respect to the case with no home production.

Next, we perform a counter-factual exercise in which we shut down price and income effects one at the time, and compare the evolution of the shares as implied by the model with those in the data. This exercise is similar to the one performed in Herrendorf, Rogerson, and Valentinyi (2013), and it is reported in Figure 6. The lesson that we can draw is that also in the model with home production both income and price effects are key to account for actual shares. However, there seem to be a key difference between market and home services. With no price effects (left panel), the model accounts for the entire decline of the home share over the period. On the other hand, the non-homotheticity is not able to account for the entire rise of market services. To sum up, these results suggest that the decline of the home sector is explained by the different degree 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 Slow Down in Home Labor Productivity after 1978

As documented in Bridgman (2013), home labor productivity growth out-paces that of the market economy during the 1948-1977 period (2.5% versus 2.1%). After that period, labor productivity growth fluctuates around zero (see Figure 7, left panel). This is a remarkable slowdown, both for magnitude and for its long lasting behavior. As home services are substitutes for services in the

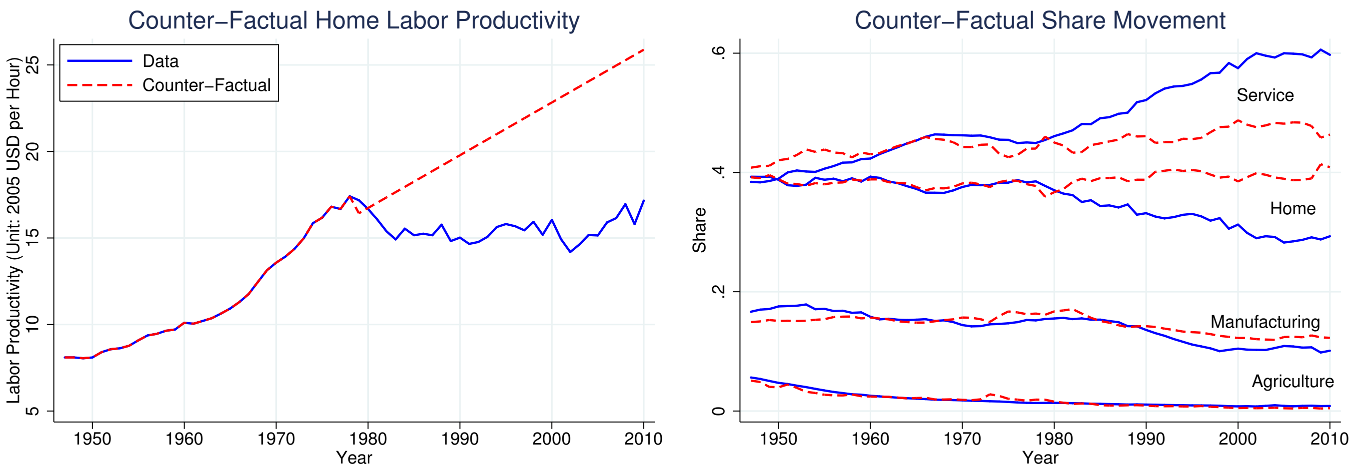

Figure 7: Counter-Factual Experiment: No Slow-Down in Home Labor Productivity after 1978: Labor Productivity (Left), Movement of Shares (Right)

Table 2: Various Statistics in 2010, Data and Model's Counter-Factual Prediction

	Extended Consumption Share		Consumption Share		Consumption per Capita	
	Bench	Counter-Factual	Bench	Counter-Factual	Bench	Counter-Factual
Agriculture	0.004	0.005	0.006	0.008 (33.3%)	255	279 (9.4%)
Manufacturing	0.105	0.123	0.148	0.208 (40.5%)	6097	7138 (17.1%)
Service	0.585	0.464	0.827	0.784 (-5.2%)	33992	26946 (-26.1%)
Home	0.306	0.409	-	-	-	-

Note: Consumption per capita is in 2005 U.S. dollar. The numbers in brackets are percent changes from our benchmark's fitted value (model 3-d).

market, it is reasonable to ask which is the quantitative effect of this slowdown 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 (6), evolves now in a different fashion due to the counter-factual evolution of home productivity $\hat{A}_t^{sh}$. To run the counter-factual we use model 3-d, which provides the best estimate of the model. The outcome of the exercise is displayed on the right panel of Figure 7.

