# Lifecycle Saving in Dual Earner Households

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# Life–Cycle Saving in Dual Earner Households

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One of the conspicuous changes in the U.S. economy in the last 50 years is the rise in labor market participation for married women (e.g., Goldin [1990]). This raises measurement questions about the U.S. GDP: since the National Accounts only include market transactions (i.e., they omit home production), increases in female labor force participation raise the GDP but corresponding diminutions in home production of services such as food preparation, house keeping, and child care do not lower it; thus, formal government statistics almost certainly overstate aggregate output gains on net. Increases in women's market work may also affect the economy's aggregate average propensity to save (APS): to the extent that saving for retirement, a period of life when labor force participation is zero in any case, has risen in step with net increases in living standards rather than gross market earnings, the numerator of the APS will have grown more slowly than the GDP in its denominator. This paper attempts to measure the effects of increased female labor market participation on household saving behavior; future drafts will attempt to use its measurements to access the recent growth of net aggregate output and changes in the aggregate average propensity to save.

The aggregate average propensity to save for the U.S. has trended downward in the last decades, and we want to examine whether changes in female labor force participation could be part of the reason. The following simple examples illustrate why one might suspect a connection. (i) In a "traditional" household, suppose a husband works two–thirds of his adult life, earning \$900,000, but his wife never does market work. Suppose the household saves \$300,000 for retirement — seeking to hold its consumption level constant. (ii) In a second traditional household, the husband alone works outside of the house — for two–thirds of his adult life — and he earns \$1,800,000. Assuming preference orderings are homothetic, suppose the second household saves \$600,000 for its retirement. (iii) In a third household, the husband works for two–thirds of his adult life and earns \$900,000. His wife also works outside of the house and earns \$900,000. As she does so, she drastically cuts back on home production; so, the household purchases market replacements for the lost services. Suppose the replacements cost \$900,000. Then since the household's "net" earnings are the same as first household, suppose that it also saves \$300,000 for retirement. These examples suggest why we think that the economy's APS might tend to fall as a larger fraction of households behave according to the third pattern: market earnings, fully registered in the GDP, may rise faster than savings.

This paper attempts to quantify the phenomenon suggested above. We might think of two polar alternatives. (1) The recent increase in female labor force participation has arisen from a reduction in barriers to women's business–sector careers. In this scenario, market work is a response to new opportunities; hence, rising participation rates do not entail a high opportunity costs. We call this the "discrimination hypothesis." (2) The recent rise in female market participation is a consequence of technological change, which is gradually eroding the comparative advantages of home production. In responding to technological progress, households substitute factory production for home production. In this case, net

gains from market participation may be much smaller than measured increases in GDP. We call this the "substitution hypothesis."

The organization of this paper is as follows. Section 1 presents a life–cycle model of household behavior in which wives can vary their time allocation between home production and market work. Section 2 discusses our data sources. Section 3 presents our estimates of output losses due to reduced home production when women engage in market work.

## 1. The Model

This section presents a life–cycle model of an individual household's behavior. The model leads to a regression equation. Below we estimate the equation using micro data.

The regression equation has the form

$$\ln(NW_i) = \ln(\kappa) + \ln(Y_i^M + (1-\theta)\cdot Y_i^F) + \epsilon_i\,, \tag{1}$$

where $NW_i$, $Y_i^M$, and $Y_i^F$ are, respectively, net worth at age 65, the present value of male lifetime earnings, and the present value of (actual) female lifetime earnings for household $i$; where $\kappa \in (0,1)$ and $\theta \in (0,1)$ are parameters to be estimated; and where $\epsilon_i$ is a regression error reflecting, say, measurement error in $NW_i$.

Life–Cycle Model. Focus on a single household that lives over ages $s = 0$ to $s = T$. It has market consumption $c_s$ at age $s$. The household includes a man and wife. The man earns $y_s^m$ at age $s$, inelastically supplying labor. At exogenously specified age $R$, the household retires, and $y_s^m$ drops to zero. Let $h_s^f \in [0,1]$ be the fraction of each day that the woman works in the labor market – i.e., hours away from home work. Prior to age $R$, the wife earns wage $w_s^f$ for each day of market work. For $s > R$, $h_s^f = 0$.

