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On the Trends of Technology, Family Formation, and Women's Time Allocation

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Abstract

Advanced economies have experienced a sharp decline in fertility and marriage rates over the past several decades, alongside rising educational attainment and substantial shifts in women's time allocation. To investigate the forces behind these trends, we develop a quantitative general equilibrium model with endogenous marriage, fertility, educational investment, and women's time use. The model incorporates factor-neutral, skill-biased, and gender-biased technological change, which jointly determine the wage structure and the trade-offs households face. Calibrating the model to Japan, we find that skill- and gender-biased technological change jointly account for about 30% of the decline in fertility between 1970 and 2020, with technologies favoring female labor supply explaining most of this effect. These forces operate through higher opportunity costs of childrearing and weaker incentives to marry. Counterfactual experiments show that ignoring the joint determination of education and time allocation leads to substantial misattribution of the drivers of fertility decline. Together, the results demonstrate that understanding long-run demographic change requires a unified framework that integrates these interconnected household decisions.

Keywords: Fertility, Marriage, Home Production, Women's Time Allocation, Skill-biased Technological Change, Gender-biased Technological Change, Japan.
JEL Classification: D10, E10, J10, O11

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1 Introduction

Over the past several decades, advanced economies have undergone a secular transformation of the family structure and time allocation within households, as well as a substantial shift in the wage structure. Marriage rates have declined and couples are having fewer children, while dedicating a larger portion of their resources toward sending their children to college for skill acquisition, despite the escalating costs of education. The gender wage gap has narrowed, partly reflecting a greater increase in educational attainment among women, which in turn implies higher opportunity costs of childcare and home production.

The objective of this study is to develop a unified framework to comprehensively explain these observed trends and to investigate their underlying forces. The main contribution of this paper is twofold: (1) constructing a unified framework that incorporates all these key factors influencing decisions of families in general equilibrium (GE); and (2) uncovering important roles of technological changes that favor female labor supply in explaining the declining trends in fertility and marriage. Counterfactual experiments based on the model echo the importance of these two contributions: omitting joint decision margins, such as educational investment and time use, can mislead assessments of the drivers of declining fertility.

In our model, individuals initially enter the economy as singles and subsequently encounter a potential partner, making decisions regarding marriage. They allocate their disposable time among various activities, including market work, home production, leisure, and childcare. Married couples make choices regarding the number of children and the level of education for them, considering quantity-quality trade-offs (Becker and Barro 1988; Barro and Becker 1989). Wages are determined in the competitive market, and the production function differentiates between high-skilled and low-skilled labor, as well as between men and women, as potentially distinct factors of production. In our model, the technology of market production can grow through three factors: the growth of factor-neutral technology or total factor productivity (TFP), skill-biased technological change (SBTC), and gender-biased technological change (GBTC). The SBTC can also be decomposed into two parts, a general one and one that is specific to female labor supply.

We calibrate the model to Japanese data to match the time trends of key endogenous variables—fertility, marriage, time allocation, education, and wage structure—over the past 50 years (1970–2020). Japan witnessed a dramatic decrease in total fertility rate from above 2.1 in 1970 to around 1.3 in 2020, as well as a simultaneous decline in marriage rates. While the gender gap in wage and education level narrowed, substantial disparities in wages and time allocation between men and women remain. Although female labor participation has increased over time, the average time married women spend on both market work and housework has declined. To obtain detailed information on time allocation, we use various micro-level datasets such as the Survey on Time Use and Leisure

Activities. Additionally, we utilize the Employment Status Survey to acquire wage rates by gender and skill to calibrate the underlying technological parameters. Furthermore, we use the price data of housework-assisting durable goods to quantify the technological advancements in home production.

Using the calibrated model, we conduct a series of counterfactual experiments and derive two main insights. First, we shut down individual time-varying parameters, such as specific technological components, to examine how fertility would have evolved absent changes along each dimension. These counterfactuals indicate that SBTC and GBTC jointly account for about 30% of the decline in the TFR between 1970 and 2020, while TFP growth has only a negligible effect. Among these factors, technological changes that favor female labor, namely GBTC and female-specific SBTC, account for the larger share, explaining about 21% of the overall 30% contribution. By raising the relative productivity of female labor, these technologies increase the opportunity cost of childbearing and reduce fertility within marriage. They also lower marriage rates, as the value of remaining single rises relative to marriage. When women can earn a sufficiently high income on their own, the gains from marriage decline, particularly given the additional time demands of home production.

The second counterfactual emphasizes the importance of a unified framework that jointly models interconnected choice margins, such as education and time use. We fix one margin at its 1970 level and solve the model for the 2020 economy, both with and without technological change. Ignoring endogenous adjustments along these margins leads to biased inferences about the drivers of fertility decline. When schooling is held fixed, technological change explains little of the observed decline in fertility, because households cannot respond to higher skill premia by increasing educational investment. This weakens the quantity–quality trade-off and understates the contribution of SBTC. In contrast, when time use is fixed, shutting down GBTC and female SBTC accounts for nearly the entire fertility decline between 1970 and 2020. Fixing time allocation dampens the role of time and monetary costs of children because the trade-off between work and childcare is weakened, thereby overstating the relative importance of technological change. Taken together, these results underscore the value of a unified framework for understanding declining fertility.

This study is most closely related to the large literature on family and macroeconomics, particularly studies examining the determinants of fertility and marriage.[1] To the best of our knowledge, this study is the first attempt to construct a unified model that encompasses fertility, marriage, education, and women's time allocation, while considering the

[1] See, for example, Greenwood, Seshadri, and Vandenbroucke (2005); Voena (2015); Greenwood et al. (2016); Cordoba, Liu, and Ripoll (2019); Eckstein, Keane, and Lifshitz (2019); Yamaguchi (2019); Delventhal, Fernández-Villaverde, and Guner (2021); Kim, Tertilt, and Yum (2024); Mahler, Tertilt, and Yum (2025); Zhou and Xi (2025). For a comprehensive survey, see Doepke and Tertilt (2016) and Doepke, Hannusch, Kindermann, and Tertilt (2023).

endogenous wage structure. We demonstrate the interconnections among these factors and highlight the critical role each factor plays in jointly explaining the observed trends in both family dynamics and the macroeconomy.

The paper closest to ours is Greenwood et al. (2023), who propose a theory of endogenous marriage, fertility, and labor supply that incorporates technological development. Their model is calibrated to capture family trends in the U.S. since the late nineteenth century, providing a framework to analyze long-term trends in structural change and household behavior in a tractable manner. However, their model does not distinguish between men and women. This gender distinction is potentially important, given that many countries have experienced a narrowing gender wage gap (e.g., Goldin 2014; Blau and Kahn 2017), which can significantly influence family formation and time allocation within households.

We therefore consider the gender distinction in our model and show that technological changes that favor female labor supply have played a crucial role in explaining the long-run trends regarding families, such as declining fertility and marriage. While similar mechanisms—linking fertility or marriage declines to relative increases in women's wages—appear in earlier studies (e.g., Galor and Weil 1996; Caucutt et al. 2002; Regalia et al. 2019), the distinctive feature of our study is to go one step further: we trace these wage dynamics back to their structural source, i.e. technological change, developing a quantitative GE framework.

By doing so, we provide a deeper understanding of the forces driving changes in household behavior and demographics. Such understanding is especially crucial for designing effective family policies, which have attracted growing attention in many countries facing persistently low fertility, since the effectiveness of such policies depends critically on why fertility is so low. Our unified framework serves as a valuable laboratory for uncovering the underlying sources of these demographic trends: we demonstrate that omitting key decision margins, such as educational investments and time use, can mislead assessments of the drivers of declining fertility, underscoring the importance of incorporating these factors in the model.

There is also a large body of literature that investigates the roles of technological change to account for the dynamics of the wage structure (Katz and Murphy 1992; Krusell et al. 2000; Kawaguchi and Mori 2016; Taniguchi and Yamada 2023). Heathcote et al. (2010) and Abbott et al. (2019) consider the technology that distinguishes among labor supply of different skills and genders, accounting for the rich heterogeneity in the dynamics of wage inequality. The market wage structure not only influences the career plans of men and women, but also shapes their decisions regarding family formation, as it shapes how time is allocated among market work, household production, childcare, leisure, and across household members.[2] We contribute to the literature by studying the roles of various

[2] Jang and Yum (2022) study nonlinear relationship between wages and work hours in some occupations

forms of technological change on the decisions of families, particularly family formation and time allocation.

Finally, our study also focuses on the time allocation of married women and builds upon the literature that examines the determinants of female labor supply, including the wage structure and fiscal policies.[3] Our study contributes to the literature by studying the effects of various technological changes and evolving costs of childbearing in explaining the time trends in women's time allocation, such as increasing trends in leisure.

The rest of this paper is organized as follows. Section 2 presents the relevant data and discusses the trends in family and macroeconomic variables of interest. Section 3 describes the quantitative model, while Section 4 discusses the model's parametrization. The numerical results are presented in Section 5 and Section 6 presents a conclusion.

2 The Time Trends of Family Facts

In this section, we examine the trends of various facts surrounding families in Japan. Figure 1(a) shows the path of the total fertility rates in Japan, which represents the average number of children that each woman gives birth to over her life-cycle.[4] In the early 1970s, the fertility rate exceeded the replacement rate that is needed to keep the population from decreasing, but started to decline quickly thereafter. By the mid-2000s, it had fallen below 1.3 and stayed at around 1.3 to 1.4 until 2020.

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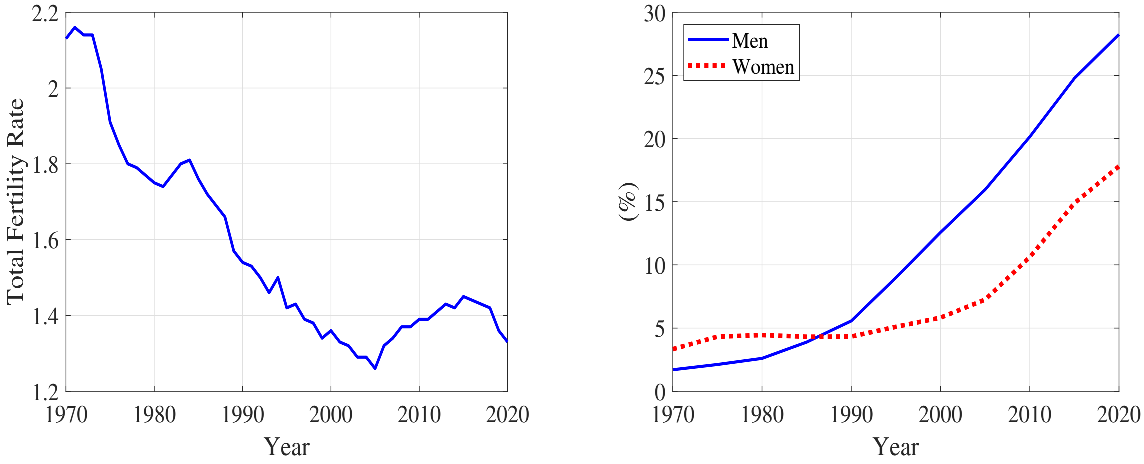
and argue that the rise in experience premium has a negative impact on the participation of women.

[3] See also, Attanasio et al. (2008), Albanesi and Olivetti (2009), Guner et al. (2012), Jones et al. (2015), Bick and Fuchs-Schundeln (2017), Borella et al. (2023), and Kitao and Mikoshiba (2023).

[4] More precisely, it is computed as the average number of children that a hypothetical cohort of women would have if they were subject to the fertility rates of a given year during their whole lives.



(a) Total Fertility Rate (b) Fraction of Never-Married at Age 50

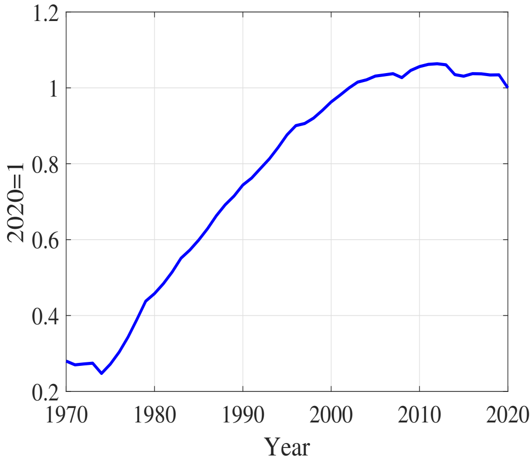
Figure 1: Fertility and Marriage

Source: Vital Statistics, Ministry of Health, Labour and Welfare, and Population Census, Ministry of Internal Affairs and Communications.

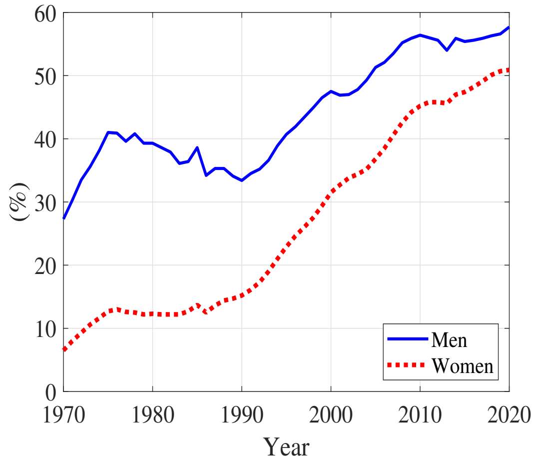
While fertility rates declined rapidly, marriage rates also declined. Figure 1(b) shows the fraction of men and women aged 50 who have never been married in their life. The share was less than 5% until the late 1980s for men and until the early 1990s for women, but it rose quickly and reached 28% for men and 18% for women by 2020. Note that out of wedlock birth is uncommon in Japan. According to the OECD Family Data in 2020, the share of births outside of marriage is 2.4% in Japan, the lowest among the OECD countries.[5]

The cost of raising a child also increased during the last decades. As shown in Figure 2, the college enrollment rate increased from less than 30% in 1970 to almost 60% for men in 2020. The rise is more dramatic for women. Less than 10% of women went to college in 1970, but the share exceeded 50% in 2020. The cost of attending college also increased at the same time, as shown in the path of the average college tuition fee in Figure 2(a).

[5]The share is 41% for the U.S. and 42% for the EU countries on average. See also Myong et al. (2021) and Ho and Wang (2024) for structural models that explicitly incorporate stigma associated with out-of-wedlock births. Given the small number of birth outside of marriage, we do not model them explicitly and assume that only couples give birth.



(a) College Tuition Fee



(b) College Enrollment Rate

Figure 2: College Costs and Enrollment

Source: College tuition fee is based on the Consumer Price Index, Ministry of Internal Affairs and Communications. (a) depicts the price index of college tuition fees relative to the headline CPI. The data on 4-year college enrollment rates are from the School Basic Survey by the Ministry of Education, Culture, Sports, Science and Technology.

Not only the financial cost, but also the time that parents spend on raising children increased in the last 50 years. Table 1 shows the time allocation of married men and women of working age in the late 1970s and 2010s.[6] Both men and women increased the share of time spent on childcare, and women especially allocate a much larger share of their time on childcare than did men, and the share increased from 7.1% to 13.9%. This occurred at the same time as the number of children decreased and childcare time per child rose even more rapidly.[7]

Table 1 shows that while married women spend more time on childcare, they allocate a significantly smaller fraction of their time to housework and market work. The time for leisure increased from 17.5% to 23.1%.