Without the slowdown in home productivity there is almost no divergence between the market services share and the home share over the period considered. The exercise thus suggests that, other conditions equal, the slowdown in home productivity is crucial to account for the late acceleration of the share of market services. Models not displaying an explicit home production sector might miss an important factor which determines the raise of the market services sector.

Table 2 reports the level of shares in the data and in the counter-factual for the year 2010. Regarding the extended consumption shares, the market services share is 0.59 in the data and

0.46 in the counter-factual experiment. Most part of this difference is compensated by the home share, which is 0.31 in the data 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 0.83 in the data and 0.78 in the counter-factual.

The last two columns of Table 2 show the difference between per capita consumption in the data and in the counter-factual experiment. Without the slowdown in home productivity, agriculture and manufacturing consumption is larger than in the data, while market services are at a substantial lower level than in the data. This is due to the large amount of home production in the counter-factual experiment with respect to the data, which depends on the sustained growth of home labor productivity. This result suggests that the slowdown in home productivity is crucial also for the evolution of real shares of GDP.

5 Robustness

5.1 Excluding Government

To be added.

5.2 Different Labor Share across Sectors

To be added.

6 Conclusion

In this paper we study a model of structural transformation with home production and estimate it 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 share of market services that can be also produced at home grows slower with income with respect to the share of market services without a home counterpart.

The estimated model is then used to run counter-factual experiments. In particular, we measure the contribution of the slowdown in home productivity growth to the late acceleration of the share of market services 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. Additional Figures and Tables