The model is as follows: any household $i$ determines its life–cycle behavior from

$$\max_{c_s \geq 0,\, h_s^f \geq 0} \int_0^T e^{-\rho\cdot s}\cdot u(c_s - A\cdot[h_s^f]^\beta)\,ds\,, \tag{2}$$

$$\text{subject to: } \dot{a}_s = r\cdot a_s + y_s^m + h_s^f\cdot w_s^f - c_s\,,$$

$$a_0 = 0 \quad \text{and} \quad a_T \geq 0\,,$$

$$h_s^f = 0 \text{ all } s > R\,.$$

Assume isoelastic preferences:

$$u(x) \equiv \frac{[x]^\gamma}{\gamma}\,, \quad \gamma < 1\,. \tag{3}$$

Assume

$$A > 0 \quad \text{and} \quad \beta \geq 1\,. \tag{4}$$

The household's net worth is $a_s$. In the terminology above,

$$a_{65} = NW\,. \tag{5}$$

The interest rate is $r$. In the terminology above,

$$Y^M = \int_0^T e^{-r\cdot(s-65)}\cdot y_s^m\,ds \qquad \text{and} \qquad Y^F = \int_0^T e^{-r\cdot(s-65)}\cdot h_s^f\cdot w_s^f\,ds\,. \tag{6}$$

For simplicity, assume

$$R \leq 65\,. \tag{7}$$

Discussion. Suppose that in a "tradition" household the wife never works. Then $h_s^f = 0$ all $s$ in model (2), and the model is entirely conventional.

Suppose that in a "modern" household the wife does some market work. Since her market work reduces her home production, the household's flow of utility will fall unless there is a counterbalancing increase in market consumption. Model (2) registers this as follows: the household's flow of utility for $s \in [0, R]$ is $u(c_s - A\cdot[h_s^f]^\beta)$, with $A > 0$ and $\beta \geq 1$ constants. The first hour of the wife's market work inconveniences the household less than, say, the tenth hour, and is easier to replace with market goods.

Our specification merely assumes that modern and traditional households are identical after retirement. For $s > R$, perhaps home production and leisure are indistinguishable. Or, perhaps after that time the wife's (and husband's) supply of home production depends on a leisure/home work tradeoff beyond the scope of this paper.

Solution of Model (2). Define

$$z_s \equiv c_s - A\cdot[h_s^f]^\beta\,. \tag{8}$$

Then one can transform (2) to

$$\max_{z_s\geq 0,\, h_s^f\geq 0} \int_0^T e^{-\rho\cdot s}\cdot u(z_s)\,ds\,, \tag{9}$$

$$\text{subject to: } \dot{a}_s = r\cdot a_s + y_s^m + h_s^f\cdot w_s^f - A\cdot[h_s^f]^\beta - z_s\,,$$

$$a_0 = 0 \text{ and } a_T \geq 0\,,$$

$$h_s^f = 0 \text{ all } s > R\,.$$

The current-value Hamiltonian for the transformed problem is

$$\mathcal{H} = u(z_s) + \lambda_s\cdot[r\cdot a_s + y_s^m + h_s^f\cdot w_s^f - A\cdot[h_s^f]^\beta - z_s]\,. \tag{10}$$

Since the Hamiltonian is jointly concave in $z_s$ and $a_s$, the following conditions are necessary and sufficient for an optimum:

$$\frac{\partial \mathcal{H}}{\partial z_s} = 0 \Longleftrightarrow u'(z_s) = \lambda_s \tag{$i$}$$

$$\frac{\partial \mathcal{H}}{\partial h_s^f} = 0 \Longleftrightarrow \lambda_s \cdot [w_s^f - \beta \cdot A \cdot [h_s^f]^{\beta-1}] = 0 \tag{$ii$}$$

$$\dot{\lambda}_s = \rho \cdot \lambda_s - \frac{\partial \mathcal{H}}{\partial a_s} \Longleftrightarrow \dot{\lambda}_s = \lambda_s \cdot [\rho - r]\,, \tag{$iii$}$$

$$\dot{a}_s = r \cdot a_s + y_s^m + h_s^f \cdot w_s^f - A \cdot [h_s^f]^{\beta} - z_s\,, \tag{$iv$}$$

$$\lambda_T \geq 0 \text{ and } \lambda_T \cdot a_T = 0\,, \tag{$v$}$$

$$a_0 = 0\,. \tag{$vi$}$$

Consider the optimum. Conditions (i) and (iii) show $\lambda_s > 0$ all $s$; thus, (v) implies