[6]The data is based on the Survey on Time Use and Leisure Activities. The Survey is conducted every five years. Although the data for 2021 is available, we use the 2016 data as the most recent one to focus on the long-term trend and avoid being influenced by the short-term effects of the COVID shock.

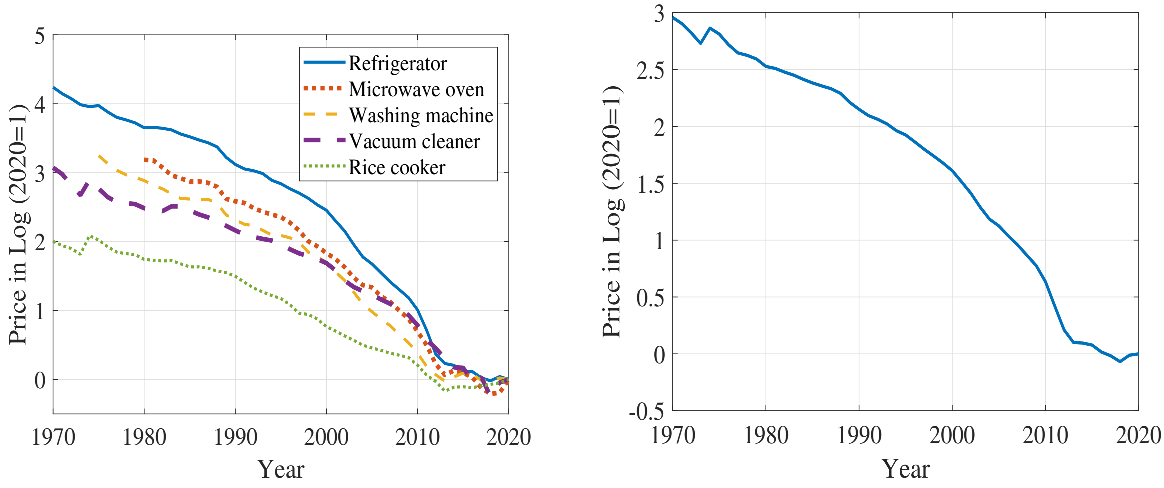
[7]Similar trends have been observed to varying degrees in other countries. See Aguiar and Hurst (2007), Ramey and Ramey (2010), and Doepke and Zilibotti (2017). Guryan et al. (2008) show that the trend of rising childcare time is more pronounced among more educated and higher-income parents in the U.S. and that a similar pattern is observed within and across countries in a sample of 14 countries.

Table 1: Time Allocation of Married Men and Women (% of disposable time)

	Men			Women		
	1976	2016	Change	1976	2016	Change
Market work	77.45	71.52	−7.7%	37.22	30.61	−17.8%
Housework	0.71	2.11	+197.2%	38.19	32.32	−15.4%
Childcare	0.49	2.72	+455.1%	7.14	13.93	+95.1%
(per child)	(0.22)	(1.68)	(+663.6%)	(3.24)	(8.61)	(+165.7%)
Leisure	21.34	23.65	+10.8%	17.46	23.14	+32.5%
Total	100.0%	100.0%		100.0%	100.0%	

Source: Survey on Time Use and Leisure Activities. Ministry of Internal Affairs and Communications. Average time use of married men and women aged 25-59.

The decline in the hours dedicated to housework occurred at the same time as the advancement in home production technology. Figure 3 shows the price index of major household appliances, such as refrigerators, washing machines, and vacuum cleaners, relative to the headline CPI. The relative price declined at an annual rate of 4 to 8%. The price indices of those goods are summarized as the index of *housework-assisting durable goods*. Figure 3(b) shows the path of their relative price, which declined at an annual rate of 5.75% between 1970 and 2020, while the relative prices of other items such as food and houses did not grow significantly.



(a) Price of Major Home Durables

(b) Price Index

Figure 3: Price of Housework-assisting Durable Goods

Source: Consumer Price Index, Ministry of Internal Affairs and Communications. Each plotted line indicates the price index relative to the headline CPI. "Durable Goods" in the legend on (b) represents the price index of *housework-assisting durable goods*, including refrigerators, microwave ovens, washing machines/dryers, vacuum cleaners, rice cookers, and gas stoves, relative to the headline CPI.

Over time, as the family structure and time allocation changed, macroeconomic environment and wage structure shifted. Table 2 shows the real wage rates by gender and skill in 1970 and 2020, where high-skill represents those with college degrees or above.[8] The wage rate of low-skilled women in 1970 is set to 1 for normalization. Wages increased for all groups, with women's wage growth being higher than men's within each skill group. The average wage of women grew at an annual rate of 1.37%, while men's increased at 0.91%. Since there is also a rise in the share of high-skilled workers among both men and women, the average growth rate is higher than the growth rates within skill groups.

The wage growth of low-skilled women is higher than that of high-skilled women. As a result, the women's skill premium, defined as the ratio of high-skill wage to low-skill wage, declined from 1.65 to 1.55 in 2020, as shown in the bottom section of Table 2. Men's skill premium has not changed much between 1970 and 2020. Taniguchi and Yamada (2021) also demonstrate similar trends of men and women's skill premiums in Japan since 1980 using the EU KLEMS database.

The gender gap is defined as the ratio of women's wages to men's wages, and it has

[8] We use the Employment Status Survey (ESS) data between 1982 and 2017, which contain information about work hours and annual earnings by gender and education level. The ESS data is based on statistical products provided by the Statistics Center, an independent administrative agency based on the Statistics Act.

We use the real wage index of the Monthly Labour Survey since 1970 to extrapolate the wage in the 1970s.

narrowed over the last five decades, from 0.51 to 0.64 on average. Note that the change in gender gap is larger on average than the gender gap within the skill groups, since there was also a change in the composition of worker skills by gender.

Table 2: Wages by Gender and Skill, Gender Gap, and Skill Premium

		1970	2020	Ann. Growth
Women	Low Skill	1.00	1.66	1.02%
	High Skill	1.65	2.57	0.89%
	Weighted Avg.	1.03	2.03	1.37%
Men	Low Skill	1.83	2.72	0.79%
	High Skill	2.49	3.67	0.78%
	Weighted Avg.	2.01	3.17	0.91%
Gender Gap	Low Skill	0.55	0.61	–
	High Skill	0.66	0.70	–
	Weighted Avg.	0.51	0.64	–
Skill Premium	Men	1.36	1.35	–
	Women	1.65	1.55	–
	Weighted Avg.	1.46	1.42	–

Source: Employment Status Survey (ESS) and Monthly Labour Survey (MLS). Wage of low-skilled women in 1970 is set to 1.0 for normalization. *Gender gap* is defined as the ratio of women's wages to men's wages. *Skill premium* is defined as the ratio of high-skill wages to low-skill wages.

As shown in Table 3, the share of female workers in the labor force increased from 31% in 1970 to above 45% in 2020, and the rise is driven by an increase in the number of high-skilled women in the labor force. Low-skilled male workers represented 50% of the labor force in 1970, and the share declined to 29% over the last 50 years. Men, both low and high-skilled, constitute 54% of the labor force in 2020.[9]

We use these observations to calibrate the technological progress during the last half century in Section 4. It is important to consider the dramatic change in the composition of labor supply to account for the shift in the wage structure and productivity of different types of labor inputs.

[9]For structural models with endogenous labor participation decisions of women in Japan, see, for example, Kitao and Mikoshiba (2023) and Yamaguchi (2019).

Table 3: Distribution of Workers by Gender and Skill

	1970	2020
Women		
Low Skill	29.7%	28.5%
High Skill	1.4%	17.4%
Total	31.1%	45.9%
Men		
Low Skill	50.2%	29.0%
High Skill	18.7%	25.2%
Total	68.9%	54.1%
Total	100.0%	100.0%

Source: Population Census, Ministry of Internal Affairs and Communications.

3 Model

3.1 Overview

An individual of our model enters the economy as single and is matched with another single person upon entry. The pair chooses to get married if the value of marriage exceeds the value of staying single and remain single otherwise.

A married couple chooses consumption of market goods and non-market goods. The latter is produced at home, using durable goods and housework time as inputs. The couple also decides how many children to have. Parents derive utility from the quantity and quality of children, taking into account the time and money cost of raising children and educating them.[10] The household allocates disposable time toward leisure, home production, market work, and childcare. Single individuals consume market and non-market goods and allocate their time to leisure, home production, and market work. Market goods are produced using skilled and unskilled labor and wages are determined in the competitive market.

The framework is static to keep the model tractable. Individuals make one-time decisions about marriage, and then about consumption and time allocation, as well as fertility and education in the case of married couples. The model aims to examine how time-varying factors influence the evolving patterns of decision making by families and we abstract from roles of uncertainty and additional heterogeneity within cohort.

[10]We assume that only married couples have children and abstract from single mothers and fathers given that births out of wedlock are uncommon in Japan, as discussed in Section 2.

3.2 Preferences

Married households derive utility from a couple's consumption of market goods c, non-market goods n, total leisure time of husband and wife $l = l_m + l_f$, the number of children k, and the quality of children q. The utility function is denoted as $u^M(c/\eta, n/\eta, l, k, q)$, where η represents the equivalence scale of consumption goods for the couple, and is given as follows.

$$u^M(c/\eta, n/\eta, l, k, q) = \alpha\frac{(c/\eta)^{1-\rho}-1}{1-\rho}+\beta\frac{(n/\eta)^{1-\nu}-1}{1-\nu}+\mu\frac{l^{1-\lambda}-1}{1-\lambda}+\phi\frac{k^{1-\kappa}-1}{1-\kappa}+\xi\frac{q^{1-\psi}-1}{1-\psi}, \quad (1)$$

Parameters α, β, μ, ϕ, and ξ represent the weight attached to utilities from the consumption of market and non-market goods, leisure time, and the number and quality of children, respectively. Parameters ρ, ν, λ, κ, and ψ represent the curvature of the utility function and affect how households respond to a changing environment by reallocating resources to maximize the utility.

A single individual of gender $g \in \{m, f\}$, male and female, derives utility from the consumption of market goods c, non-market goods n, and leisure l. The utility function is denoted as $u_g^S(c, n, l)$ and given as:

$$u_g^S(c, n, l) = \alpha_g\frac{c^{1-\rho}-1}{1-\rho}+\beta_g\frac{n^{1-\nu}-1}{1-\nu}+\mu_g\frac{l^{1-\lambda}-1}{1-\lambda} \quad (2)$$

Parameters α_g, β_g, and μ_g denote the preference weight on consumption of market goods, non-market goods and leisure time, respectively, which may depend on gender g.

3.3 Children

A married couple derives utility from both the number of children k, as well as the quality of children q. Raising children is costly for parents in two ways: time and money for basic childcare and money for education. Basic childcare is required for all children and education investment is based on the choice of the family. For basic childcare, a married couple must spend a financial cost b per child, and each parent of gender g must spend time ζ_g per child.

Parents choose how many financial resources to invest in child education, which raises the quality of children. We assume that parents choose a mix of skills for their children, with a fraction s of high skill and $1-s$ of low skill. It costs χs per child to equip them with skill s.[11]

The quality of children is denoted as q and it increases utility of parents. We assume that the quality depends on the skill level s that parents choose to endow their children

[11] In what follows, we call the choice of children's skill level s also as schooling decision made by parents. As discussed in more detail in Section 4, s corresponds to college enrollment rates in calibration.

with, and also on how much the skill is valued in the market. We define the quality of children as

$$q = sw_h + (1-s)w_l, \tag{3}$$

where w_h and w_l represent high and low-skill wages, respectively. Wages are exogenous to parents, but they are determined endogenously in the labor market as a function of the supply of the skill and exogenous technological change, as discussed in Section 3.6.

We assume that parents do not differentiate educational investment by the gender of children. Consequently, the gender of children does not enter the problem of married individuals.

3.4 Home Production

Home goods n are produced according to the following function with two inputs, durable goods (d) and housework hours (h):

$$n = [\omega d^\sigma + (1-\omega)h^\sigma]^{1/\sigma} \tag{4}$$

σ is the parameter that determines the elasticity of substitution between durable goods and labor input. Durable goods are priced at π per unit. For married households, h is the sum of housework hours supplied by husband and wife, $h = h_m + h_f$.

3.5 Household Problems

Single Households: Single individuals allocate their disposable time, normalized to 1, to leisure l, home production h, and market work $1-l-h$. They allocate income to the consumption of market goods c, and durable goods d priced at π.

The value function of single individuals of gender g is given as follows.

$$S_g = \max_{c,d,l,h} \left\{u_g^S(c,n,l)\right\} \tag{5}$$

s.t.

$$c + \pi d = w_g(1-l-h) \tag{6}$$

where w_g denotes the wage rate of individuals of gender g. Note that we abstract from heterogeneity within cohort, including difference in education levels. The wage of each gender is computed as the weighted average of low and high-skill wages determined in the labor market, as discussed in more detail in Section 3.6.

Married Households: Married couples allocate earnings of husband and wife net of costs of childcare to consumption of market goods c and durable goods d. Married households also choose the number of children k and education investment for children

s. The household decision for the investment in education determines the quality q of children.

We assume that the time allocation of married men is exogenous and they supply labor at home and in the market inelastically, and their time contribution to the home production and childcare is also exogenously given. Therefore, the time allocation decision of the couple is in regard to the wife's time for leisure l_f, home production h_f, and market work, which is given by $(1 - \zeta_f k - l_f - h_f)$, the total disposable time net of time spent on childcare, leisure, and home production.

The value function of married households is defined as

$$M = \max_{c,d,l_f,h_f,k,s} \left\{ u^M(c/\eta, n/\eta, l, k, q) \right\} \tag{7}$$

s.t.

$$c + \pi d + \chi sk + bk = \sum_g w_g(1 - \zeta_g k - l_g - h_g) \tag{8}$$

where the housework is given by $h = h_m + h_f$, leisure $l = l_m + l_f$ and the quality of children $q = sw_h + (1 - s)w_l$.

The value of a married *individual* of gender g is given by

$$\widehat{M}_g = \widehat{u}_g^M(c^*/\eta, n^*/\eta, l_g^*, k^*, q^*), \tag{9}$$

where a variable with an asterisk denotes the optimal choice from the above problem of married households. Utility function $\widehat{u}_g^M$ of a married individual is defined similarly to (1), with leisure l_g of each individual, rather than that of a household. This value is relevant in the decision of marriage as discussed below.

Equilibrium Conditions: We now describe equilibrium conditions of married and single household problems presented above. Substituting the home production equation (4) and the budget constraint (8) in the utility function of married households (1), the value function reads as

$$\begin{aligned} M \;&=\; \max_{d,l_f,h_f,k,s} \left\{ \alpha \frac{\left\{ [\sum_g w_g(1 - \zeta_g k - l_g - h_g) - \pi d - \chi sk - bk]/\eta \right\}^{1-\rho} - 1}{1-\rho} \right. \\ &+\; \left. \beta \frac{\left\{ \left[(\omega d^\sigma + (1-\omega)h^\sigma)^{1/\sigma} \right] /\eta \right\}^{(1-\nu)} - 1}{1-\nu} + \mu \frac{l^{1-\lambda} - 1}{1-\lambda} + \phi \frac{k^{1-\kappa} - 1}{1-\kappa} + \xi \frac{q^{1-\psi} - 1}{1-\psi} \right\}, \end{aligned}$$

The first order conditions of married households problem with respect to d, l_f, h_f, k, and s, respectively, are defined as follows:[12]

$$\begin{aligned}
d: &\quad \alpha(1/\eta)^{1-\rho}c^{-\rho}\pi = \beta(1/\eta)^{1-\nu}n^{1-\sigma-\nu}\omega d^{\sigma-1} &(10)\\
l_f: &\quad \alpha(1/\eta)^{1-\rho}c^{-\rho}w_f = \mu(l_m + l_f)^{-\lambda} &(11)\\
h_f: &\quad \alpha(1/\eta)^{1-\rho}c^{-\rho}w_f = \beta(1/\eta)^{1-\nu}n^{1-\sigma-\nu}(1-\omega)(h_m + h_f)^{\sigma-1} &(12)\\
k: &\quad \alpha(1/\eta)^{1-\rho}c^{-\rho}(w_m\zeta_m + w_f\zeta_f + \chi s + b) = \phi k^{-\kappa} &(13)\\
s: &\quad \alpha(1/\eta)^{1-\rho}c^{-\rho}\chi k = \xi q^{-\psi}(w_h - w_l) &(14)
\end{aligned}$$

The equation (10) represents the trade-off between the benefit obtained from additional home goods consumption by an extra unit of durable goods purchase, and the loss from market goods consumption. The conditions (11) and (12) equate the marginal benefit of an additional hour on leisure and housework, with the cost from reduced work hours and lower consumption.