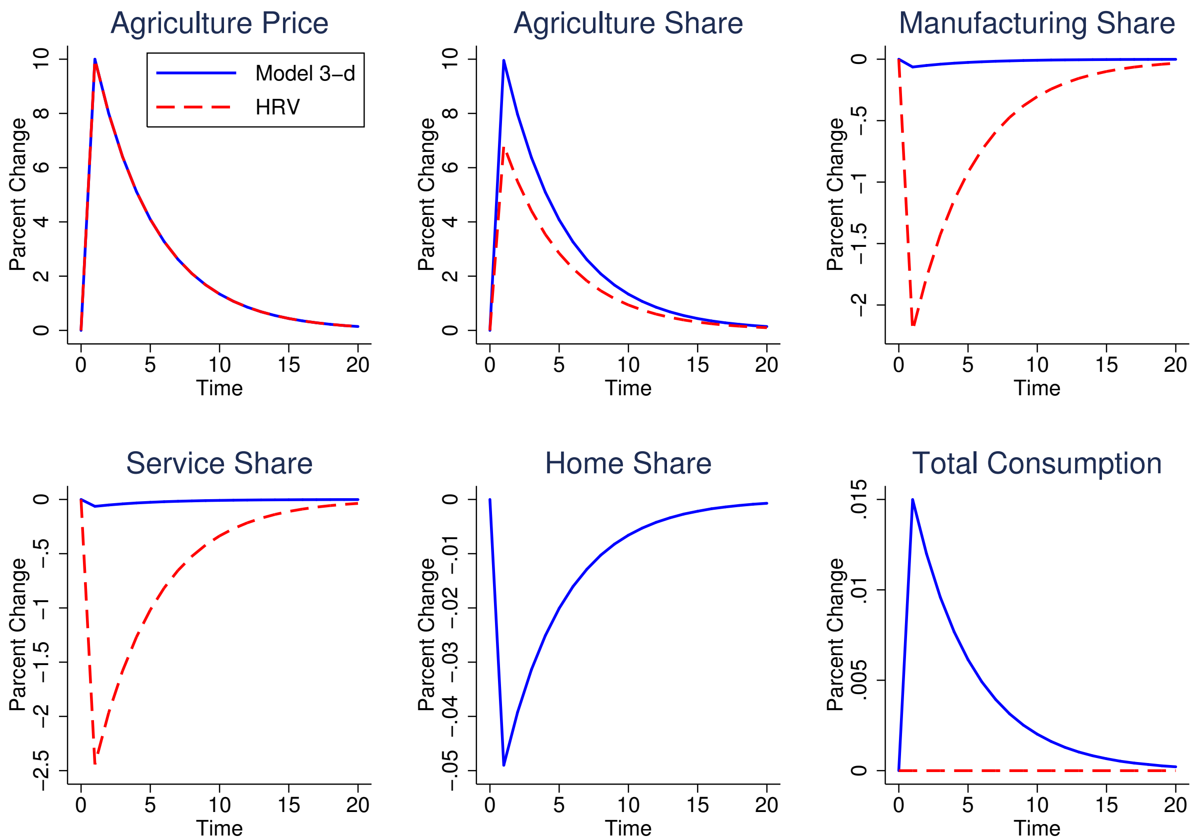

Figure 8: Effect of an Increase in Agriculture Price on Sectoral Shares. Comparison with Herrendorf, Rogerson, and Valentinyi (2013).

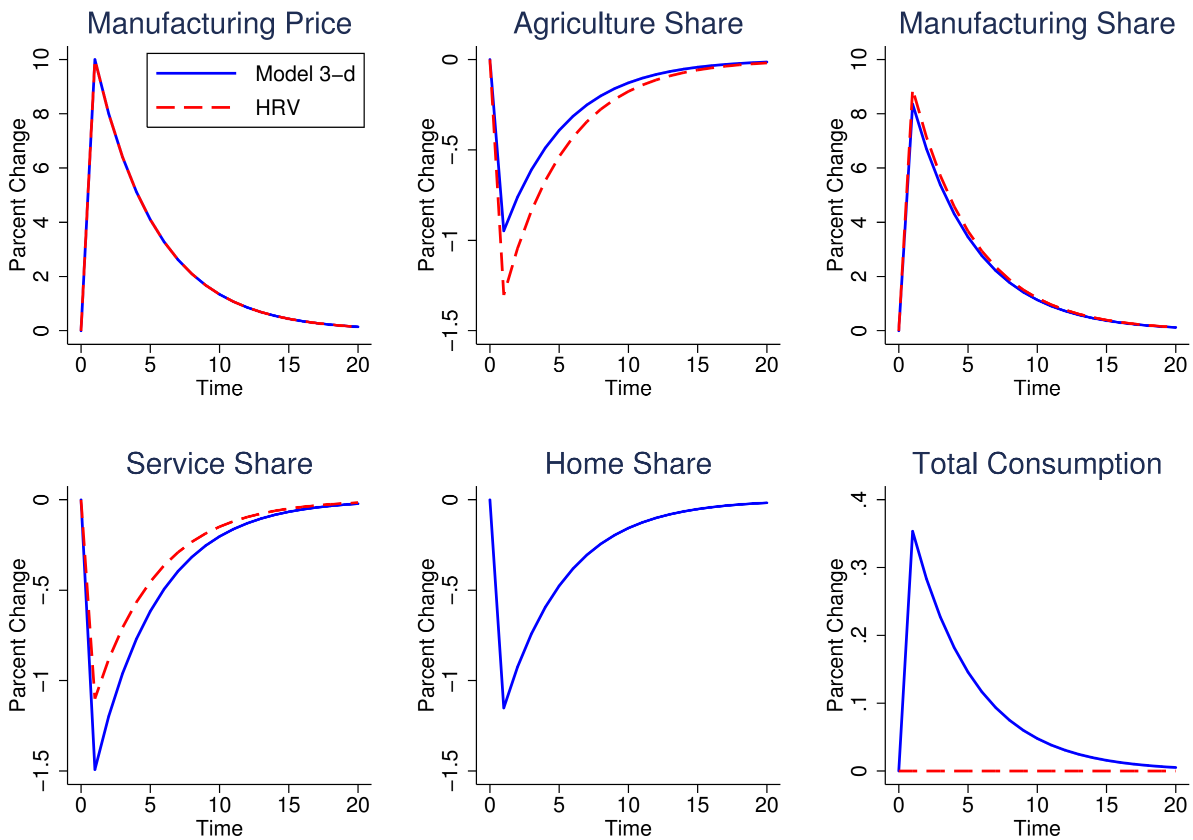

Figure 9: Effect of an Increase in Manufacturing Price on Sectoral Shares. Comparison with Herrendorf, Rogerson, and Valentinyi (2013).