$$a_T = 0\,. \tag{11}$$

From (i),

$$\frac{[z_s]^{\gamma-1}}{\gamma} = \lambda_s\,.$$

Taking logs and then time derivatives,

$$(\gamma - 1) \cdot \dot{z}_s / z_s = \dot{\lambda}_s / \lambda_s\,.$$

Using (iii),

$$\dot{z}_s / z_s = (r - \rho)/(1 - \gamma)\,.$$

Integrating both sides from 0 to $s$,

$$z_s = z_0 \cdot e^{\frac{r-\rho}{1-\gamma} \cdot s}\,. \tag{12}$$

Multiply every term in (iv) by $e^{-r \cdot (s-65)}$. Then

$$\begin{aligned} \frac{d(e^{-r\cdot(s-65)} \cdot a_s)}{ds} &= e^{-r\cdot(s-65)} \cdot [\dot{a}_s - r \cdot a_s] \\ &= e^{-r\cdot(s-65)} \cdot [y_s^m + h_s^f \cdot w_s^f - A \cdot [h_s^f]^{\beta} - z_s]\,. \end{aligned} \tag{13}$$

Integrating both sides from $s = 65$ to $s = T$, using the fundamental theorem of calculus, and noting that $R \leq 65$ means the first three right–hand side terms are zero, we have

$$-a_{65} = -\int_{65}^{T} e^{-r\cdot(s-65)} \cdot z_s \, ds \iff a_{65} = \int_{65}^{T} e^{-r\cdot(s-65)} \cdot z_s \, ds \,. \tag{14}$$

Integrating both sides of (13) from $s = 0$ to $s = T$, we have

$$\begin{aligned} 0 - 0 &= \int_{0}^{T} e^{-r\cdot(s-65)} \cdot [y_s^m + h_s^f \cdot w_s^f - A \cdot [h_s^f]^\beta - z_s] \, ds \\ &\iff Y^M + Y^F - \int_{0}^{T} e^{-r\cdot(s-65)} \cdot A \cdot [h_s^f]^\beta \, ds = \int_{0}^{T} e^{-r\cdot(s-65)} \cdot z_s \, ds \,. \end{aligned} \tag{15}$$

Since $\lambda_s > 0$ all $s$, condition (ii) implies

$$h_s^f = [\frac{w_s^f}{\beta \cdot A}]^{\frac{1}{\beta-1}} \,. \tag{16}$$

Then

$$A \cdot [h_s^f]^\beta = A \cdot [\frac{w_s^f}{\beta \cdot A}]^{\frac{\beta}{\beta-1}} = A^{\frac{-1}{\beta-1}} \cdot [w_s^f]^{\frac{\beta}{\beta-1}} \cdot [\beta]^{\frac{-\beta}{\beta-1}} \,.$$

And,

$$h_s^f \cdot w_s^f = [\frac{w_s^f}{\beta \cdot A}]^{\frac{1}{\beta-1}} \cdot w_s^f = [w_s^f]^{\frac{\beta}{\beta-1}} \cdot [\beta]^{\frac{-1}{\beta-1}} \cdot [A]^{\frac{-1}{\beta-1}} \,.$$

Hence,

$$A \cdot [h_s^f]^\beta = \theta \cdot h_s^f \cdot w_s^f \,, \tag{17}$$

where

$$\theta \equiv A^{\frac{-1}{\beta-1}} \cdot [\beta]^{\frac{-\beta}{\beta-1}} \cdot [\beta]^{\frac{1}{\beta-1}} \cdot [A]^{\frac{1}{\beta-1}} = \frac{1}{\beta} \,. \tag{18}$$

Digressing for a moment, note that since $\beta \geq 1$, we have

$$\theta \in (0, 1] \,. \tag{19}$$

Returning to (15), substituting from (17) yields

$$\begin{aligned} &Y^M + Y^F - \int_{0}^{T} e^{-r\cdot(s-65)} \cdot A \cdot [h_s^f]^\beta \, ds \\ &\quad = Y^M + Y^F - \theta \cdot Y^F = \int_{0}^{T} e^{-r\cdot(s-65)} \cdot z_s \, ds \,. \end{aligned} \tag{20}$$

