

On the Intra-Household Public Goods and Fertility Trade-Off

Arnab K. Basu, Tsenguunjav Byambasuren and Nancy H. Chau*

This version: January 21, 2022

Abstract

This paper explores an infinite-horizon dynamic model of intra-household public goods, fertility, and child mortality in which child survival is subject to the provision of household public goods. An overlapping generation model we developed explains the empirically observed relationship between fertility rate, household-level public goods, and infant mortality. In this framework, the household public goods provision reduces child mortality and enhances the earning capacity of surviving children. The model demonstrates how intra-household public goods provision is associated with fertility decisions through its impacts on child health and parents' earning potential in the long run. The model with endogenous household public good provision and intergenerational transfer suggests that households make trade-offs between intra-household public goods and fertility conditional on the survival probability of offspring, a complement of child mortality.

JEL Classification: D11, D64, H41, J13, O12

Keywords: household public goods, fertility, child mortality, intergenerational transfers

*Basu: Charles H. Dyson School of Applied Economics and Management, Cornell University, 441 Warren Hall, Ithaca, NY 14853 & Institute for the Study of Labor (IZA) (email: arnab.basu@cornell.edu); Byambasuren: Charles H. Dyson School of Applied Economics and Management, Cornell University, 438 Warren Hall, Ithaca, NY 14853 (email: tb497@cornell.edu); Chau: Charles H. Dyson School of Applied Economics and Management, Cornell University, 201A Warren Hall, Ithaca, NY 14853 & Institute for the Study of Labor (IZA) (email: hyc3@cornell.edu).

1 Introduction

Households and family members, typically the parents, make numerous household-level decisions such as the purchase of house or car, number of children, and education of their own and their children (see [Bergstrom, 1997](#); [Strauss et al., 2000](#); [Behrman, 1997](#), for literature on household decision making). These include decisions toward both pure and impure public and private goods, and in this paper, we focus on household decisions about household public goods. Although the literature considers children as the prime example of household-level public goods ([Weiss and Willis, 1985](#); [Chiappori and Weiss, 2001](#); [Rasul, 2000](#)), we separate fertility decisions from the other decisions about household public goods and analyze the interaction or trade-off between the two. We also model how a household can endogenously decide on the provision of household public goods¹ given its impact on child health, which could determine parents' earning potentials in the future.

This paper formulates an overlapping generations model of intra-household public goods in which the association between household-level public goods and fertility decisions has been explored from the economic perspective, in particular, through a trade-off between the provision of household public goods and fertility. There are two potential channels through which intra-household public good and fertility are associated with each other. First, households decide not to have a child to avoid a potential mortality incidence of their child due to a lack of investment in intra-household public goods. Second, consistent with the allocation of time approach ([Becker, 1960, 1965](#)), households would have to postpone their fertility decisions to be able to afford a household public goods provision by working additional hours.

Several interesting results emerge from our analysis. Notably, first, the maximal discounted utility was linearly proportional to the weighted average of utilities gained over the adulthood and old age periods when fertility level, one of two choice variables in our model, was optimally chosen by two-period lived individuals maximizing the present discounted value of their utility. Second, we find that household investment in health-beneficial intra-household public goods increases an individual's utility over the old age period through more consumption afforded by an increased intergenerational transfer receipt due to higher survival likelihood of the child. Third, we also find that an individual's utility during adulthood increases in response to investment in household public goods when the investment is less than the certain upper bound because too

¹Throughout the paper, we use the term *household public good* mainly with fuels used at home or indoor air quality in mind, which is a key component so far overlooked. Previous empirical literature also uses the term *local (or intra-household) public good* to describe indoor air quality, arguing that larger households benefit more from a reduction in indoor air pollution or transition to clean fuels ([Chaudhuri and Pfaff, 2002](#); [Kumar and Viswanathan, 2007](#)). In this paper, we thus use the terms of household public goods, household-level public goods, and intra-household public goods, interchangeably. Relatedly, [Pfaff et al. \(2004\)](#) examine a household-production model to demonstrate household-level environmental Kuznets curve, in particular, household Engel curve for indoor air quality. But it is worth noting that the household public good in our setting should be considered in general, not limited to household's energy choice.

much investment in household public goods lowers the adulthood consumption. Finally, there are two empirical implications of the model. First, investment in intra-household public goods from which each member of the household benefits and fertility are negatively associated, or there is a trade-off between household public goods and fertility decisions. Second, lack of household-level public goods provision is positively correlated with child mortality. These main findings are consistent with our empirical results that we found using India's DHS (1992-2016) data².