The condition (13) equates the marginal benefit of having a child through direct utility from the larger number of children, with the marginal cost of raising a child, the time and money to spare for basic childcare and education. In equation (14), the marginal cost of expenditures to educate children is equated with the higher utility from the better quality of children.

Turning to the problem of single individuals, substituting the equation for the home production (4) and the budget constraint (6) in the utility function (2), the value function reads as

$$S_g = \max_{d,l,h}\left\{\alpha_g\frac{[w_g(1-l-h)-\pi d]^{1-\rho}-1}{1-\rho} + \beta_g\frac{[\omega d^\sigma + (1-\omega)h^\sigma]^{\frac{1-\nu}{\sigma}}-1}{1-\nu} + \mu_g\frac{l^{1-\lambda}-1}{1-\lambda}\right\}$$

The first order conditions of single households problem with respect to d, l, and h, respectively, are given as follows.

$$\begin{aligned}
d: &\quad \alpha_g c^{-\rho}\pi = \beta_g n^{1-\sigma-\nu}\omega d^{\sigma-1} &(15)\\
l: &\quad \alpha_g c^{-\rho}w_g = \mu_g l^{-\lambda} &(16)\\
h: &\quad \alpha_g c^{-\rho}w_g = \beta_g n^{1-\sigma-\nu}(1-\omega)h^{\sigma-1} &(17)
\end{aligned}$$

Similar to the problem of married households, the first order conditions represent the tradeoff between the utility from the consumption of market and home goods (15), time for leisure (16), and housework (17).

Marriage Decision: Upon individuals' entry to the economy, each individual is matched with a potential partner. The pair makes a draw of a common joy shock r from the distribution $F(r)$.

[12]Note that the constraint set is not convex due to the term χsk in the married household's budget constraint. The budget set and the computation method need to be modified to overcome the problem. See, for example, Jones et al. (2010) for the method in a model similar to ours.

Given that we focus on the time allocation decision of married women, and for simplicity, we focus on the marriage decision of women and abstract from men's decision to marry. Women choose to marry if the sum of the value of marriage and the joy shock exceeds the value of staying single. Otherwise the pair will not marry and remain single. The decision rules are given as follows:

$$\begin{cases} \text{marry if} & \widehat{M}_f + r \geq S_f \\ \text{single if} & \widehat{M}_f + r < S_f \end{cases}$$

3.6 Market Production and Wages

A representative firm produces the final output using labor supplied by men and women that consists of two different skill levels: high and low. We allow for imperfect substitutability among the four types of labor input and for the growth rates of the productivity that potentially differ across them. More specifically, the firm produces output Y with unskilled labor L and skilled labor H according to the production function:

$$Y = F(L, H) = Z \left[L^{\varphi} + AH^{\varphi}\right]^{1/\varphi}, \tag{18}$$

where Z represents the neutral technology level and A governs the gender-neutral skill-biased technological change (SBTC). L and H are composites of male and female labor of each skill type, L_g and H_g for $g \in \{m, f\}$, and they are defined as follows:

$$L = \left[L_m^{\gamma} + BL_f^{\gamma}\right]^{1/\gamma} \tag{19}$$

$$H = \left[H_m^{\gamma} + A_f BH_f^{\gamma}\right]^{1/\gamma} \tag{20}$$

B and A_f govern the GBTC and SBTC specific to female workers, respectively.[13]

The firm rents labor from individuals at market wage rates $w_{g,s}$ for each $g \in \{m, f\}$ and $s \in \{l, h\}$ to maximize profit. The problem is formulated as follows:

$$\max_{L_m, L_f, H_m, H_f} \left\{ F(L, H) - \sum_g (L_g w_{g,l} + H_g w_{g,h}) \right\}$$

The labor market is competitive and wages for skilled and unskilled labor of each gender are determined to equate supply and demand. Labor demand is derived from the firm's profit maximization problem described above, while labor supply by gender and skill is determined by households' labor supply and schooling decisions. Specifically, total hours worked are aggregated for each gender g, based on households' labor supply decisions. Given this gender-specific labor, a fraction s constitutes high-skill labor input,

[13] Alternatively, one could specify the formula so that there is one technology parameter multiplying low and high female labor, respectively. We chose the current specification so that we can isolate the skill-biased part of GBTC from the general one.

and the remaining fraction $1-s$ constitutes low-skill labor input for each gender. Appendix E provides the formal definitions and a more detailed discussion of labor market clearing conditions.

In equilibrium, market wages are given as marginal product of each type of labor.

$$\begin{aligned} w_{m,l} &= F_{L_m} = \widetilde{Z} L^{\varphi-\gamma} L_m^{\gamma-1} \\ w_{m,h} &= F_{H_m} = \widetilde{Z} A H^{\varphi-\gamma} H_m^{\gamma-1} \\ w_{f,l} &= F_{L_f} = \widetilde{Z} L^{\varphi-\gamma} B L_f^{\gamma-1} \\ w_{f,h} &= F_{H_f} = \widetilde{Z} A H^{\varphi-\gamma} A_f B H_f^{\gamma-1} \end{aligned} \tag{21}$$

where $\widetilde{Z} = Z\left[L^{\varphi} + AH^{\varphi}\right]^{\frac{1}{\varphi}-1}$.

The wage rates by gender and skill, $w_{g,s}$, determine the wages that appear in the households' problem described in Section 3.5. In particular, the wage rate for gender $g \in \{m, f\}$, denoted by w_g, is computed as the weighted average of high- and low-skill wages using the schooling level s as weights:

$$w_g = s \cdot w_{g,h} + (1-s) \cdot w_{g,l}. \tag{22}$$

In addition, the wage rates for each skill level, w_s for $s \in \{l, h\}$, which are used to compute the quality of children in (3), are defined as the simple average of male and female wages:

$$w_s = \frac{w_{m,s} + w_{f,s}}{2}. \tag{23}$$

4 Calibration

We would like the model presented above to align with the facts presented in Section 2. We assign some parameter values directly from the data, and determine other parameter values so that the model-generated moments match their data counterparts over the fifty-year period from 1970 to 2020, as explained in more detail below. The former include parameters related to preference and technology and the latter include parameters on childcare costs and home production.

We chose the 1970–2020 period for our analysis due to limitations in data availability. Microdata necessary to impute the time use of single and married individuals have been available only since 1976, from the Survey on Time Use and Leisure Activities. Labor market data prior to 1970 are not comprehensive enough to compute wage and employment by gender and education. The calibrated parameters are summarized in Table 4. Appendix A provides additional details of the data used in the calibration.

4.1 Preference Parameters

4.1.1 Calibration Strategy

For the equivalence scale η, we assume the OECD equivalence scale and set it to 1.5 for married households.[14] For the utility function of married households (1), we set the weight parameter α to 1 for normalization and the risk aversion parameter ρ to 2. The remaining preference parameters—including four weight parameters, $\{\beta, \mu, \phi, \xi\}$, and four curvature parameters, $\{\nu, \lambda, \kappa, \psi\}$,—are jointly calibrated to match the observed trajectories of fertility, marriage, schooling, and women's time allocation over the period 1970–2020, based on the objective function detailed below. Regarding the marriage joy shock, we assume that each male-female pair draws a shock from the Gumbel distribution $F(r)$ and calibrate its two defining parameters along with the preference parameters for married couples.

For the utility function of single households (2), we assign the same curvature parameters as those used for married households. For the weight parameters, we set $\alpha_g = 1$ for normalization, and then calibrate β_g and μ_g to match the time allocation patterns of single individuals in 1970.

Now we define the objective function to pin down preference parameters to be determined within the model. We need to determine ten preference parameters: four weight parameters and four curvature parameters that enter the utility function of married households, and two parameters for the marriage joy shock. Let $\boldsymbol{\theta} = \{\beta, \nu, \mu, \lambda, \phi, \kappa, \xi, \psi, \mathbf{a}, \mathbf{d}\}$ denote the vector of parameters, where $\mathbf{a}$ and $\mathbf{d}$ represent the location and scale parameters of the Gumbel distribution. We choose these parameters so that the model replicates the observed paths of key moments—fertility rates, marriage rates, schooling, and time allocation—over the period 1970–2020.

We choose $\boldsymbol{\theta}$ to minimize the sum of squared percentage deviations between the model-implied and data moments over time, formulated as follows:

$$\min_{\boldsymbol{\theta}} \left\{ \sum_i \sum_t \left(\frac{x_{it}^M(\boldsymbol{\theta}) - x_{it}^D}{x_{it}^D} \right)^2 \right\},$$

where $x_{it}^M(\boldsymbol{\theta})$ denotes the model-implied moment for variable $i \in \{k, m, s, l_f, h_f\}$ in year $t \in \{1970, \ldots, 2020\}$ given parameters $\boldsymbol{\theta}$, and x_{it}^D represents the corresponding data moment. Resulting parameter values are summarized in Table 5, and the fit of the model to the data is presented in Section 5.1.

The model is overidentified, and changes in any parameter can affect all endogenous variables, since all choices are interconnected through the equalization of marginal conditions. Nevertheless, the levels and time variation of endogenous variables provide

[14] In Appendix D.1, we examine the robustness of the main results by additionally allowing for adjustments to the scale for children, where $\eta = 1.5 + 0.3k$.

identifying information for the parameter vector $\boldsymbol{\theta}$. First, time variation across years t for a given variable i helps identify its curvature parameter. To see this, consider the ratio of the first-order conditions (10)–(14) evaluated at two different years. Time variation in the variable, together with changes in the associated shadow prices, generates the variation necessary to identify the curvature parameter. By contrast, the overall magnitude of a variable relative to other variables helps identify the corresponding weight parameter. From the first-order condition, matching the level of a variable requires adjusting either the weight parameter or the curvature parameter. Once the curvature parameter is pinned down by time variation, cross-variable differences in magnitudes serve to identify the weight parameter, conditional on curvature.

4.1.2 More Details on Data Targets

As described above, we need data for target moments related to fertility, marriage, time allocation and schooling to pin down the values of preference parameters from the first order conditions.

Fertility and Marriage Rates: The average number of children per married couple, k_t, is computed as $k_t = TFR_t/m_t$, where TFR_t represents the total fertility rate at time t and m_t is the fraction of married individuals. The total fertility rates declined from 2.13 in 1970 to 1.33 in 2020, based on the Vital Statistics. The marriage probabilities fell from 0.967 in 1970 to 0.822 in 2020, based on the Population Census data. They imply the number of children per married couple falling from 2.203 in 1970 to 1.618 in 2020. These as well as the data between 1970 and 2020 are used as target moments.

Time Allocation: For data on the time allocation of single and married men and women, we use the Survey on Time Use and Leisure Activities and the data from individuals aged between 25 and 59.[15] For married women, the shares of total disposable time for market work, housework and leisure are 37.2%, 38.2%, and 17.5%, respectively, in 1970. The shares in 2020 are 30.6%, 32.3%, and 23.1%, respectively.

Schooling: We use the School Basic Survey to obtain the college enrollment rates between 1970 and 2020. The average rate of men and women rose from 0.169 in 1970 to 0.543 in 2020.

[15] https://www.stat.go.jp/data/shakai/2016/index.html

4.2 Home Production and Durable Goods

For the home production function (4), we follow McGrattan et al. (1997) and Greenwood et al. (2005) and set σ to 0.282.[16] ω is set for normalization so that the durable goods consumption in 1970 is 1.

The price index of housework-assisting durable goods declined at an annual rate of -5.75% between 1970 and 2020 and we use this value as the growth rate of durable goods price π_t. We set the price level in 1970 so that the average share of household expenditures of durable goods matches the data.

4.3 Costs of Childcare

The time for basic childcare, ζ_g, is computed based on the Survey on Time Use and Leisure Activities. We divide the average time spent for childcare by men and women, respectively, by the number of children per married couple k_t in each year.

The financial cost of basic childcare b is computed based on the sum of the fees for school and extracurricular activities. The data is obtained from the Survey on Children's Learning Expenses conducted by the Ministry of Education, Culture, Sports, Science and Technology.[17]

The cost of education χ represents the costs of sending a child to college. We use the data from the Student Life Survey conducted by the Japan Student Services Organization (JASSO), and compute it as the sum of the tuition fees and living costs of a student enrolled in a college. See Appendix A for more details about the data source and composition of the cost of education.

4.4 Production Technology

In the production technology, there are two time-invariant parameters (φ, γ) that govern the substitutability across different labor inputs, and four time-varying parameters

[16] There are several empirical studies that estimate the home production function and the elasticity between time spent at home and goods and services that can be purchased in the market. The empirical studies in the literature suggest that the elasticity varies by the type of goods and services considered. See, for example, Aguiar and Hurst (2007), Gardes (2019), and Cossu et al. (2023). These estimates, however, do not exactly correspond to the elasticity between the housework hours and housework-assisting durable goods that fits our model.

[17] Note that b includes education expenditures before high school graduation, and costs for cram schools and tutoring. Some of these may be aimed at preparing for college entry. However, we are unable to identify the specific purpose of these expenditures. On average, spending on cram schools and tutoring accounts for about 2% of annual household income, which is relatively low compared to countries like Korea (around 7%, according to Kim et al. 2024). In terms of trends, these expenditures on cram schools and tutoring have remained stable over time, whereas college tuition has increased much more rapidly relative to the income growth. For these reasons, we believe it is reasonable to separate the basic financial cost from the college education cost.

$\{Z_t, A_t, A_{f,t}, B_t\}_t$ that capture the productivity levels of each labor input. For the former, we set $\varphi = 0.7$ following the estimates reported in Taniguchi and Yamada (2023), which use data from OECD countries, including Japan. The value implies an elasticity of substitution between low and high skill labor of around 3.5, which is in the range of estimates in the literature. We set γ, which is related to the elasticity between male and female labor, to 0.7, also following Taniguchi and Yamada (2023).

We calibrate the four time-varying parameters to match the wage level of each labor input, thereby replicating the observed evolution of the wage structure over the past 50 years. First, Z_t stands for the level of general productivity, or what is referred to in this study as TFP. Second, A_t and $A_{f,t}$ represent the productivity levels specific to skilled-labor, which govern the SBTC. A_t applies to both men and women's skilled-labor inputs and $A_{t,f}$ applies only to women's. Lastly, B_t represents the productivity level specific to female labor supply of both skill types, which governs the GBTC.