We are now ready to deduce equation (1). Using (5), (14), and (20), we have

$$\frac{NW}{Y^M + (1-\theta)\cdot Y^F} = \frac{\int_{65}^{T} e^{-r\cdot(s-65)}\cdot z_s\, ds}{\int_{0}^{T} e^{-r\cdot(s-65)}\cdot z_s\, ds}\,.$$

Cancel $e^{r\cdot 65}$ and $z_0$ from the top and bottom on the right side, substitute from (12), and define

$$\sigma \equiv -r + \frac{r-\rho}{1-\gamma}\,. \tag{21}$$

Then

$$\frac{NW}{Y^M + (1-\theta)\cdot Y^F} = \frac{\int_{65}^{T} e^{\sigma\cdot s}\, ds}{\int_{0}^{T} e^{\sigma\cdot s}\, ds}\,. \tag{22}$$

Call the ratio on the right–hand side $\kappa$. Note that

$$\kappa \equiv \frac{\int_{65}^{T} e^{\sigma\cdot s}\, ds}{\int_{0}^{T} e^{\sigma\cdot s}\, ds} \in (0,1)\,. \tag{23}$$

From (22)–(23),

$$\frac{NW}{Y^M + (1-\theta)\cdot Y^F} = \kappa\,. \tag{24}$$

Taking logs of both sides, we have derived equation (1).

Discussion. Given homotheticity of preferences, a natural outcome to expect might be

$$\frac{NW}{Y^M + Y^F} = \text{constant}\,. \tag{25}$$

For a household with a non-working wife, (24) and (25) are identical. With a working wife, the two are different, and, indeed, our model implies that the left–hand side of (25) is not constant — rather it will decline with increases in $Y^F$. National Income and Product Accounting omits home production from output (because it is too difficult to measure). Once one neglects the value of home production, it is easy to overlook the consequences of its absence. Our analysis implies that such a mind set will tend to cause one to perceive a drop in private wealth accumulation during periods in which women reduce hours of work at home in preference for market jobs: if $Y^F = 0$, we predict

$$\frac{NW}{Y^M + Y^F} = \frac{NW}{Y^M + (1-\theta)\cdot Y^F} = \kappa\,,$$

but when $Y^F > 0$, we predict

$$\frac{NW}{Y^M + Y^F} < \frac{NW}{Y^M + (1-\theta)\cdot Y^F} = \kappa\,.$$

Return to the introduction's two alternative hypotheses. Under the "discrimination hypothesis," improving opportunities for careers have raised the value of women's time. Since $h_s^f$ is a fraction, we can encompass a pure gain in opportunities by setting $\beta = \infty$ in (2). That implies $\theta = 0$. In other words, a household gains from a woman's market–work hours on a one–for–one basis.

Under the "substitution hypothesis," increases in women's hours of market work entail a non–negligible loss in home production. In the extreme case, $\beta = 1$ and $A = w^f$ in (2) — so that a dollar of earnings leads to a dollar's worth of lost home production. In the latter case, $\theta = 1$.

In summary, polar extreme cases are

$$\text{"discrimination hypothesis:"} \qquad \theta = 0\,,$$

$$\text{"substitution hypothesis:"} \qquad \theta = 1\,.$$

Additional Interpretation. Different women might work different amounts. One reason is that some women may have higher market work efficiency than others and hence command higher wages. Equation (16) shows a higher $w_s^f$ leads to a higher level of market hours $h_s^f$. Equation (24) remains valid in the different cases, however, because as $h_s^f \cdot w_s^f$ rises, home production declines proportionately — see (17). Similarly, different women may have different efficiencies at home production, in other words different coefficients $A = A_i$ in (2). According to (16), women with high efficiency at home devote few hours to market labor. Nevertheless, (24) remains valid, with the magnitude of $A$ not affecting $\kappa$ or $\theta$.

## 2. Data

This section is very abbreviated in this draft.

Our data source is the Health and Retirement Study (HRS). The survey started in 1992 with a large sample of individuals aged 51–61. The survey also includes those individuals' spouses. The survey runs every other year. The original sample was given the opportunity to sign a waiver allowing their Social Security earnings records 1951–91 to be linked with the HRS. About 80% of the sample agreed to the waiver. Additional W2 (tax form) data for 1981–1991 was eventually linked to the HRS as well.