The main contributions of this paper to the long-standing economic literature on household fertility decisions, which goes back to the economic theory of population growth originated by seminal work of Malthus, are twofold. First, we add intra-household public goods as potential determinants of the household fertility decisions. In the neoclassical theory of fertility (Becker, 1960; Becker and Lewis, 1973), income, education, work status, and child costs, which include opportunity costs, play key roles in the fertility decision. The empirical results of this theory are mixed. There exist several empirical studies that support Becker's theory (Leibowitz, 1974; Heckman and Walker, 1990; Nguyen-Dinh, 1997). For instance, using a panel data of 3,458 households in the United States obtained from the Consumer Expenditure Survey, Caudill and Mixon (1995) show that family income, both wife's and husband's education, a family residence which captures variation in the opportunity cost of children, and work status are vital contributing factors in the fertility decision. Similarly, Wang and Famoye (1997) test the fertility hypothesis of Becker and Lewis using data of about 5,500 households from the Michigan Panel Study of Income Dynamics (PSID) by estimating a generalized Poisson regression model and find that wife's education level and working status, household income, and race are important determinants explaining the household fertility decisions. On the other hand, Melkersson and Rooth (2000), an example of empirical studies that oppose the Becker's theory of fertility, could not find any significant effects of proposed determinants on the number of births based on fertility data from the Swedish Level of Living Survey.

Second, the present paper also touches upon and adds to economic studies on the relationship between child mortality and fertility (Olsen and Wolpin, 1983; Wolpin, 1984; Barro and Becker, 1989; Sah, 1991; Boldrin and Jones, 2002; Doepke, 2005). Our model is consistent with the result from the Barro-Becker model, that is, a fall in child mortality rate enhances fertility. In the Barro-Becker framework, the main explanation of the fertility response to child mortality is a quantity-quality tradeoff: child mortality increases the cost of having a surviving child, and thus parents prefer smaller family to invest more on each child's education and quality in general, resulting in a fertility decline (Becker and Lewis, 1973; Barro and Becker, 1989). In addition to being consistent,

²We motivate our theoretical framework numerically and empirically by analyzing all four waves of publicly available household-level data from India's Demographic Health Survey (DHS) over the past 25 years since 1992. Using this data, rich in both temporal and spatial dimensions, we investigate the fertility behavior of Indian women and examine the relationship between household public goods (in the examples of household energy choice, indoor smoking behavior, and vaccination of the child) and fertility decisions among nationally representative households in India.

we extend the literature by interacting or relating the child mortality-fertility relationship with household public goods, e.g., household fuel choice or indoor air pollution, indoor smoking behavior, and child vaccination. Our model fundamentally differs from the Barro-Becker framework: lack of investment in household public goods causes child mortality, and thus parents (i) invest more in intra-household public goods to improve infant survival and to ultimately maximize intergenerational transfers that they expect to receive when they become old and (ii) postpone fertility decisions during adulthood (i.e., fertility declines). Hence, similar to the Barro-Becker model, fertility declines in response to growing child mortality; however, as a distinction from the Barro-Becker framework, our overlapping generations model focuses on child mortality in a family that lacks in the intra-household public good provision, which is motivated by our brief empirical analysis.

Household energy choice, the most significant contributor to indoor air quality with more than one-third of the world population relying on solid fuels, is an important example of an intra-household public good, in addition to children, that has been often ignored in the literature. Hence, we relate our analysis, especially the application of our theory, to the energy economics literature of household fuel choice considering this literature as one of the subfields where our theoretical framework relates and can be applied. This paper makes numerous contributions to economic literature on energy choice at the household level. Notably, we present what is, to our knowledge, the first economic model of fuel use characterizing the fuel choice as a household public good in the economic literature on household fuel use. The energy choice at the household level or indoor air quality can be viewed as household-level public good due to its non-rival and non-excludable characteristics³.