The data from the Employment Status Survey (ESS) is used to obtain the wage of workers by skill and gender.[18] We then compute the time paths of the productivity levels, Z_t, A_t, $A_{f,t}$, and B_t, such that the baseline model replicates the time paths of wage rates across gender and skill, $\{w_{m,l,t}, w_{m,h,t}, w_{f,l,t}, w_{f,h,t}\}_t$. In doing so, we assume that wage rates grow at a constant rate between 1970 and 2020. The targeted wage levels in 1970 and 2020, along with the implied growth rates, are reported in Table 2.

First, the gender-biased technology level B_t is computed for each t from the ratios of female and male low-skill wage equations:

$$\frac{w_{f,l,t}}{w_{m,l,t}} = B_t \left(\frac{L_{f,t}}{L_{m,t}}\right)^{\gamma-1}$$

Here, the wage ratio on the left-hand side is observed in the data for each year t, while the labor inputs on the right-hand side are derived from the baseline model. With B_t, we also compute the gender-specific skill-biased technology level $A_{f,t}$ from the high-skill wage equations:

$$\frac{w_{f,h,t}}{w_{m,h,t}} = A_{f,t} B_t \left(\frac{H_{f,t}}{H_{m,t}}\right)^{\gamma-1}$$

We then derive the aggregate low and high-skill labor L_t and H_t for all t using (19) and (20), and obtain the general skill-biased technology level A_t from the ratios of low and high-skill wage equations:

$$\frac{w_{m,h,t}}{w_{m,l,t}} = A_t \left(\frac{H_t}{L_t}\right)^{\varphi-\gamma} \left(\frac{H_{m,t}}{L_{m,t}}\right)^{\gamma-1}$$

[18]The ESS has information about the gender-specific wage for the skill types that correspond to our definition of low and high skills since 1982 only. Therefore we use the real wage index of the Monthly Labour Survey in the 1970s to extrapolate the wage rate of each type.

Finally, we set Z_t to the path of $w_{m,l,t}$. We set Z_t in the initial period of 1970 so that $w_{f,l,0} = 1$ for normalization.

$$w_{m,l,t} = Z_t \left[L_t^{\varphi} + A_t H_t^{\varphi}\right]^{\frac{1}{\varphi}-1} L_t^{\varphi-\gamma} L_{m,t}^{\gamma-1}$$

As discussed in Section 3.6, aggregate labor supply by gender and skill is determined by households' labor supply and education decisions. However, when labor inputs are computed solely from these decisions, the implied labor composition need not match the data. In the model, schooling s matches the college graduation rates during the transition, which also determine the contemporaneous skill composition. In the data, by contrast, the share of skilled workers reflects the stock of college-educated workers across all cohorts, incorporating educational decisions made decades earlier – an aspect that the model's static structure cannot capture.

While the model is internally consistent, this discrepancy between model-implied and observed labor inputs can bias the calibration of technological parameters. To address this issue, we introduce adjustment factors that absorb the gap between model-implied and observed labor inputs in the baseline economy. This allows the model to replicate not only wage dynamics but also the observed labor composition by skill and gender, thereby identifying technological parameters based on the empirical labor composition.[19] Further details are provided in Appendix E.

[19] To construct labor inputs by gender and skill in 1970 and 2020, we use the ESS to obtain average hours worked by skill and gender, and the Population Census to measure the total number of workers in each group. As in the wage calculations, we assume that total hours worked evolve at a constant rate between the two years.

Table 4: Calibration Parameters

	Description	Value
Preference		
ρ, α	Curvature and weight: consumption (married)	2.0, 1.0
ν, β	Curvature and weight: home goods (married)	2.007, 0.054
λ, μ	Curvature and weight: leisure (married)	0.113, 0.433
κ, ϕ	Curvature and weight: child (married)	2.085, 0.206
ψ, ξ	Curvature and weight: child quality (married)	0.969, 0.132
β_g	Weight: home goods (single)	0.001 (men)
		0.049 (women)
μ_g	Weight: leisure (single)	0.867 (men)
		2.040 (women)
Childcare Costs		
$\zeta_{m,t}$	Basic childcare time (men)	0.002 (1970), 0.017 (2020)
$\zeta_{f,t}$	Basic childcare time (women)	0.032 (1970), 0.086 (2020)
b_t	Basic childcare fin. cost	0.053 (1970), 0.081 (2020)
χ_t	Education cost	0.059 (1970), 0.124 (2020)
Home Production		
σ	EOS b/w durables and housework	0.282
ω	Share of durables	0.0161
π	Durable goods price	-0.0575 (growth)
Market Production and Technology		
Z_t	Neutral technology	0.0033 (growth)
A_t	High-skill productivity (SBTC)	0.0051 (growth)
$A_{f,t}$	High-skill productivity (women) (SBTC)	0.0099 (growth)
B_t	Women's productivity (high) (GBTC)	0.0045 (growth)
φ	EOS b/w low and high-skill labor	0.70
γ	EOS b/w men and women	0.70
Other Parameters		
η	Equivalence scale	1.5
d, a	Marriage joy shock distribution	0.740, -1.285

5 Numerical Results

This section presents the numerical results of our model. First, we present the outcome of the baseline model, and then show how various factors of the model contribute to the trends of key variables. We achieve this by simulating the transition while eliminating or changing the magnitude of each factor one by one, keeping all the other elements unchanged from the baseline model. More precisely, we will consider the roles of different types of technological changes and various costs related to childcare.

5.1 Baseline Model

Table 5 shows the results for the baseline model in 1970 and 2020, with the data counterpart. As discussed in section 4, preference parameters are calibrated to match the data targets for marriage probability, fertility rate, and time allocated for market work, housework and leisure of married women over the fifty-year period between 1970 and 2020. The model's outcome aligns well with the data. For singles, we assume the same curvature parameters as married couples, and set the weight parameters to target time allocation data in 1970. Both market hours and housework hours decline and leisure time increases in 2020 in line with data of singles.

Table 5: Baseline Model and Data

		Data		Model	
Variable	Description	1970	2020	1970	2020
Marriage and Fertility					
m	Fraction of married	0.967	0.822	0.982	0.843
k	Number of children	2.203	1.618	2.009	1.600
–	Total fertility rate	2.130	1.330	1.972	1.349
Time Allocation of Married Households					
hr	Market work hours (men)	0.775	0.715	0.775	0.715
	Market work hours (women)	0.372	0.306	0.398	0.334
h	Housework hours (men)	0.007	0.021	0.007	0.021
	Housework hours (women)	0.382	0.323	0.368	0.294
l	Leisure (men)	0.213	0.237	0.213	0.237
	Leisure (women)	0.175	0.231	0.168	0.234
Time Allocation of Single Households					
hr	Market work hours (men)	0.715	0.663	0.715	0.576
	Market work hours (women)	0.639	0.584	0.639	0.477
h	Housework hours (men)	0.037	0.030	0.037	0.029
	Housework hours (women)	0.148	0.119	0.148	0.125
l	Leisure (men)	0.249	0.307	0.249	0.395
	Leisure (women)	0.213	0.297	0.213	0.397
Schooling					
s	Fraction of college graduates	0.169	0.543	0.215	0.604

Figure 4 shows the model's predicted paths of married women's time allocation, which are compared with the data. The model generates a secular decline in married women's time spent on housework, a mild decline in their market work and a gradual increase in leisure time in line with the transition of the data. The time for childcare increases throughout the transition, while the number of children declines between 1970 and 2020.

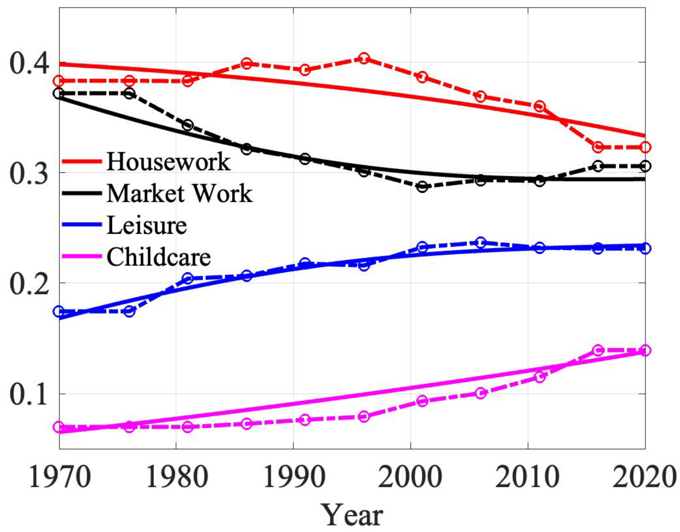
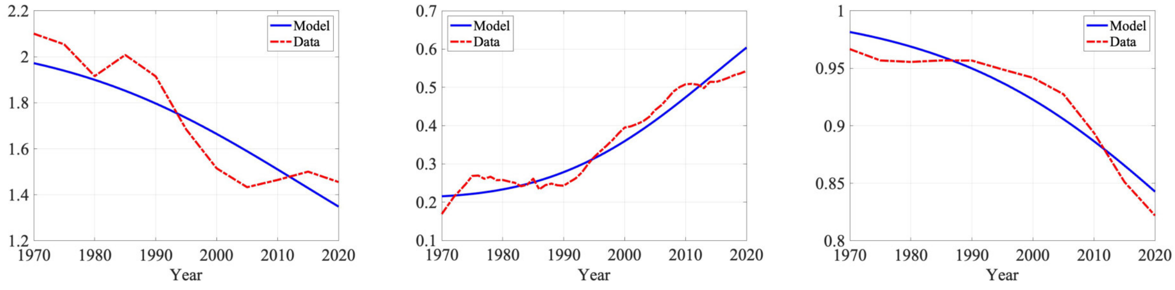


Figure 4: Time Allocation of Married Women: Baseline Model (lines) and Data (circles)

Figure 5 shows the trend of family formation and educational attainment in the model and data, represented by the shift in total fertility rates, college enrollment rates and marriage rates in each plot. Married couples choose to have fewer children over time, which is driven by the evolution of the financial cost of childcare and the opportunity cost of raising children, as represented by the change in women's wages driven by the skill- and gender-biased technological changes.

The marriage rates decline over time, as shown in Figure 5(c), as the relative attractiveness of being married wanes. The merit of marriage stems from the possibility of having children and enjoying their quantity and quality, and the ability of sharing resources to exploit economies of scale in consumption of home and market goods. The decline in the optimal number of children, higher wage rates due to technological growth, and cheaper input of home production to substitute housework all work in favor of deciding to remain single in our model.

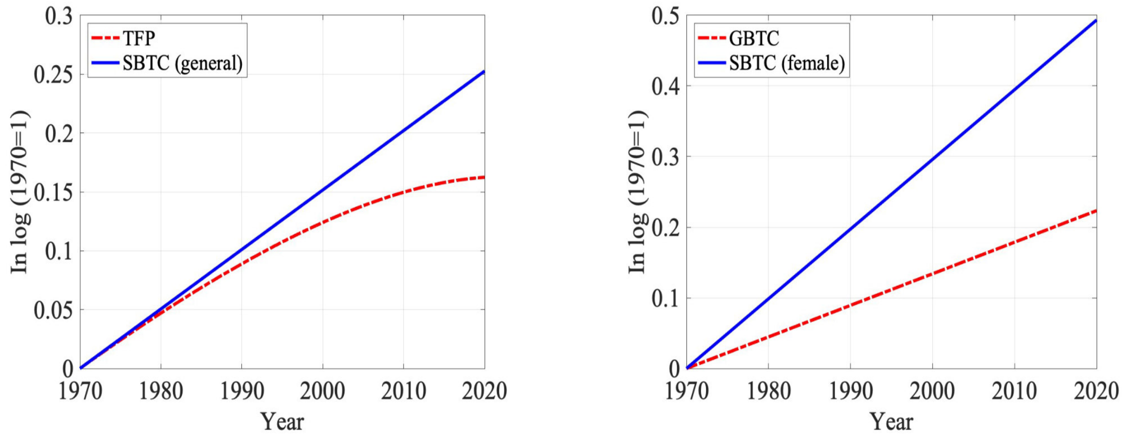
The model also generates the rising investment in education, following the upward trajectory of the share of college graduates in the data, as shown in Figure 5(b). Given the rising fixed cost of children and higher income, parents choose to give children higher education over having more children, tilting the quantity-quality trade-off toward the latter.



(a) Total Fertility Rate (b) Schooling (c) Marriage Rate

Figure 5: Fertility, Marriage and Schooling: Baseline Model and Data

As described in Section 4.4, we compute the technology level B_t, $A_{f,t}$, A_t, and Z_t from the gender- and skill-specific wages and labor supply of each type of worker. Using data from 1970 and 2020 and assuming that wages and labor supply grow at a constant rate, the paths of the four technology levels are given as in Figure 6. The annualized growth rates between 1970 and 2020 are 0.33%, 0.51%, 0.99%, and 0.45% for Z_t, A_t, $A_{f,t}$, and B_t, respectively, as reported in Table 4.



(a) TFP and SBTC (general) (b) GBTC and SBTC (female)

Figure 6: Technological Growth

Our calibration results indicate that technologies specific to female labor supply (i.e., $A_{f,t}$ and B_t) grew faster than neutral technology. While this result naturally arises given that gender wage gaps have shrunk substantially over the past decades, one might wonder what technological changes specific to women account for such a divergence. Several studies reveal the differing comparative advantages between men and women in market production. Men typically excel in 'brawn' tasks that require physical skills, while women exhibit more strength in 'brain' tasks utilizing more communication and soft skills. These studies demonstrate that technologies and industrial structures have developed in ways that favor women' comparative advantage, such as the rise of service economies (Galor and

Weil 1996, Ngai and Petrongolo 2017, Rendall 2018) and information and communication technology (Autor et al. 1998, Taniguchi and Yamada 2023).[20] In this paper, we are agnostic about the concrete sources of technological changes. Our aim is to capture the underlying technological changes that replicate the evolution of wage structure across genders and skills to examine their implications for family and demographic trends.

In the next section, we simulate various scenarios in which the technological growth is assumed to follow alternative paths.

5.2 Roles of Technology

In this section, we investigate how the technological progress during the last half century may have affected the trends of women's time allocation and family formation. We consider alternative paths of wage rates by assuming a different technological process and simulate the transition of the model which is otherwise identical to the baseline model.

We run counterfactual experiments under five alternative scenarios about technology. First, we assume that the level of general technology, or the TFP, will remain at the same level as in 1970, that is, $Z_t = Z_{1970}$ for all t. Second, we mute the general SBTC and set $A_t = A_{1970}$, and third, we set $A_{f,t} = A_{f,1970}$ throughout the transition. Fourth, we assume that there is no GBTC and set $B_t = B_{1970}$. Finally, we assume that there is no progress in the home production technology and the price of housework-assisting durable goods stays at the same level throughout the transition.