For retired males, we estimate lifetime earnings from the linked Social Security records and survey earnings data for 1992, 1994, 1996, 1998, 2000, and 2002. We simply assume that men work every year from years of education + 6 to their stated retirement year. We estimate a random effects earnings dynamics model and use it to impute any missing earnings figures. The Social Security and W2 data is top coded, and our earnings dynamics equation is estimated from a likelihood function which takes this into account. We capitalize lifetime earnings for each man with a 4%/year real interest rate. Table 1 summarizes our distribution for $Y^M$.

For our sample of women, we cannot assume earnings in every year. Thus, we use only actual earnings from the data. We nevertheless make a correction for years of work in jobs not covered under the Social Security system. Again, we capitalize lifetime earnings with a 4%/year real interest rate. Table 2 summarizes our distribution for $Y^F$.

The HRS collects data on households' net worth in each survey wave. The survey net worth includes real estate, financial assets, own business, and autos. The survey separately collects data on pension and Social Security flows for retired individuals, and we compute the expected present value of each of these flows and add them to our net worth figure. Table 3 summarizes our distribution for $NW$.

## 3. Results

Section 1 derived our basic regression equation from a theoretical model. This section presents regression results.

Consider a household born at time $t$ and currently age $s$, so that the time now is $s+t$. Suppose that the household is a retired couple and that its current net worth is $NW_{st}$. Let the lifetime earnings of the household's adult male be $Y_{st}^M$ and let the same for its adult female be $Y_{st}^F$, with each figure given in present value at time $s+t$. Then Section 1 derives a relation

$$\frac{NW_{st}}{Y_{st}^M + (1-\theta)\cdot Y_{st}^F} = \frac{\int_s^T e^{\sigma\cdot v}\,dv}{\int_0^T e^{\sigma\cdot v}\,dv}\,, \tag{26}$$

where $T$ is the household's maximal age and

$$\sigma = -r + \frac{r-\rho}{1-\gamma}$$

with $r$ the real interest rate (taken to be .04 in this paper), $\rho$ the subjective discount rate, and $\gamma < 1$ the power in the household's isoelastic utility function. The loss in home production — valued in consumption–good units — when a wife gives up a fraction, say, $h^f$, of her day of home production for market work is $A\cdot[h^f]^\beta$, $\beta \geq 1$. We think of $0 \leq h^f < 1$. Section 1 shows that when the wife allocates her time efficiently between home and market work, we have

$$A\cdot[h_{st}^f]^\beta = \theta\cdot h_{st}^f\cdot w_{st}\,, \tag{27}$$

where $w_{st}$ is her market wage and $\theta \equiv 1/\beta$, with $\theta$ the same parameter as appears in (1). This section attempts to estimate $\theta$.

After taking logs of both sides of (26), we convert it into a regression equation by appending an error $\epsilon_{st}$ to the right–hand side:

$$\ln(NW_{st}) = \alpha_0 + \ln(Y_{st}^M + (1-\alpha_1)\cdot Y_{st}^F) + \ln(\int_s^T e^{\alpha_2\cdot v}\,dv) + \epsilon_{st}\,,$$

where $\theta = \alpha_1$ and $\sigma = \alpha_2$. We can think of $\epsilon_{st}$ as measurement error in $\ln(NW_{st})$. In fact, since macroeconomic shocks seem to have affected asset prices throughout the economy in recent years, we add time dummies $\chi_i(s+t)$ for the survey years $i = 1994, 1996, 1998$, and 2000 (omitting 2002), where

$$\chi_i(s+t) = \begin{cases} 1, & \text{if } s+t=i \\ 0, & \text{otherwise} \end{cases}\,.$$

Thus, our regression equation becomes

$$\ln(NW_{st}) = \alpha_0 + \ln(Y_{st}^M + (1-\alpha_1)\cdot Y_{st}^F) + \ln(\int_s^T e^{\alpha_2 \cdot v}\, dv) + \sum_{i=1994}^{2000} \alpha_i \cdot \chi_i(s+t) + \epsilon_{st}\,. \quad (28)$$

Notice that $\alpha_0$ reflects $-\ln(\int_0^T e^{\sigma \cdot v}\, dv)$. If a proportional income tax $\tau$ reduces all market earnings in practice, $\alpha_0$ reflects $\ln(1-\tau)$ as well.