The theoretical foundation of household energy choice and factors affecting the fuel-switching behavior of households has been limited, while there is a growing literature of empirical studies that attempt to identify the determinants driving household fuel transition (see [Muller and Yan \(2018\)](#) for a comprehensive survey of literature on conceptual and theoretical frameworks of household fuel choice in developing countries.) Household choice of cooking fuel was initially determined by household income according to the “energy ladder” theory, heavily relying on traditional income effects in consumer model ([Heltberg, 2005](#); [Chambwera and Folmer, 2007](#); [Kowsari and Zerriffi, 2011](#); [Lay et al., 2013](#); [Das et al., 2014](#)). However, the energy ladder model has been criticized by the fact that households in developing countries consume multiple fuels at the same time instead of completely transitioning from one fuel type to another ([Masera et al., 2000](#); [Ngui et al., 2011](#); [Kroon et al., 2013, 2014](#)). As a result, the “fuel stacking” theory has been proposed, suggesting that households use a

³Every family members benefit or harm from the household fuel choice without any competition, and it is expensive or impossible to prevent anyone from breathing air inside the house, while previous studies in household fuel use literature considered a fuel used at home as a non-food consumption good. As a public good, family members can have different willingness to pay for clean air or clean fuel, but they would consume the same quantity of air inside the house. Also child mortality is one of the negative externalities of indoor air pollution. Access to clean energy, therefore, exhibits the properties of public goods.

combination of clean and polluting fuels with a certain fraction⁴.

Following those earlier theoretical models, more sophisticated utility maximization models of urban and rural (or agricultural) households emerged to better explain fuel choice patterns, a component of household public goods in our generic model. First, [Edwards and Langpap \(2005\)](#) and [Gupta and Köhlin \(2006\)](#) proposed urban household models in which utility-maximizing consumers subject to budget constraint choose commercial and non-commercial fuels simultaneously conditional on fuel prices. Second, another wave of studies including [Heltberg et al. \(2000\)](#), [Chen et al. \(2006\)](#) and, [Manning and Taylor \(2014\)](#) introduced market failures of rural households in developing countries (incomplete markets for fuels, agricultural products, labor, and finance or credit) in the theoretical framework of fuel choice. Those non-separated farm household models link the fuel choice with agricultural production and address a set of rural market failures. In opposition to earlier studies, in our theoretical framework, households maximize discounted utility by choice of two indicators including, first, investment in household-level public goods (for example, access to clean cooking fuel) that benefits the survival likelihood as well as future earning potentials of each offspring, and, second, fertility decisions conditional on the likelihood of survival. We solve the household maximization problem for each family dynasty over the infinite horizon.

The present study also contributes to literature on optimal provision of household public goods and household public good-child mortality link. First, the findings from previous empirical studies suggest that household fuel choice is endogenous in a mortality-fuel choice relationship ([Duflo et al., 2008](#); [Schindler et al., 2017](#); [Basu et al., 2020](#)). Since household fuel choice or indoor air quality can be generalized as household public good, motivated by those existing results, we present overlapping generations model in this paper to better understand the driving mechanism of household decisions about investment in household-level public goods and its association with child mortality or health in general⁵. Although there is a rich literature on the relationship

⁴Several energy studies conducted at the household level in developing countries documented the sociodemographic determinants of household fuel choice, which are consistent with the “fuel stacking” theory, including education and gender of the household heads in urban India ([Farsi et al., 2007](#)), tastes and cultural preferences in Burkina Faso ([Ouedraogo, 2006](#)), urban India ([Farsi et al., 2007](#)) and Mozambique ([Arthur et al., 2012](#)), household size in India ([Rao and Reddy, 2007](#); [Basu et al., 2020](#)), Kenya ([Ngui et al., 2011](#)) and urban and rural areas in a set of developing countries ([Kroon et al., 2013](#)), and education or awareness in reducing the demand for traditional fuels ([Heltberg, 2004, 2005](#); [Rao and Reddy, 2007](#); [Farsi et al., 2007](#); [Chambwera and Folmer, 2007](#); [Njong and Johannes, 2011](#); [Alem et al., 2016](#)). [Alem et al. \(2016\)](#) also find that households’ economic status and price of alternative energy sources are important socioeconomic factors that determine household fuel choice in urban Ethiopia using a random-effects multinomial logit regression based on three rounds of the Ethiopian Urban Socioeconomic Survey over the period 2000-2009. [Kuo and Azam \(2019\)](#) empirically examined the stacking of fuels for rural and urban households in India and investigated the determinants of household cooking fuel choice using panel data from India Human Development Survey. Relatedly, their results from a random-effects multinomial logit model suggest that women’s bargaining power and price of liquid petroleum gas (LPG) are found as significant contributors to urban household’s decisions about the adoption of clean fuels.