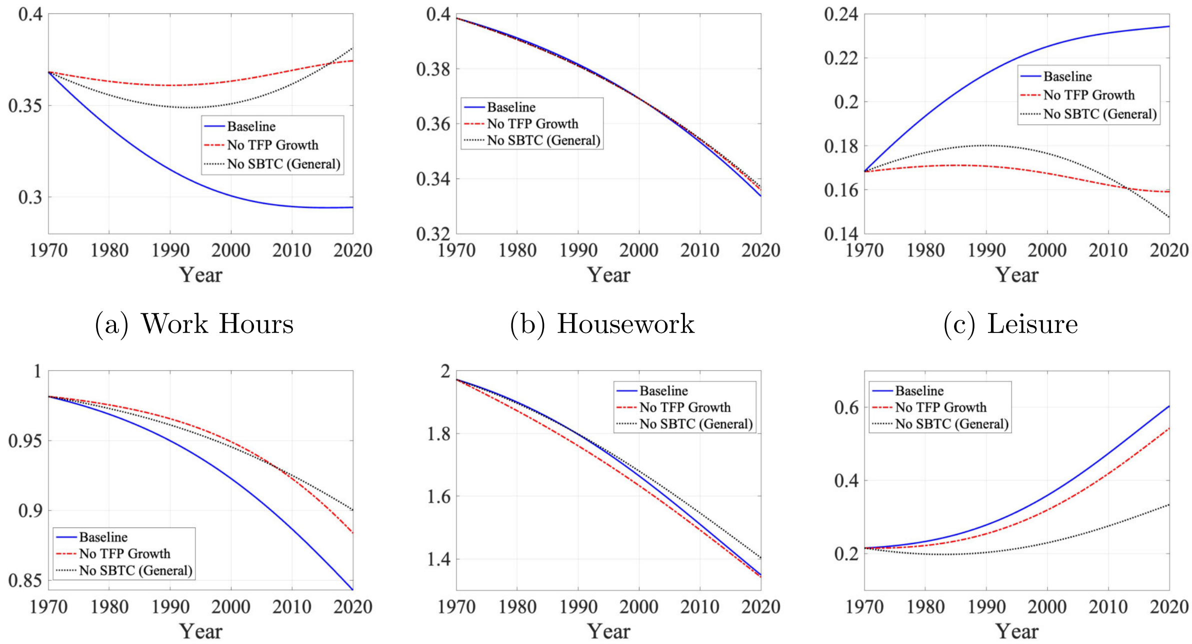
In the experiments, wages adjust not only to the alternative productivity paths but also to endogenous changes in labor supply to satisfy the equilibrium wage equations. Distribution of labor supply evolves according to individuals' endogenous responses in work hours and a shift in skill distribution driven by the education investment.

Roles of Production Technology: Figure 7 shows the paths of married women's time allocation to market work, home production, and leisure, as well as the paths of marriage rates, total fertility rates, and schooling under the first two experiments about technological progress. When there is no TFP growth or general skill-biased technological change, household income will be significantly lower as husbands' earnings decline. Although women's wages are also lower, income effects dominate and married women increase work hours and reduce leisure time.

Under both experiments, schooling is also lower, since they are not able to afford as much education as in the baseline given the lower household income. The decline is more pronounced without the general SBTC, as households not only suffer from low income but also no longer enjoy the higher return to skill from their investment in children's education, and they have lower incentives to spend financial resources on education. Fertility rates

[20] See also Johnson and Keane (2013) and Rendall (2024).

do not change much. Income effects reduce fertility rates in the same direction as they reduce leisure and schooling, but the decline in the opportunity costs of childcare time has positive effects on fertility and offsets the negative effects, resulting in a muted response.



(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 7: Roles of Technology: No TFP Growth and No SBTC (general)

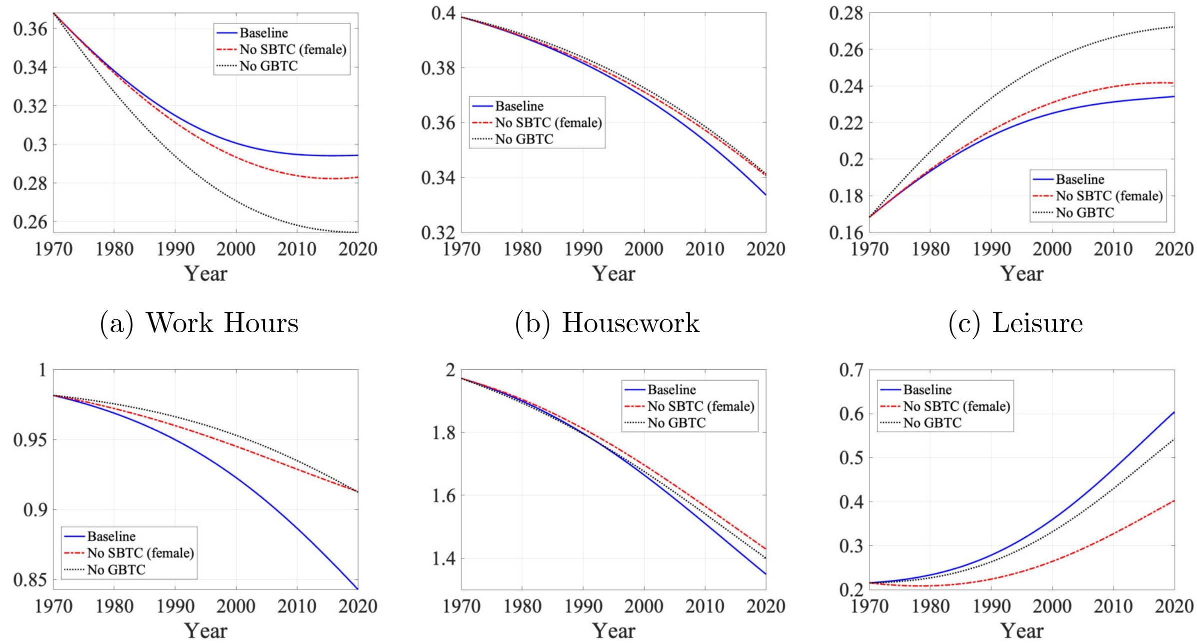
Note: "No TFP Growth" and "No SBTC (general)" show the paths of variables when the TFP level and general skill-biased technology are fixed at 1970 levels, respectively. The top three panels show married women's time allocation to work hours, housework and leisure.

Figure 8 shows the results when there is no skill-biased technological change specific to female workers (female SBTC) and when there is no gender-biased technological change (GBTC). Under these two scenarios, women's productivity in the market declines while mens' productivity remains unaffected. Couples respond to this change by reducing work hours of women and allocating more time to housework and leisure. As summarized in Table 6, married women's market work in 2020 shifts from 29.4% of total time in the baseline to 28.3% without the female SBT and to 25.4% without the GBTC. Hours for leisure will increase from 23.4% in the baseline model to 24.2% and 27.2% without the female SBT and the GBTC, respectively.

The lack of female SBTC and GBTC lowers women's wage and more directly deteriorates the economic conditions of single women compared to those of married women. Therefore, marriage becomes more attractive to women, resulting in higher marriage rates as shown in Figure 8(d). Under these scenarios, women's wages are lower, and fertility rates are slightly higher than in the baseline model, driven by a rise in the marriage rates.

Regarding the decision of education investment, Figure 8(f) shows that schooling declines during the transition with no female SBTC and GBTC. The effect is more pronounced under the scenario of no female SBTC, in which the productivity decline is concentrated among high-skilled women. If women's wages are low, the time cost of basic childcare is lower in terms of their lost market opportunities, and the demand of families regarding children tilts toward quantity of children.

Taken together, these numerical exercises indicate that technological change has contributed to the decline in fertility over the past 50 years. Quantitatively, SBTC and GBTC jointly account for about 30% of the overall decline in the TFR between 1970 and 2020. In particular, general SBTC, female-specific SBTC, and GBTC reduce the TFR by 0.054, 0.080, and 0.051, respectively, for a combined decline of 0.185 points. Given that the TFR fell by 0.623 points (= 1.972 − 1.349) over this period, these technological changes explain roughly 30% of the total decline. Among them, technological changes related to female labor supply—GBTC and female-specific SBTC—account for about 21% of the overall fertility decline, while the remaining 9% is due to general SBTC.



(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 8: Roles of Technology. No SBTC (female) and No GBTC

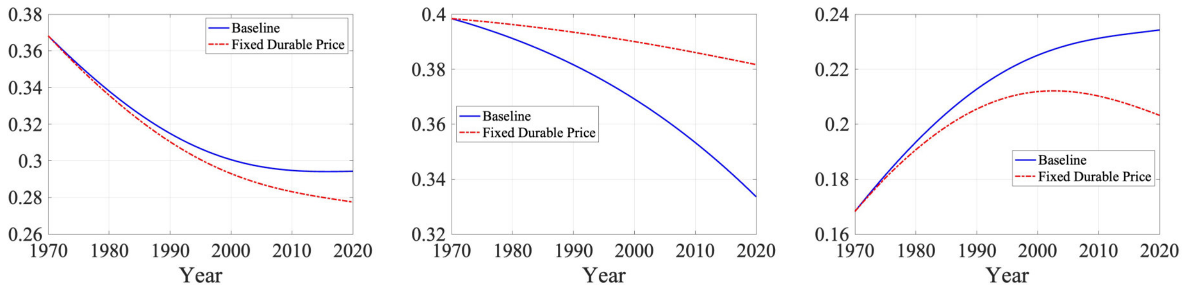
Note: "No SBTC (female)" and "No GBTC" show the paths of variables when the skill-biased technology for female and gender-biased technology are fixed at 1970 levels, respectively. The top three panels show married women's time allocation to work hours, housework and leisure.

Table 6: Roles of Technology

	1970	2020	TFP	SBT general	SBT female	GBT	Dur. Price
Family and Education							
Fertility (TFR)	1.972	1.349	1.342	1.403	1.429	1.400	1.350
Schooling	0.215	0.604	0.543	0.334	0.402	0.542	0.606
Marriage	0.982	0.843	0.884	0.900	0.913	0.912	0.845
Time Allocation of Married Women							
Work Hours	0.368	0.294	0.374	0.381	0.283	0.254	0.278
Leisure	0.168	0.234	0.159	0.147	0.242	0.272	0.203
Housework	0.398	0.334	0.335	0.337	0.341	0.341	0.382
Childcare	0.065	0.138	0.131	0.134	0.135	0.132	0.138

Note: In each experiment, one of the technological process (TFP growth, general SBTC, female-SBTC, GBTC, and home production technology) is held fixed at the 1970 level, while everything else is as in the baseline economy in 2020.

Roles of Home Production Technology: We now consider the roles of the advancement of home production technology. As shown in Figure 3, the price of housework-assisting durable goods rapidly decreased throughout the last half century and contributed to a decline in the cost of producing home goods. To quantify the effects of the price change, we simulate the transition assuming that the price of housework-assisting durable goods stays at the same level as in 1970, $\pi_t = \pi_{1970}$ for all t. The long-run effects are shown in the last column of Table 6, and Figure 9 displays the paths of time allocation of married women. As shown in Figure 9(b), the large decline in the housework hours of married women disappears. The rise of housework hours relative to the baseline model is compensated by a decrease in market work hours and leisure.



(a) Work Hours (b) Housework (c) Leisure

Figure 9: Roles of Home Production Technology

5.3 Childcare Costs

As discussed in Section 2, households have faced rising costs of childcare both in terms of financial expenses and parental time during the last several decades. In this section, we consider three alternative scenarios in which these costs grow more slowly during the transition.

In the first scenario, we assume that the increase in married women's childcare time per child is limited to half of the increase in the baseline model. More precisely, we let the time for childcare increase by 48% between 1970 and 2020 in the experiment instead of 96%. In the second scenario, the growth in the basic financial cost of childcare b_t is assumed to be half of that of the baseline model. In the third scenario, we allow the cost of education χ_t, required to equip children with high skills, to rise more slowly, at the half the speed of the baseline, so that the education costs would increase by 54% over the 50-year period, instead of the 108% assumed in the baseline model.

Figure 10 shows the effects of alternative childcare cost under the three scenarios, compared to the baseline. Long-run effects of key variables are summarized in Table 7.

As shown in Figure 10(f), when the education cost is lower, married couples would raise the investment in education. Although the education cost is lower, the total fertility rate remains almost unchanged, as parents choose to allocate more resources to education and quality of a child rather than quantity, to exploit the lower cost of schooling.

However, the opposite responses occur when the cost of basic childcare is lower, both in terms of time and money. As shown in Figure 10(e), parents would have more children compared to the baseline transition and instead reduce their investment in education of each child.

In terms of married women's time allocation, when they face lower time costs of basic childcare, they are able to spend more time market work, whereas the opposite is true when the financial cost of basic childcare is low, as shown in Figure 10(a). Higher fertility in the latter scenario is accompanied by more time spent by married women on childcare and a decline in work hours.

Since we take into general equilibrium effects, a rise in education investment leads to a rise in high-skilled labor, compressing the skill premium. As a result, the positive effects on schooling is diminished, although the net effect remains positive. Similarly, negative effects on education investment are mitigated through general equilibrium effects under the two scenarios of low basic time and financial costs.

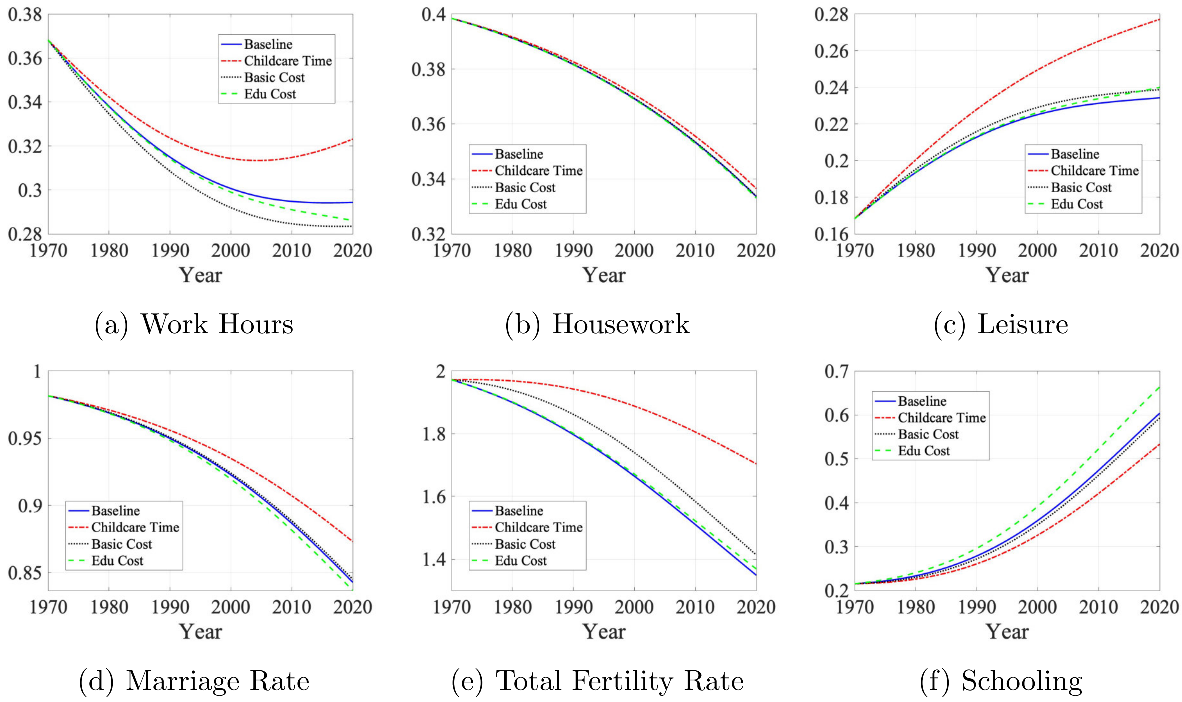


Figure 10: Roles of Childcare Cost

Table 7: Roles of Childcare Costs

	1970	2020	Basic Time	Basic Money	Edu Cost
Family and Education					
Fertility (TFR)	1.972	1.349	1.704	1.414	1.369
Schooling	0.215	0.604	0.533	0.593	0.664
Marriage	0.982	0.843	0.873	0.845	0.837
Time Allocation of Married Women					
Work Hours	0.368	0.294	0.323	0.283	0.286
Leisure	0.168	0.234	0.277	0.239	0.240
Housework	0.398	0.334	0.336	0.334	0.333
Childcare	0.065	0.138	0.063	0.144	0.141

Note: In each experiment, one of the childcare cost is assumed to be low, while everything else is as in the baseline economy in 2020.