B. 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's 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

$$\frac{\partial \mathcal{L}}{\partial c^a} = 0 \Longrightarrow \frac{\beta^t (\omega^a)^{1/\sigma} (c_t^a + \bar{c}^a)^{\frac{-1}{\sigma}} (C_t)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^a \tag{7}$$

$$\frac{\partial \mathcal{L}}{\partial c^m} = 0 \Longrightarrow \frac{\beta^t (\omega^m)^{1/\sigma} (c_t^m + \bar{c}^m)^{\frac{-1}{\sigma}} (C_t)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^m \tag{8}$$

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

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

Raise (9) and (10) to $1-\gamma$, sum them and raise to $\frac{1}{1-\gamma}$ to obtain

$$\frac{\beta^t (\omega^s)^{1/\sigma} (c_t^s + \bar{c}^s)^{\frac{-1}{\sigma}} (C_t)^{\frac{1}{\sigma}}}{C_t} = \lambda_t \left[(p_t^{sm})^{1-\gamma} \psi^\gamma + \left(p_t^{sh}\right)^{1-\gamma} (1-\psi)^\gamma \right]^{\frac{1}{1-\gamma}}. \tag{11}$$

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

$$p_t^s \equiv \left[\psi^\gamma (p_t^{sm})^{1-\gamma} + (1-\psi)^\gamma \left(p_t^{sh}\right)^{1-\gamma} \right]^{\frac{1}{1-\gamma}}, \tag{12}$$

that is, one unit of the services consumption bundle costs p_t^s. Note that by using (12) we can write

$$\frac{\beta^t (\omega^s)^{1/\sigma} (c_t^s + \bar{c}^s)^{\frac{-1}{\sigma}} (C_t)^{\frac{1}{\sigma}}}{C_t} = \lambda_t p_t^s. \tag{13}$$

Now sum FOCs (7) and (8) and use the definition of p_t^s to obtain

$$\frac{\beta^t (\omega^s)^{1/\sigma} (c_t^s + \bar{c}^s)^{\frac{-1}{\sigma}} (C_t)^{\frac{1}{\sigma}}}{C_t} c_t^s = \lambda_t \left[p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh} + p_t^{sh} \bar{c}^{sh} \right] \tag{14}$$

Recall now from (13) that

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

so we can use the last expression in (14) to obtain

$$p_t^s c_t^s - p_t^{sh} \bar{c}^{sh} = p_t^{sm} c_t^{sm} + p_t^{sh} c_t^{sh}. \tag{15}$$

Now raise each condition (7), (8) and (13) to $1 - \sigma$ and sum across conditions

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

raise to $\frac{1}{\sigma-1}$ 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 (7), (8) and (13) to obtain

$$P_t C_t = \sum_{i=a,m,s} p_t^i c_t^i + \sum_{i=a,m,s} p_t^i \bar{c}^i. \tag{16}$$

Use (15) 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 (16) 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*: Given C_t, the household solves:

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

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

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

C. Derivation of Sectoral Share Equations

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

$$
\begin{aligned}
\mathcal{L} \;=\; & \left((\omega^a)^{1/\sigma}(c^a+\bar{c}^a)^{\frac{\sigma-1}{\sigma}}+(\omega^m)^{1/\sigma}(c^m+\bar{c}^m)^{\frac{\sigma-1}{\sigma}}+(\omega^s)^{1/\sigma}(c^s+\bar{c}^s)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \\
& +\lambda\left[E-p^ac^a-p^mc^m-p^{sm}c^{sm}-p^{sh}c^{sh}\right],
\end{aligned}
$$

where $c^s=\left[\psi(c^{sm})^{\frac{\gamma-1}{\gamma}}+(1-\psi)(c^{sh}+\bar{c}^{sh})^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}$. The first order conditions are;

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

where $\Psi\equiv(\omega^a)^{1/\sigma}(c^a+\bar{c}^a)^{\frac{\sigma-1}{\sigma}}+(\omega^m)^{1/\sigma}(c^m+\bar{c}^m)^{\frac{\sigma-1}{\sigma}}+(\omega^s)^{1/\sigma}(c^s+\bar{c}^s)^{\frac{\sigma-1}{\sigma}}$. From the first order conditions, we can derive the following share equations;

$$\frac{p^ac^a}{E}=f_1\equiv\frac{(p^a)^{1-\sigma}\omega^a\Phi_1}{\Phi_2}-\frac{p^a\bar{c}^a}{E} \tag{17}$$