⁵[Basu et al. \(2020\)](#) provide an extensive review of existing epidemiological and economic studies that investigate the simple association between indoor air pollution (IAP) and infant mortality and estimate the

between ambient air pollution, an important environmental example of a public good, or outdoor environmental conditions and fertility rates in developed and developing countries, no research theoretically addresses the interactions between intra-household public goods (e.g., household fuel choice or indoor air quality) and fertility behaviors⁶. As household public good determines the likelihood of child survival, it is an important factor for individuals or households to internalize in their fertility decisions. Our model thus is the first theoretical framework in which households optimize their fertility decisions for a given level of investment in household public goods, as well as clean fuel investment in the energy economics literature.

Second, as another contribution to the theoretical literature on household public good and its association with child mortality as well as fertility, we provide the first household public good model with dynamic structure. A dynamic investment decision model is needed to capture the decision about investing in household-level public goods, while all existing models of, for example, household fuel choice, are static. Like our setting, [Manning and Taylor \(2014\)](#) might be seen as an exception in the theoretical literature of fuel use in that it too attempts to depart from a static feature of the model and examines the decision whether invest in modern cooking and heating appliances (e.g., gas stoves or LPG purchase). But unlike our setting, investment in a gas stove is taken as exogenously given and, as such, it does not take into account endogenous investment in clean fuel—the central theme of our model in this paper. With a focus on the effect of migration on household’s gas stove-investment decisions, [Manning and Taylor \(2014\)](#) provides a simplified two-stage model where the investment decision is limited only to gas stove investment due to increased income of remittances, while we accommodate a model with infinite periods, in each period, two generations live together. It is questionable to consider that their dynamic model endogenizes the investment decision of whether or not to buy a gas stove since it does not explicitly accommodate migration decision response to any change in gas stove investment, another major instance of a household public good provision. The dynamic feature of our setting instead aims to capture the intergenerational motivation of parents’ investment in the household public goods and child’s survival likelihood across generations.

Our intra-household public goods model is also consistent with experimental evidence from existing studies examining the determinants of an individual’s willingness to pay for health-beneficial consumer products. For example, [Levine et al. \(2018\)](#) review the drivers of investment in products with health benefits and find that

causal effect of IAP on child mortality.

⁶See [Nieuwenhuijsen et al. \(2014\)](#), [Vizcaíno et al. \(2016\)](#) and [Carré et al. \(2017\)](#) for systematic surveys of epidemiological studies on the effect of outdoor air pollution on human fertility as studies on public good-fertility link in the example of ambient air quality. From the epidemiological perspective, indoor or household air pollution reduces the human fertility and even causes infertility through increasing oxidative stress that potentially leads to polycystic ovarian disease, which is one of the significant factors of infertility ([Kelly, 2003](#); [Lodovici and Bigagli, 2011](#); [Apte and Salvi, 2016](#)). On the other hand, [Kishore and Spears \(2014\)](#) shows that having a son as a firstborn in an urban Indian household increases the probability of using clean cooking fuel by 2 percentage points, i.e., enhances a household investment in intra-household public goods.