It is important to exercise caution in interpreting the quantitative results presented in this section and to consider potential avenues for further research as extensions of the current study. We focus on the decisions made by households, assuming that the changes in wages, durable goods prices, and time and financial costs of childcare, and education costs are taken as given. However, the time and money parents spend on basic childcare for each child may well be endogenously chosen by them. Furthermore, the prices of childcare or education may well be determined in the market, reflecting the shifts in underlying fundamentals, similar to how wages are determined in the labor market.[21]

If the government were to implement policies aimed at reducing the time or financial costs of childcare, our model suggests that parents would reallocate the saved resources toward some other economic activities. However, in a model with endogenous childcare costs, parents may respond to the policy change by spending additional money and effort per child. Moreover, the increased demand for childcare resulting from the reform may influence the price of childcare services. The continuous increase in childcare time and financial costs over an extended period, at a rate surpassing income growth, suggests that such a response is possible.

The results of the experiments in this section can also be interpreted to imply that the fact that parents face the necessity to allocate more time and resources into raising a child compared to 50 years ago critically affects the optimal number of children that they choose to have. To fully account for the endogenous evolution of childcare costs and efforts, a richer model is needed and this is something we leave for future research.

5.4 Roles of the Unified Framework

One of the main contributions of this paper is the development of a unified framework that jointly incorporates family formation, household time allocation decisions, and technological progress both at home and in the market. In this section, we simulate the model under alternative specifications in which some of these elements are treated as exogenous, in order to highlight the role of the unified framework. These experiments provide insight into the interactions across key margins of household choices, including educational investment, time use, marriage, and fertility, and demonstrate the importance of accounting for these interactions when analyzing drivers of family dynamics.

We consider four cases: (1) exogenous schooling, (2) exogenous time allocation for market work and housework, (3) exogenous marriage, and (4) exogenous fertility among married couples. In each case, we fix one variable: education (s), hours of market work and housework h_f, marriage m, or fertility k, respectively, at its 1970 level and solve the model for the 2020 economy.

We first compute the baseline outcomes under each of the four exogenous scenarios. In these scenario-specific baseline simulations, other time-varying components, such as tech-

[21]Studies have considered the factors contributing to the increasing costs of education observed over the past decades. Jones and Yang (2016) construct a general equilibrium model that incorporates skill and sector-biased technological changes to investigate the impact of technology on college costs and educational attainment in the U.S. Cai and Heathcote (2022) develop a model of the college market and demonstrate that the growing income inequality has been a significant driver of tuition hikes in the U.S. since 1990.

nological progress and education costs, follow the calibrated paths used in the benchmark economy, while only the selected variable is fixed exogenously. We then conduct counterfactual experiments under alternative paths of technological parameters and examine how the effects of technological developments differ from those obtained in the benchmark model.

To clarify the computational procedure and interpretation of the results, we note two points. First, when considering exogenous time allocation for market work and housework, we do not fix leisure time. Because fertility remains endogenous in this experiment, total childcare time is also endogenous. Fixing time in all other activities would therefore violate the time constraint. Since the time constraint is central to fertility decisions and the focus of this experiment is on endogenous time allocation for work, we allow leisure time to adjust to satisfy the time constraint. Second, in the experiment of exogenous fertility, childbearing decisions among married couples are fixed. However, the total fertility rate (TFR) continues to vary endogenously because marriage decisions remain endogenous in this experiment.

Table 8 summarizes the key results for the cases with exogenous schooling and exogenous time use. Results for the cases with exogenous fertility or exogenous marriage are reported in Table 10 in Appendix B. The columns under "Benchmark" in Table 8 reproduce the results presented above for the benchmark model. The columns labeled "Exogenous Schooling 2020" and "Exogenous Time Use 2020" first report the baseline results in which the only difference from the benchmark is that one key variable, schooling or time use, is held fixed at its 1970 level, while other time-varying parameters, including technological progress, follow the calibrated paths used in the benchmark economy.

Both exogenous schooling and exogenous time use generate a higher TFR in 2020 relative to the 2020 benchmark model with all variables endogenous (column "Benchmark 2020"). For example, exogenous time use implies a TFR of 1.782 in 2020, which is 32% higher than in the benchmark model with endogenous time allocation. With working hours fixed both at home and in the market, leisure time is substantially lower. Because they do not reduce market work hours as observed in the data, they earn higher income, which increases fertility through an income effect.

The rows labeled "No GBTC" and "No SBTC (female)" in Table 8 report results in which these technological changes are shut down. A key finding is that ignoring endogenous adjustments in education or time allocation generates substantial bias in attributing the drivers of a fertility decline.

For example, under exogenous schooling, the TFR declines from 1.972 to 1.459 over 50 years. Shutting down female SBTC raises the TFR in 2020 to 1.473, only 0.014 points above the baseline of 1.459. This increase implies that female SBTC account for only 2.7% of the fertility decline of 0.513 (= 1.972 − 1.459), suggesting a limited impact of SBTC on fertility. With education fixed, SBTC does not generate a strong substitution from the quantity to the quality of children as observed in the benchmark model, thereby understating its effect on fertility decline.

By contrast, the role of technological change is overstated when time use is treated as exogenous. Under exogenous time use, the TFR declines from 1.972 to 1.782 between 1970 and 2020, corresponding to a decline of only 9.6%. Shutting down GBTC and female SBTC yields TFRs of 1.853 and 1.883 in 2020, which are 3.8% and 5.7% higher, respectively, than the baseline value of 1.782. If these effects were additive, they would imply a combined increase of 9.5% (= 3.8% + 5.7%), suggesting that almost the entire fertility decline (9.5% out of 9.6%) would be attributed to these two technological changes.

The intuition for this overestimation is straightforward. When time use is exogenous, the importance of other mechanisms, particularly the time and monetary costs of children, is substantially diminished. The time cost becomes less relevant when households do not face a trade-off between market work and childrearing. The monetary cost is also less binding because fixed and relatively high working hours generate higher income. As a result, under exogenous time use the TFR declines by only 9.6% over 50 years, with most of the decline attributed to technological change rather than to adjustments in the time costs of children.

Table 8: Importance of the Unified Framework: (GBTC and female-SBTC)

	Benchmark 1970	Benchmark 2020	Exogenous Schooling 2020	Exogenous Time Use 2020
Baseline				
Fertility (TFR)	1.972	1.349	1.459	1.782
Schooling	0.215	0.604	0.215	0.608
Marriage	0.982	0.843	0.897	0.848
Work Hours	0.368	0.294	0.348	0.368
Leisure	0.168	0.234	0.174	0.052
Housework	0.398	0.334	0.337	0.398
No GBTC				
Fertility (TFR)	1.972	1.400 (+0.051)	1.481 (+0.022)	1.853 (+0.071)
Schooling	0.215	0.542 (−0.062)	0.215 (0.000)	0.554 (−0.054)
Marriage	0.982	0.912 (+0.069)	0.952 (+0.055)	0.927 (+0.079)
Work Hours	0.368	0.254 (−0.040)	0.304 (−0.044)	0.368 (0.000)
Leisure	0.168	0.272 (+0.038)	0.217 (+0.043)	0.061 (+0.009)
Housework	0.398	0.341 (+0.007)	0.344 (+0.007)	0.398 (0.000)
No SBTC (female)				
Fertility (TFR)	1.972	1.429 (+0.080)	1.473 (+0.014)	1.883 (+0.101)
Schooling	0.215	0.402 (−0.202)	0.215 (0.000)	0.415 (−0.193)
Marriage	0.982	0.913 (+0.070)	0.924 (+0.027)	0.923 (+0.075)
Work Hours	0.368	0.283 (−0.011)	0.329 (−0.019)	0.368 (0.000)
Leisure	0.168	0.242 (+0.008)	0.193 (+0.019)	0.057 (+0.005)
Housework	0.398	0.341 (+0.007)	0.340 (+0.003)	0.398 (0.000)

Note: Columns "Benchmark" report the results with technological change, allowing all choice margins for married households—fertility, schooling, and wife's time allocation—to adjust endogenously (i.e., those reported in Table 6). Columns "Exogenous Schooling" and "Exogenous Time Use" refer to results in which schooling choices and time allocation to market work and housework are fixed at their 1970 levels.

5.5 Extension of the Analysis to Other Countries: The Case of Korea

In this subsection, we examine whether the model can replicate the trends in family formation and women's time allocation in other countries, thereby serving as a validation exercise and supporting the model's credibility. We choose Korea as an example since we can obtain the necessary data to simulate the model and compare the results to data covering a relatively long period of 20 years, from 1999 to 2019. Also, since births outside of marriage are rare in Korea as well, it is straightforward to apply our model, in which only married households make fertility decisions.

Although Japan and Korea have experienced similar qualitative trends in family formation and women's time allocation, the quantitative changes have been different. For example, Korea has been experiencing a more dramatic decline in fertility and a sharper increase in educational attainment over the last twenty years (See columns 1–2 in Table 9 for Korean data). The key questions are: (1) to what extent the model can replicate the long-run trends in family formation and women's time allocation observed in Korea, and (2) what explains the differences in the speed of the trends between Korea and Japan.

We first address the question (1) by simulating the model from 1999 to 2019, using Korea-specific values for the model's time-varying inputs—such as childcare costs, prices of household durable goods, and technological parameters that shape wage profiles. In contrast, we retain the curvature parameters of the utility functions that determine the elasticity of variables to changing environment at the values calibrated in our baseline model of Japan. We then assess how well the model tracks the changes in the key endogenous variables over the period. See Appendix C for details on the data sources, variable definitions, and values for the Korea-specific parameters.

Table 9 shows the values of key variables in the data in 1999 and 2019, and compare them to the model's outcome. Note that the levels of key variables in the initial year of 1999 exactly match the Korean data by adjusting the weight parameters in the utility function, making it easier to assess how well it replicates the observed trends. The fertility rate declines from 1.425 in 1999 to 0.918 in 2019 in the data, and about 70% of the observed changes is explained by the model. The model also accounts for the rise in college enrollment rates and the decline in marriage rates well. The model qualitatively captures the shift in married women's time allocations, though not perfectly in magnitude.

We then turn to the second question: what explains the differences in the speed of the trends between Korea and Japan, such as the relatively faster decline in fertility rates in Korea? To investigate this, we implement the same counterfactual experiments as in Sections 5.2 and 5.3, but now using Korean data—that is, we shut down technological changes and increases in childcare costs based on Korean data and solve for the implied time paths of each variable.

The results suggest that rising childcare costs—both in money and time—are important drivers of fertility decline, as is also the case in Japan. In Korea, however, time and monetary costs increased more rapidly—at annual rates of 2.1% and 7.4%, compared with 2.0% and 0.9% in Japan—largely accounting for the differences in the speed of the trends between the two countries. As explained in Appendices A and C, these costs include expenditures of time and money on children's pre-college education, such as private tutoring, in both countries. Although the sources of these increases are beyond the scope of this paper, their importance is consistent with influential work by Kim, Tertilt, and Yum (2024), which highlights private educational investments and their externalities as key mechanisms behind very low fertility in Korea.

Technological change has also contributed to declining fertility rates in Korea, but the relative importance of different technologies differs from the Japanese case. In Korea, SBTC (general) and the resulting quantity–quality trade-off plays the dominant role, rather than technological changes that favor female labor supply. Over the past 20 years, the real wage rate for women in Korea rose at an annual rate of 0.79%, lower than the 1.39% observed in Japan, even though the female share of labor inputs remained unchanged during the period (about 39% in both 1999 and 2019). Consequently, the resulting GBTC and female-SBTC are relatively small, and the contribution of technological changes that favor female labor supply to fertility decline is therefore limited in Korea.

Table 9: Baseline (Model and Data)

	Data		Model	
	1999	2019	1999	2019
Family and Education				
Fertility (TFR)	1.425	0.918	1.425	1.080
Schooling	0.485	0.694	0.485	0.701
Marriage	0.991	0.920	0.991	0.900
Time Allocation of Married Women				
Market work hours	0.230	0.204	0.230	0.221
Housework hours	0.264	0.254	0.264	0.241
Leisure	0.436	0.477	0.436	0.459

6 Conclusion

Many developed countries have experienced the secular decline in fertility and marriage rates, as well as a shift in women's time allocation, over the past half century. Simultaneously, technological advancements drove the dynamics of the wage structure, driven by the general productivity growth and skill and gender-biased technological changes. These factors have influenced the trade-off involved in the time and resource allocation decisions of families.

We develop a tractable model in which men and women make decisions regarding marriage, fertility, and time allocation for various activities, including market work, home production, leisure, and childcare. Married couples determine the number of children they have and how much they invest in their skill development while considering the time and financial costs of childcare and education.

We calibrate the model using macro and micro data from Japan, a country that has witnessed a significant decline in fertility and marriage rates, and a reduction in the average family size over the past five decades. Our quantitative analysis reveals that technological progress that favors female labor supply contributes to declines in fertility and marriage rates. Neutral and general skill-biased technological growth leads to a decline in work hours and a rise in leisure time of married women. A rise in education levels is largely explained by the SBTC and a general increase in income level. Furthermore, we find that an increase in the financial and time costs of basic childcare results in lower fertility rates. Without a rise in education costs, college enrollment rates would have been even higher, though the effects on fertility rates would have been negligible.

The analysis demonstrates that accounting for the trends of family formation and time allocation is not simple, and emphasizes the importance of considering the interaction of various micro and macro factors surrounding families. Changes in technology and the wage structure play a crucial role in determining the dynamics of household income and the opportunity costs associated with childcare and home production. The significant, yet decreasing, gender wage gap influences decisions regarding women's time allocation among different activities. Furthermore, the advancement of home production technology has significantly reduced the burden of housework. Additionally, the increase in the time and financial costs of childcare directly affects the trade-off between quantity and quality faced by parents. This study presents a model that takes into account these forces and their interplay within a comprehensive framework.

Several factors are taken as given in this study and warrant further explanation. In particular, we do not investigate the underlying drivers of the observed trends in factor-biased technological change in both market and home production, nor the shifts in key family constraints such as childcare and education costs. Notably, we show that childcare time has increased substantially since the 1970s and has played an important role in shaping the evolution of marriage and fertility rates. Incorporating mechanisms such as parental time investment in children's human capital or evolving preferences for parental time spent with children would be valuable extensions. These are important directions that we leave for future research.

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A Data Targets

Marriage Rates We use the Population Census data to construct the time series of marriage rates. The Census survey is conducted every five years, and it records the shares of individuals across four different marital statuses (never-married, currently married, divorced and currently not married, and widows/widowers) for each gender and age group. We compute the fraction of ever-married individuals at age 50 every five years between 1970 and 2020 and use the average of the ratios calculated separately for men and women aged 45-49 and 50-54 as targets for calibration.

Time Allocation: The Survey on Time Use and Leisure Activities provides detailed information on individuals' time allocation at five-year intervals since 1976. We use the data to draw the time allocation patterns for men and women with different marital statuses, following the steps outlined below.

First, for each year, we calculate the time spent on four different activities (housework, childcare, leisure, and market work) for the age groups between 25 and 59 and for the four groups of individuals by marital status and gender (married men, married women, unmarried men, and unmarried women). Note that we let "leisure" include the combined time spent on activities such as "rest and relaxation," "hobbies and amusement," "sports," "volunteering and social activities," and "social life."