Finally, our choice of $T$ will affect our estimate our estimate of $\sigma$. Since our treatment of pensions and Social Security benefits — as well as our theoretical modeling in Section 1 — implicitly assumes complete annuity markets, if $\pi_s$ is the probability of death at age $s$, in place of $\int_s^T e^{\sigma \cdot v}\, dv$ we should use

$$\int_{s+t}^T \pi_x \cdot \int_{s+t}^x e^{\sigma \cdot v}\, dv\, dx = \int_{s+t}^T [\int_{s+t}^T \pi_x\, dx]\, e^{\sigma \cdot v}\, dv\,. \quad (29)$$

Let $\vec{\psi}_x \equiv (\psi_{x,1}, \psi_{x,2}, \psi_{x,3})$ give the probability, respectively, of a single surviving adult male at age $x$, a single surviving adult female, or a surviving couple.[1] We start with $\vec{\psi}_x = (0,0,1)$. Thereafter, in discrete time (to match the empirical mortality table), for all $x = s+t+1, ..., 110$, with 110 the practical maximal age, we have

$$\psi_{x,1} = \psi_{x-1,1} \cdot (1 - \pi_{x-1}^M) + \psi_{x-1,3} \cdot (1 - \pi_{x-1}^M) \cdot \pi_{x-1}^F\,,$$

$$\psi_{x,2} = \psi_{x-1,2} \cdot (1 - \pi_{x-1}^F) + \psi_{x-1,3} \cdot \pi_{x-1}^M \cdot (1 - \pi_{x-1}^F)\,,$$

$$\psi_{x,3} = \psi_{x-1,3} \cdot (1 - \pi_{x-1}^M) \cdot (1 - \pi_{x-1}^F)\,.$$

Noticing that $\psi_{s+t,1}$, for instance, takes the place of $\int_{s+t}^T \pi_x^M\, dx$ in (30), we use a trapezoidal approximation

$$\begin{aligned} I(s+t,\sigma) \equiv \omega \cdot \sum_{v=s+t}^{109} \frac{1}{2} \cdot [\psi_{v,1} \cdot e^{\sigma \cdot v} + \psi_{v+1,1} \cdot e^{\sigma \cdot (v+1)}] + \\ \omega \cdot \sum_{v=s+t}^{109} \frac{1}{2} \cdot [\psi_{v,2} \cdot e^{\sigma \cdot v} + \psi_{v+1,2} \cdot e^{\sigma \cdot (v+1)}] + \\ \sum_{v=s+t}^{109} \frac{1}{2} \cdot [\psi_{v,3} \cdot e^{\sigma \cdot v} + \psi_{v+1,3} \cdot e^{\sigma \cdot (v+1)}]\,, \end{aligned} \quad (30)$$

[1] For notationally simplicity, we assume here that the adult male and female are the same age. However, that is inessential — and the empirical analysis does not impose it.

where $\omega$ is the consumption weight of a single adult relative to a couple. Following the Social Security system, we assume $\omega = 2/3$.

Table 4 provides parameter estimates for

$$\ln(NW_{st}) = \alpha_0 + \ln(Y_{st}^M + (1-\alpha_1)\cdot Y_{st}^F) + \ln(I(s+t,\alpha_2)) + \sum_{i=1994}^{2000} \alpha_i \cdot \chi_i(s+t) + \epsilon_{st}\,. \quad (31)$$

We use nonlinear least squares (NLLS). We develop starting values from a linear regression of our constant and time dummies over a grid of values for $(\theta, \sigma)$. Since $\theta$ should lie between 0 and 1, we have 11 evenly spaced values on $[0, 1]$ for $\theta$. The expression for $\sigma$ suggests that it lies between our value for $-r$, which is -.04, and roughly 0. We choose 31 evenly spaced grid points over $[-.1, .2]$. Thus, we have $11 \times 31$ trial values. The lowest sum of squared residuals occurs at $(.4, .01)$.

The NLLS estimate of $\theta$ is .3, and it is significantly different from both 0 and 1 (but see below). Evidently, the regression finds some support for both the discrimination hypothesis and the substitution hypothesis — but quantitative results seem closer to the former.

The estimate of $\sigma$ is slightly positive but not statistically significantly so. As remarked above, the most plausible values of $\sigma$ are slightly negative.

Our sample averages about two observations per household, and our regression error term should recognize the likelihood of positive covariances among multiple observations for the same household. Future drafts of this work will re-estimate the covariance matrix to correct this difficulty.

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