sales offer combined with free trials and time payments dramatically increases the uptake of fuel-efficient cookstoves in both rural and urban regions of Uganda. According to this technology adoption literature, one of the key factors for investment in health-beneficial household public goods, such as clean fuels and improved stoves, was found to be the provision of additional information on its health or economic benefits (Madajewicz et al., 2007; Meredith et al., 2013; Beltramo et al., 2015b). Hence, we model investment in household public goods conditional on health (e.g., probability of child survival in our model) and future economic or financial opportunities corresponding to the health conditions (transfers received during elder period)⁷. Recent theoretical and empirical studies also show that personality trait plays a critical role in human and physical capital investments. For example, Heckman et al. (2006) examine the effects of cognitive and non-cognitive skills on various behavioral and economic outcomes. For non-cognitive skills that affect individuals' investment decisions, recent empirical studies suggest that locus of control predicts health-related investments (Chiteji, 2010; Cobb-Clark et al., 2014). In addition, Abay et al. (2017) investigate the implication of non-cognitive skills (locus of control) on farmers' technology adoption decisions in Ethiopia and show that farmers with an internal locus of control are more likely to adopt new technologies or intra-household public goods such as improved cookstoves or clean energy, no indoor smoking behavior, and child vaccination.

The rest of the paper proceeds as follows. Section 2 provides background on the intra-household public goods, mortality and fertility rates, and household earnings in India, and presents the trend analysis of fertility rate associated with the household-level public good and household earnings. Section 3 formulates the model within which to examine the determination of household public goods and the potential for variation in household-level public goods to pass through into infant mortality or likelihood of survival and fertility decisions. Section 4 evaluates the welfare implications of the household public goods model. Section 5 concludes with some summary remarks.

2 Background

In this section, we discuss the trends in India's household fuel choice, indoor smoking behavior and child vaccination as major instances of investment in the intra-household public goods in our framework, fertility rate in relation to these household public goods, and household wealth. We chart the co-movement in investment in the household public goods, fertility, and earnings over time because such an exercise enables us to articulate the reasons for government intervention, if any, to influence private investment in the household public goods. For example, households in poverty and more polluted homes

⁷Another factor that explains the willingness to pay for health-beneficial products is the neighborhood or peer effect (Luoto et al., 2012; Meredith et al., 2013; Miller and Mobarak, 2014; Beltramo et al., 2015a). For example, Beltramo et al. (2015a) suggest that a neighbor's purchase of efficient cookstoves increases the odds of favoring the improved stoves by 17-22 percentage points based on a randomized control trial (RCT) in rural Uganda. However, they find that peer effects have no implications on final purchase decisions.

typically have higher fertility and a higher burden of disease due to exposure to indoor air pollution, keeping all other factors at constant (Bruce et al., 2006).

As illustrated in Figure 1a, total fertility rate⁸ for households using polluting fuel for cooking is significantly higher than that for those using clean cooking fuel in India. The total fertility rate (TFR) represents the average number of births per woman, defined as the ratio of number of births to the total number of ever-married women of reproductive age (15–49 years old). The estimate of TFR ranges from 2.5% to 4.2% and from 1.7% to 3.1% for households using dirty and clean fuels, respectively, and the fertility rates for these two different households are statistically different from each other in all years over the period 1992–2016.

Similarly, we examine the relationship between the TFR and whether anyone is smoking inside the house alongside with other household members as another example of household-level public goods. Figure 1b demonstrates that having no individual who smokes indoors, which can be seen as an investment in the household public good, is negatively associated with fertility decisions, consistent with above result for access to clean energy. We then also check if the argument is true for the provision of vaccination for children, and Figure 1c likewise presents a negative relationship between the tendency to spend on a child’s vaccination and to have a child.

In addition, we see that the TFR has been continuously decreasing over time while investment in household public goods (or use of clean fuel and child vaccination) generally has been increasing in the country (Figure 2), confirming that the household-level public goods provision in the case of clean energy access (no access) and vaccination (no vaccination) are negatively (positively) correlated with fertility across time. Additionally, Figure 3 shows that investment in the intra-household public goods (or greater use of clean fuels at homes in the left panel and vaccination of child in the right panel) is associated with greater household wealth over most of the time during the period 1992–2016.

There exist many studies that support the positive correlation between the use of clean fuel or household air quality, an important but largely ignored component of household public goods, and infant mortality. However, few empirical studies investigate the causal effect of cooking fuel choice on infant mortality. For example, Basu et al. (2020) provide empirical evidence on indoor air pollution-child mortality relationship and suggest that the use of polluting fuel for cooking significantly increases the risk of under-five and neonatal mortality using India’s Demographic Health Survey (DHS) data.