Second, for each year and individual group, we calculate the average time spent on each activity across age groups and compute the average, as an approximation of the lifetime allocation over different activities.

Finally, we calculate the share of total disposable time spent on each activity for each year. This process yields a time-series of lifetime allocation every five years between 1976 and 2016. For the year 1970, we assume the time shares to be the same as in 1976. Similarly, for 2020, we use the 2016 data. We chose not to include the latest data for 2021 due to concerns that the data may be irregular, as it reflects a period shortly after the onset of the COVID-19 pandemic.

Costs of Childcare The financial costs of basic childcare b are computed using the Survey on Children's Learning Expenses, since 1994. It records the average education expenditures for children before high school graduation under several categories, such as school and extracurricular activities. The income share of average childcare expenditures remained almost constant between 1994 and 2018, the last year before the COVID-19 pandemic. More precisely, we compute the average education expenditures for a child until the age of 18 and express them as the ratio to the lifetime income for married households (total labor earnings from age 25 to 59), based on the Family Income and Expenditure Survey. The ratio amounts to about 2.9% in each year between 1994-2018. Due to the data limitation for education expenditures in the years before 1994, we assume that the income share of child-related expenditures is constant across 1970-2020, including the years prior to 1994, since we do not have data for the period.

We use the Student Life Survey to set the education costs χ during the transition. According to the Survey's data in 2018, the average annual expenditure for college students amounted to 1.91 million yen, comprised of 0.93 million yen spent on college related-expenditures, such as tuition fees, and 0.98 million yen spent on living costs, such as housing and food expenses. While we obtained the time series of college tuition fees from the consumer price index, there are no other datasets that record other expenditures arising from college enrollment other than tuition fees, prior to 2004, when the survey started. Hence, we assume that the income share of the expenditures aside from tuition fees is constant throughout 1970-2020. Combining this and the price index for college tuition fees, we compute the total education costs χ for each year.

B Roles of the Unified Framework

As discussed in Section 5.4, we simulate the baseline model under alternative specifications in which one dimension of household behavior is treated as exogenous, thereby abstracting from endogenous decisions-making along that margin. We then simulate the model under the additional assumption of no GBTC and no female-SBTC to illustrate how counterfactual modeling assumptions can lead to different assessments of the effects of technological shifts.

Table 10 reports the results of two additional experiments, assuming exogenous fertility and exogenous marriage, respectively. As discussed in the main text, exogenous fertility refers to fixing fertility conditional on marriage; the total fertility rate (TFR) is therefore not fixed, since the marriage rate remains endogenous. Results for the cases with exogenous schooling and exogenous time use are reported in Table 8 in the main text.

Table 10: Importance of the Unified Framework: (GBTC and female-SBTC)

	Benchmark 1970	Benchmark 2020	Exogenous Fertility 2020	Exogenous Marriage 2020
Baseline				
Fertility (TFR)	1.972	1.349	1.694	1.573
Schooling	0.215	0.604	0.600	0.608
Marriage	0.982	0.843	0.843	0.982
Work Hours	0.368	0.294	0.311	0.305
Leisure	0.168	0.234	0.185	0.224
Housework	0.398	0.334	0.332	0.333
No GBTC				
Fertility (TFR)	1.972	1.400 (+0.051)	1.837 (+0.143)	1.510 (−0.063)
Schooling	0.215	0.542 (−0.062)	0.535 (−0.065)	0.547 (−0.061)
Marriage	0.982	0.912 (+0.069)	0.914 (+0.071)	0.982 (0.000)
Work Hours	0.368	0.254 (−0.040)	0.276 (−0.035)	0.263 (−0.042)
Leisure	0.168	0.272 (+0.038)	0.212 (+0.027)	0.264 (+0.040)
Housework	0.398	0.341 (+0.007)	0.339 (+0.007)	0.340 (+0.007)
No SBTC (female)				
Fertility (TFR)	1.972	1.429 (+0.080)	1.836 (+0.142)	1.540 (−0.033)
Schooling	0.215	0.402 (−0.202)	0.399 (−0.201)	0.404 (−0.204)
Marriage	0.982	0.913 (+0.070)	0.914 (+0.071)	0.982 (0.000)
Work Hours	0.368	0.283 (−0.011)	0.299 (−0.012)	0.289 (−0.016)
Leisure	0.168	0.242 (+0.008)	0.189 (+0.004)	0.236 (+0.012)
Housework	0.398	0.341 (+0.007)	0.338 (+0.006)	0.340 (+0.007)

Note: Columns "Benchmark" report results with technological change, allowing fertility, schooling, time allocation, and marriage choices to adjust endogenously (i.e., those reported in Table 6). Columns "Exogenous Fertility" and "Exogenous Marriage" fix fertility and marriage choices at their 1970 levels.

C Model Validation with Korean Data

In Section 5.5, we presented simulation results of our model calibrated to the Korean economy. In this section, we provide more details about the Korean data we used for the calibration.

We collect data on fertility, marriage, time use, education, wage rates, prices of household durable goods, and child-related costs from various sources in Korea covering the period from 1999 to 2019.[22]

Total fertility rate data are obtained from the World Bank. Marriage rate data are sourced from the United Nations, which provide the fraction of individuals who have ever married, disaggregated by year, age group, and gender. Age groups are reported in

[22] We observe irregularities in some variables in 2020, likely due to the effects of COVID-19. For this reason, we focus on the Korean economy over the 20-year period from 1999 to 2019.

five-year intervals, and we compute the marriage rate following the same method used for the Japanese data: for each gender, we approximate the marriage rate at age 50 by averaging the rates for the 45–49 and 50–54 age groups, and then take the simple average across genders. The data span from 1995 to 2015 in five-year increments, and we use the resulting time path of marriage rates.

College enrollment rates are obtained from Statistics Korea. We also use time-use data from Statistics Korea, which report hours spent on various activities by marital status. Consistent with our treatment of the Japanese data, leisure is defined as the sum of hours spent on "Voluntary Work and Community Participation," "Social Life / Recreation and Leisure," and "Travel (by purpose)." Wage rates and labor inputs by gender and skill over the past two decades are computed using data from the Korean Labor and Income Panel Study (KLIPS).

To construct prices of household durable goods, we follow the same procedure used for Japan, computing a weighted average of price indices for relevant goods, including microwave ovens, refrigerators, washing machines, vacuum cleaners, electric rice cookers, boilers, and small kitchen appliances, based on price index data from Statistics Korea. We calculate the time cost of children by dividing time spent on childcare by the fertility rate in each corresponding year.

We collect data on private education expenditures prior to college from 2007 onward using data from Statistics Korea. To obtain values for earlier years, we extrapolate data back to 1999 using the annual growth rate of private education expenditures calculated from the post-2007 data. We also collect data on college tuition fees from the Korean Council for University Education. Since data covering the full 20-year period are unavailable, we extrapolate tuition fees back to 1999 under the assumption of a constant growth rate over time. To pin down basic childcare and education costs (i.e., b and χ), we compute the total private education expenditures (through age 18) and total college tuition fees (assuming four years of enrollment), and divide each by a proxy for lifetime earnings of married households in the corresponding year. This proxy is constructed as the sum of household earnings from ages 25 to 59 in each year, based on the KLIPS data. Calibration parameters are summarized in Table 11.

Table 11: Calibration Parameters

	Description	Value
Preference		
β	Weight: home goods (married)	0.161
μ	Weight: leisure (married)	2.703
ϕ	Weight: child (married)	0.350
ξ	Weight: child quality (married)	0.066
β_g	Weight: home goods (single)	6.806 (men)
		5.792 (women)
μ_g	Weight: leisure (single)	3.846 (men)
		6.449 (women)
Childcare Costs		
$\zeta_{f,t}$	Basic childcare time (women)	0.053 (1999), 0.081 (2019)
b_t	Basic childcare fin. cost	0.006 (1999), 0.025 (2019)
χ_t	Education cost	0.090 (1999), 0.104 (2019)
Home Production		
π	Durable goods price	-0.0223 (growth)
Market Production and Technology		
Z_t	Neutral technology	0.0038 (growth)
A_t	High-skill productivity (SBTC)	0.0061 (growth)
$A_{f,t}$	High-skill productivity (women) (SBTC)	0.0003 (growth)
B_t	Women's productivity (high) (GBTC)	0.0011 (growth)
Other Parameters		
d	Marriage joy shock distribution	0.831

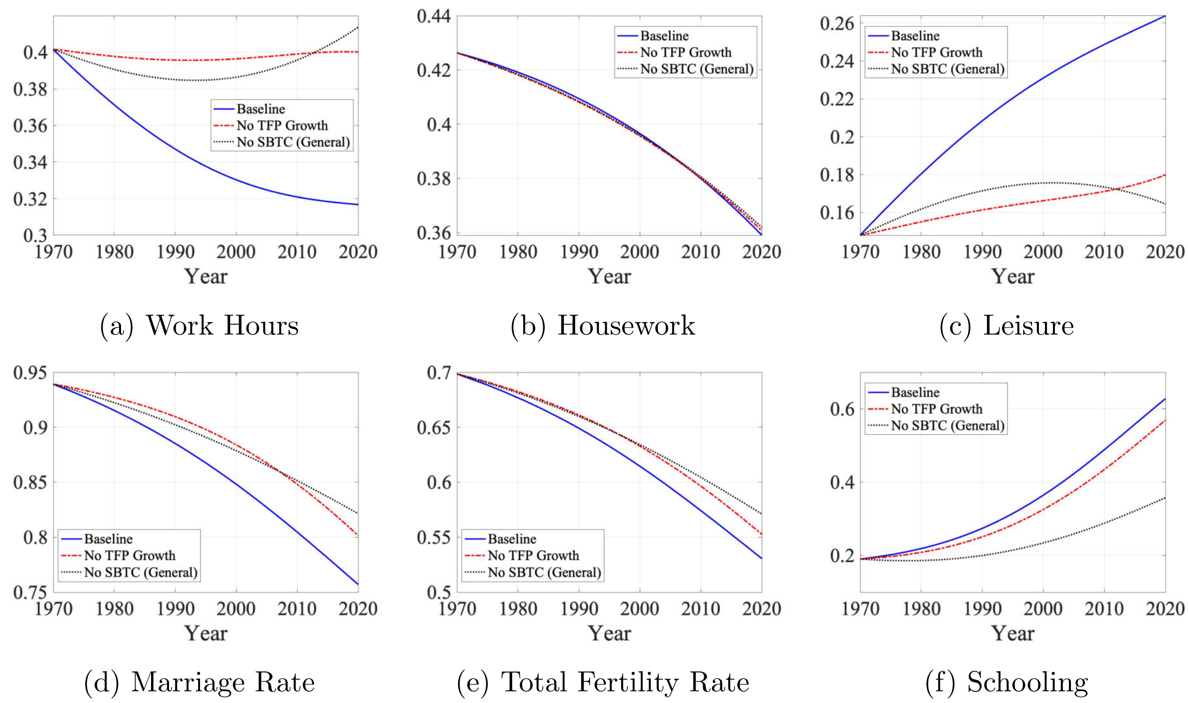
D Additional Robustness Exercises

In this section, we consider alternative specifications of the model and parametrization and discuss how our main quantitative outcome may be affected by these assumptions.

D.1 Equivalence Scale

In the baseline model presented above, we considered the equivalence scale adjustments for adult members only. In this section, we consider the adjustment of the scale for children as well. More precisely, we set the equivalence scale of a married household as $\eta = 1.5 + 0.3 \times k$, based on the OECD equivalence scale, and let couples consider the additional consumption cost of having more children in making fertility decisions.[23]

Figures 11 and 12 show the transition of key variables when we simulate the baseline model with the alternative equivalence scale, and the same model without a specific technological change. Note that the levels of the variables do not coincide with those in our original baseline simulations, since we do not recalibrate the model and focus on the marginal effects of the alternative equivalence scale in the experiments. Effects of the technology and childcare costs are similar to the baseline results presented above, qualitatively in all cases and quantitatively also in most cases.

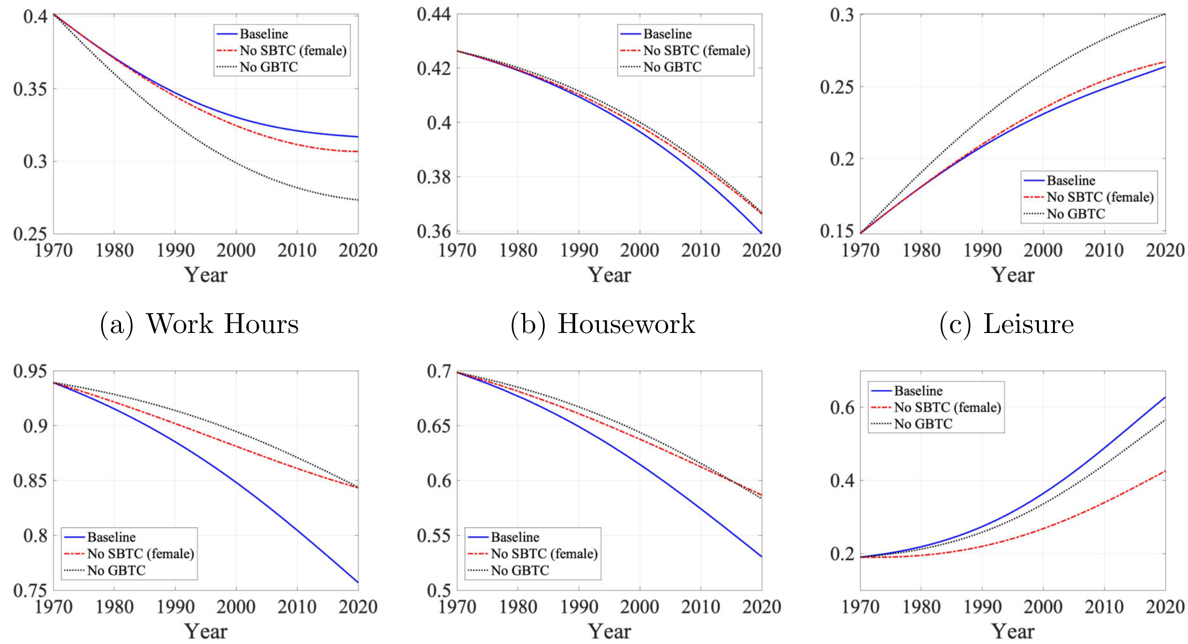


(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 11: No TFP Growth and No SBTC (general): With Alternative Equivalence Scale

[23]The experiments assume a relatively large adjustment for children, since the children are likely to be dependent and consume parents' resources for only a part of their life-time.



(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 12: No SBTC (Female) and No GBTC: With Alternative Equivalence Scale

D.2 Alternative Timing Assumptions

Our baseline model is static and households make life-time decisions upon entry to the market in each year between 1970 and 2020. In this section, we consider an alternative scenario regarding the timing of the shift in skill composition in response to parental decisions on educational investment. Specifically, we assume that there is a time lag before changes in skill composition materialize. As a result, the wage rate for each gender, $w_{g,t}$, following the formulation in (22), is now given by

$$w_{g,t} = s_{t-30} w_{g,h,t} + (1 - s_{t-30}) w_{g,l,t}. \tag{24}$$

Here, s_{t-30} denotes the schooling choice made by the parent cohort 30 periods earlier. Accordingly, the current schooling choice s_t affects the average wage only 30 periods later, when today's children become the parent generation.