$$\frac{p^mc^m}{E}=f_2\equiv\frac{(p^m)^{1-\sigma}\omega^m\Phi_1}{\Phi_2}-\frac{p^m\bar{c}^m}{E} \tag{18}$$

$$\frac{p^{sm}c^{sm}}{E}=f_3\equiv\frac{(p^{sm})^{1-\sigma}\omega^s\psi^\sigma\Omega_1^{\frac{\sigma}{\gamma}-1}\Phi_1}{\Phi_2}-\frac{p^{sm}\Omega_1^{-1}\bar{c}^s}{E} \tag{19}$$

where

$$
\begin{aligned}
\Phi_1 &\equiv\left(1+\frac{p^a\bar{c}^a+p^m\bar{c}^m+p^{sh}\bar{c}^{sh}+p^{sm}\Omega_1^{-1}\bar{c}^s+p^{sh}\Omega_2^{-1}\bar{c}^s}{E}\right), \\
\Phi_2 &\equiv(p^a)^{1-\sigma}\omega^a+(p^m)^{1-\sigma}\omega^m+(p^{sm})^{1-\sigma}\omega^s\psi^\sigma\Omega_1^{\frac{\sigma}{\gamma}-1}+\left(p^{sh}\right)^{1-\sigma}\omega^s(1-\psi)^\sigma\Omega_2^{\frac{\sigma}{\gamma}-1},
\end{aligned}
$$

and where

$$
\begin{aligned}
\Omega_1 &\equiv\left[\psi+(1-\psi)\left(\frac{1-\psi}{\psi}\right)^{\gamma-1}\left(\frac{p^{sm}}{p^{sh}}\right)^{\gamma-1}\right]^{\frac{\gamma}{\gamma-1}}, \\
\Omega_2 &\equiv\left[\psi\left(\frac{\psi}{1-\psi}\right)^{\gamma-1}\left(\frac{p^{sh}}{p^{sm}}\right)^{\gamma-1}+(1-\psi)\right]^{\frac{\gamma}{\gamma-1}}.
\end{aligned}
$$

The share equations, (17), (18), and (19), are used for estimation.

D. Estimating Structural Breaks in Home Labor Productivity

In this appendix, we discuss on how to determine the timing of structural breaks in home labor productivity, which we use in the counter-factual experiment. We follow a standard approach developed by Bai and Perron (1998, 2003),[10] which allow us to estimate multiple structural breaks in a linear model estimated by least squares.

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

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

for $j = 1, \ldots, m+1$. Our concerns are on how many regime switches (m) are there, when the regime switches happen ($T_{1,} \ldots, T_m$), and how the mean growth rate of labor productivity varies (δ_j) across the different regimes. When applying the method by Bai and Perron (1998, 2003), we allow up to 5 breaks, and used a trimming $\epsilon = 0.10$ (meaning that each regime has at least 10 observations). We also allow serial correlations in the error terms and different variance of the residuals across the regimes.

Table 3: 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 $\hat{T}_i$.

We now turn to the results of our estimation reported in Table 3. 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 statistics of no structural break ($m = 0$) versus a fixed number of breaks ($m = k$). Also,

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

$UDmax$ 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.[11] Therefore, we conclude that, at least, one break is present. Next, we note that both the $\sup F_T(2 \mid 1)$ and the $\sup F_T(3 \mid 2)$ test are significant at 5% level, while the $\sup F_T(4 \mid 3)$ isn't. The statistics, $\sup F_T(l+1 \mid l)$, 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% level 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.[12]

In conclusion, the estimation results indicate that, at 1% significance level, there is an unique break between 1978 and 1979 ($\hat{T}_1 = 31$), which has decreased the mean growth rate of home labor productivity by 2.5%. At 5% significance level, there are three breaks, the one between 1953 and 1954 ($\hat{T}_1 = 16$), the one between 1978 and 1979 ($\hat{T}_1 = 31$), and the 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 is 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. If we look at Figure 1, there are also changes in the market service share which corresponds to the three breaks. Even though the last note is interesting, in this paper, we decided to focus on the break, which happened between 1978 and 1979. The existence of this unique break is statistically-significant at 1% level, and the change is the largest in magnitude among the three breaks we found in the latter result.

[11] 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.

[12] See Bai and Perron (2003).