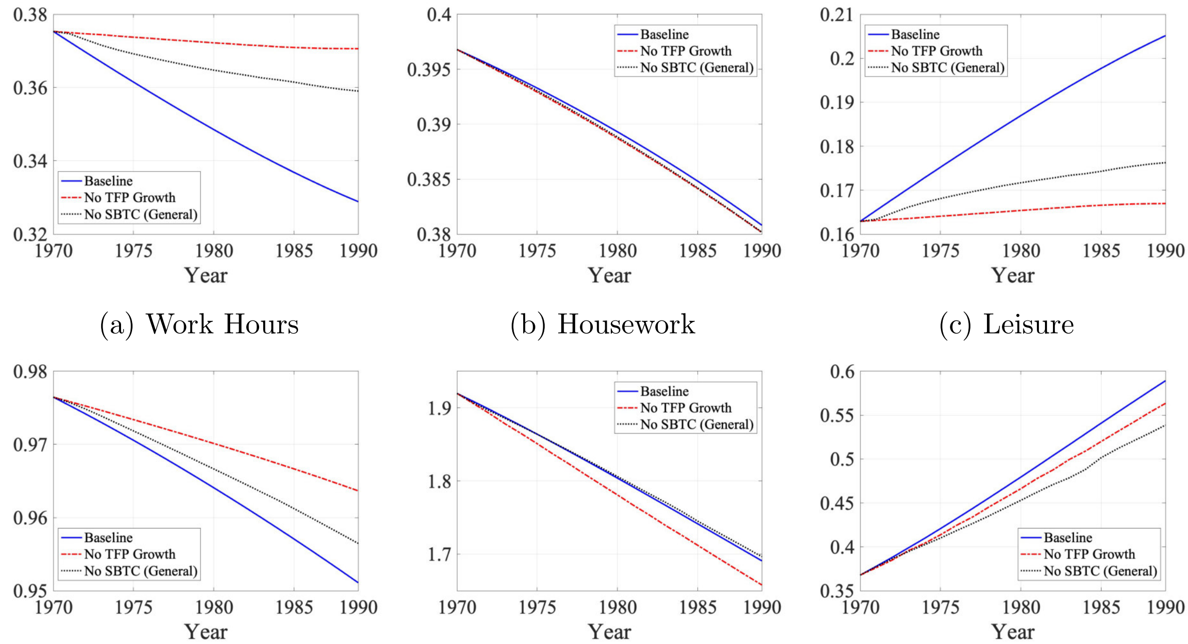
We also adopt an additional assumption about the information that parents use in making the optimal decisions about schooling. More precisely, we assume that there is a time lag of 30 years, approximately representing the average age gap between generations. For example, education investment determined in 1970 is reflected in the skill composition in 2000, and parents in 1970 decide the skill investment of children, taking into account the skill premium in 2000. In other words, the quality of children relevant for parents in year t, denoted by q_t, is now given by

$$q_t = s_t w_{h,t+30} + (1 - s_t) w_{l,t+30}. \tag{25}$$

Note that the current schooling choice s_t determines the skill distribution 30 years later. Accordingly, parents base their decisions on the wage rates that their children will receive 30 years in the future.

Obviously, assuming the current skill premium will continue through generations or that parents can perfectly predict the wage structure in the future will be both extreme and the reality should lie somewhere in between. The exercise conducted here demonstrate how the main numerical results might be affected by these timing assumptions.

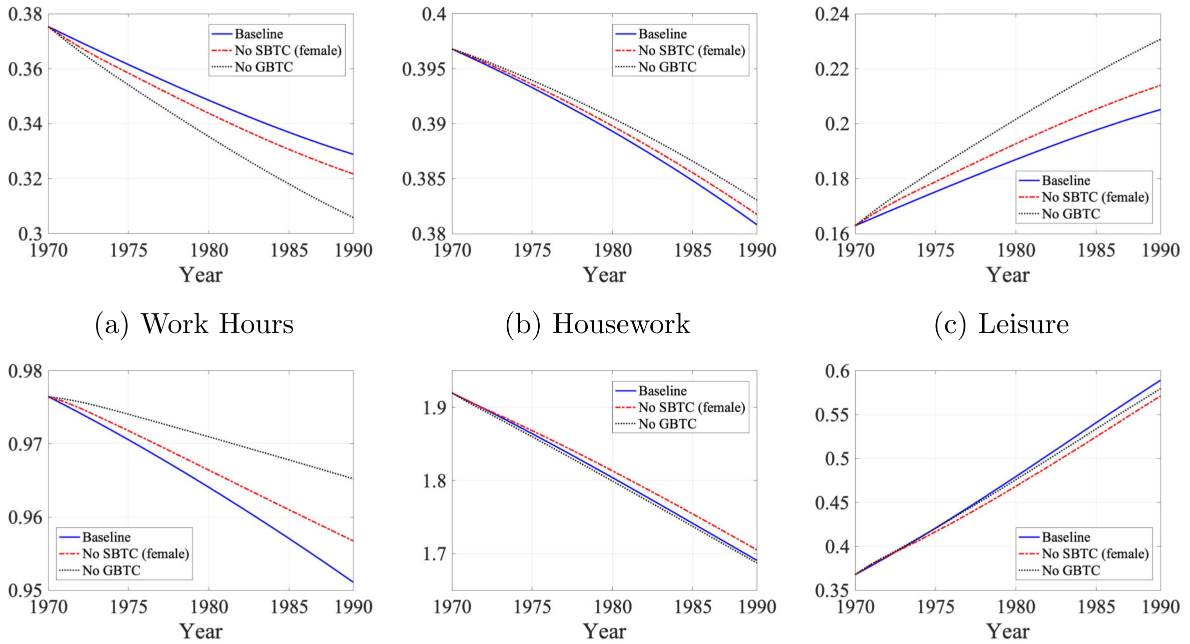
Baseline simulation results with the time lag and experiments with alternative technological process are presented in Figures 13 and 14. Note that results are presented for the period between 1970 and 1990, as we use wage data up to 2020, 30 years after 1990. Experimental results are qualitatively the same as the baseline and quantitatively similar as well.



(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 13: No TFP Growth and No SBTC (general): With Alternative Timing Assumptions



(a) Work Hours (b) Housework (c) Leisure

(d) Marriage Rate (e) Total Fertility Rate (f) Schooling

Figure 14: No SBTC (Female) and No GBTC: With Alternative Timing Assumptions

E Notes on Labor Inputs and Labor Market Clearing

This section describes how individual work hours are aggregated into the four labor inputs used in the production function, $\{L_{m,t}, L_{f,t}, H_{m,t}, H_{f,t}\}$. Let $e_{g,t}$ denote average hours worked per worker of gender $g \in \{m, f\}$ in year t. We define gender- and skill-specific labor inputs as follows:

$$L_{m,t} = (1 - s_t) \cdot e_{m,t} \cdot \bar{x}_{m,l,t} \tag{26}$$

$$L_{f,t} = (1 - s_t) \cdot e_{f,t} \cdot \bar{x}_{f,l,t} \tag{27}$$

$$H_{m,t} = s_t \cdot e_{m,t} \cdot \bar{x}_{m,h,t} \tag{28}$$

$$H_{f,t} = s_t \cdot e_{f,t} \cdot \bar{x}_{f,h,t} \tag{29}$$

where s_t denotes the share of high-skilled workers in year t. In the model, s_t is determined by parents' schooling decisions for their children. Because the model is static, this same s_t is used to characterize the skill composition of workers in year t. In the data, however, the skill composition of the workforce reflects education decisions made by many cohorts over previous decades and therefore does not necessarily coincide with the contemporaneous graduation rate during the transition.

The mismatch would bias the wage series implied by marginal products. To address this issue, we introduce $\bar{x}_{g,s,t}$, a gender- and skill-specific adjustment factor that reconciles (1) labor inputs by gender and skill observed in the data with (2) labor inputs implied by the model's schooling and hours choices. In our simulations of Japan's transition, omitting $\bar{x}_{g,s,t}$ would lead us to underestimate the magnitude of technological change and, in turn, understate its role in explaining the declines in fertility and marriage rates.

To illustrate this mechanism, we explain how $\bar{x}_{g,s,t}$ is constructed and present its time paths. Let $\{L^{data}_{m,t}, L^{data}_{f,t}, H^{data}_{m,t}, H^{data}_{f,t}\}$ denote the data counterparts of the four labor inputs in year t. Each series measures total hours worked by the corresponding group of workers, computed as the number of employed workers multiplied by average hours worked. Figure 15 plots these series using data, normalized so that their sum in 1970 equals one. The upward trends reflect growth in total employment over the past five decades, driven in part by demographic changes, increases in labor force participation, and the gradual rise in the retirement age.

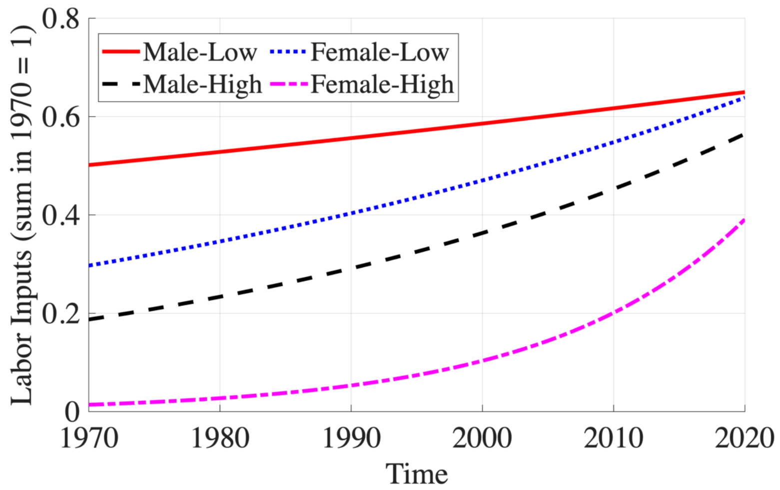


Figure 15: Labor inputs by gender and skill, 1970–2020

In the model without adjustment factors, labor supply of low- and high-skilled workers of gender g would be determined solely by schooling and work hours:

$$L_{g,t} = (1 - s_t)e_{g,t} \tag{30}$$

$$H_{g,t} = s_t e_{g,t} \tag{31}$$

In general, these model-implied labor inputs do not coincide with their data counterparts.[24]

$$L^{data}_{g,t} \neq L_{g,t}$$

$$H^{data}_{g,t} \neq H_{g,t}$$

[24] We also note that this discrepancy is not specific to a static framework; it would also arise in an overlapping generations model unless the full transitional dynamics—requiring the explicit computation of all cohorts relevant to the 1970–2020 labor market, including those born well before 1970—were taken into account, and unless the model explicitly allows households to differentiate educational investments between sons and daughters.

We therefore let $\bar{x}_{g,s,t}$ absorb this discrepancy so that our model's labor inputs match those observed in the data. Specifically, for each gender, skill level, and year, $\bar{x}_{g,s,t}$ is constructed as follows:

$$\bar{x}_{m,l,t} = \frac{L_{m,t}^{data}}{(1-s_t) \cdot e_{m,t}}$$
$$\bar{x}_{f,l,t} = \frac{L_{f,t}^{data}}{(1-s_t) \cdot e_{f,t}}$$
$$\bar{x}_{m,h,t} = \frac{H_{m,t}^{data}}{s_t \cdot e_{m,t}}$$
$$\bar{x}_{f,h,t} = \frac{H_{f,t}^{data}}{s_t \cdot e_{f,t}}$$

where $e_{g,t}$ and s_t denote hours worked and schooling levels in year t in the baseline model described in Section 5.1.

Figure 16 plots the four series for $\bar{x}_{g,s,t}$. By construction, $\bar{x}_{g,s,t} = 1$ implies that the model-implied and data labor inputs coincide exactly. The figure shows that $\bar{x}_{g,s,t}$ typically differs from one and tends to increase over time, except for high-skilled males.

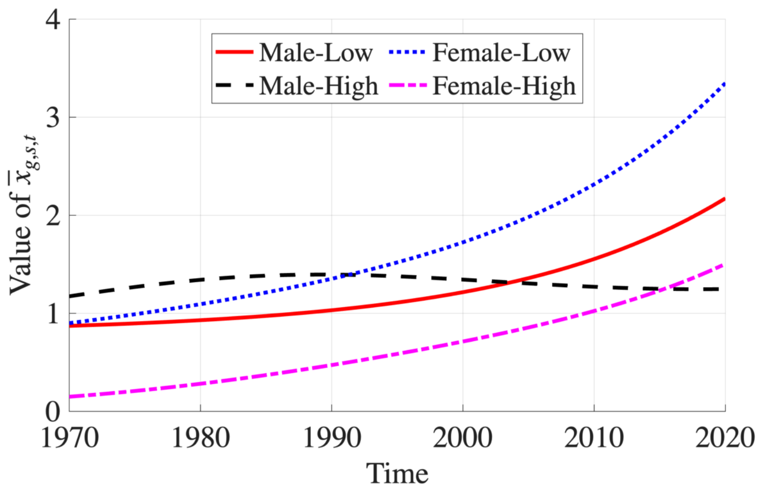


Figure 16: Adjustment factors $\bar{x}_{g,s,t}$

This discrepancy arises for two reasons. First, the model's s_t is tied to the college graduation rate in year t (i.e., the cohort graduating in that year), whereas in the data the skilled share is measured among workers of all ages holding a college degree. The latter reflects education decisions made by multiple cohorts over several decades, which the static structure of the model cannot capture.

Second, the model assumes that parents invest equally in the education of sons and daughters. In the data, however, educational attainment differs by gender, and the share of high-skilled women has increased more sharply than that of high-skilled men.

Without introducing $\bar{x}_{g,s,t}$ to bridge this gap, the model would have difficulty matching the evolving gender-education composition of the workforce. This composition is crucial for the wage dynamics across gender and skill and for identifying the paths of technological parameters discussed below.

We therefore introduce $\bar{x}_{g,s,t}$ to capture demographic and compositional forces outside the scope of the static model and hold these factors fixed in all counterfactual experiments. With $\bar{x}_{g,s,t}$ in place, the baseline model exactly reproduces the observed labor inputs.

Calibrated technological parameters could be substantially biased unless labor inputs are adjusted as described above. Figure 16 highlights two observations. First, $\bar{x}_{g,s,t}$ for high-skilled women exhibits the steepest increase, reflecting that the share of high-skilled women among workers was very small in 1970 (1.4%) but rose substantially by 2020. Second, $\bar{x}_{g,s,t}$ for low-skilled workers also increases over time, with a steeper rise for women than for men. In other words, the ratio of female to male adjustment factors has risen at both skill levels.

Absent this adjustment, part of women's wage growth would be mechanically attributed to the relative scarcity of female labor inputs rather than to female-biased technological change. Consequently, the role of technological change in raising the return to female market work would be underestimated, and its contribution to fertility and marriage declines would be understated.

In summary: (1) $\bar{x}_{g,s,t}$ reconciles labor inputs in the data and in the model by absorbing demographic and compositional factors outside the static framework; (2) its trajectory implies that female-biased technological change would be underestimated in its absence; (3) holding $\bar{x}_{g,s,t}$ fixed isolates technological parameters from these compositional forces while allowing effective labor inputs to respond endogenously to changes in schooling and work hours in counterfactual experiments; and (4) equilibrium wages $w_{g,s}$ for $g \in \{m, f\}$ and $s \in \{l, h\}$ are determined such that the labor inputs defined above equal firms' labor demand for each type of labor input.