⁸The Demographic and Health Survey (DHS) datasets for the period 1992–93, 1998–99 (in fact, some survey was collected in 2000 during the second wave), 2005–06, and 2015–16 was used to calculate the TFR for the three years before the survey, excluding the month of an interview (1–36 months before the survey). Appendix A.1 briefly describes the DHS data and provides a detailed definition of indicators used in our background checks.

These observations from the background checks and our trend analysis of the association between intra-household public goods and fertility decisions using all four rounds of India’s DHS datasets of nearly a million nationally representative households over the period 1992–2016, taken together, offer descriptive motivations for our theoretical model. First, the descriptive results suggest that lack of household public good provision is associated with a higher fertility rate. Second, it indicates that greater investment in intra-household public goods is associated with lower child mortality rates. Third, in general, the co-movement of investment in the household public good and household earnings indicates that they are positively correlated.

Additionally, we empirically find that the data shows two “clusters” – high investment in household public goods and low fertility, and low investment in household public goods and high fertility. We show this by using an unsupervised machine learning technique – clustering – on a nationally representative data. In particular, we perform the K -modes clustering⁹ given that we use categorical or dummy variables for our analysis. The optimal number of clusters (i.e., equilibria) is determined by plotting a scree plot, which shows the within-groups sum of squares¹⁰ for different numbers of clusters. Unlike clustering algorithms such as X -means clustering, which is a variation of K -means clustering, any of the information criteria such as Akaike’s Information Criterion (AIC) and Bayesian Information Criterion (BIC) is applicable for K -modes clustering to determine the optimal number of clusters. Hence, we use a scree plot visualization to determine the optimal number of clusters such that minimizes the within-groups sum of squares. The result of this analysis suggests that $K = 2$ is the optimal number of clusters (Figure 4).

With this as the selected optimal number of clusters, Figure 5 visualizes results from the K -modes clustering analysis using simple graphs¹¹. For example, Figure 5b shows that the relationship between fertility and household investment in clean energy use at home is separately located (or clustered) at two different locations on the hyperplane: the first cluster is at the top-left where there is a low investment in clean energy and high fertility, and the second cluster is at the bottom-right where there is a high investment in clean energy and low fertility. Figure 5c also presents the same association and clusters between fertility and the status of no indoor smoking, which is another example of intra-household public goods. For the association between fertility and investment in child vaccination, we have slightly different picture in which most of the data points are located at the top-right where there are high child vaccination and high fertility, and points at top-left and bottom-right are not separately clustered into two groups; however, the clustering looks reasonably the same as above.

⁹See Appendix A.2 for a more detailed discussion of the K -modes algorithm.

¹⁰The within-groups sum of squares measures the variation of individual values or scores from each group or cluster center (e.g., mode, in our case) and is generally calculated as $SSW = \sum_k \sum_i (Y_{ik} - \bar{Y}_k)^2$ where Y_{ik} is the individual score and \bar{Y}_k is the center of cluster k .

¹¹Figure 6 presents the visualizations of K -modes clustering results for various values of $K \in \{1, 5\}$, including $K = 2$, which is the optimal number of clusters suggested by the scree plot for our 5-dimensional set of categorical objects or data vectors.

The average mortality and fertility rates of the first cluster (colored with black in Figure 5) are respectively 4% and 77%. Additionally, the average rates of mortality and fertility of the second cluster (colored with red in Figure 5) are zero and 39%, respectively. In the first cluster in which fertility is high, 18%, 25%, and 88% of households respectively invest in clean fuels, no indoor smoking behavior, and child vaccination. For the second cluster in which fertility is low, the percentages of households investing in clean fuels, no indoor smoking behavior, and child vaccination are 82%, 86%, and 89%, respectively. This confirms that households with many children lack in household-level public goods provision, and parents make tradeoffs between household public goods and fertility decisions as we see that fraction of households that invest in all our considered household public goods monotonically increases as the number of children in the household get fewer.

3 The Model

In this section, we first present our overlapping generations model of the intra-household public goods, and then define the equilibrium concepts, discuss the interpretation of our model findings and provide potential policy implications based on the comparative statics.

3.1 Setup

Consider a model of overlapping generations, in which each individual live for two-periods (adulthood and old age). In particular, there are L number of family lines in each period, and each family at each period t has two members, including adult and old age. Additionally, the collection of family lines at a given period t is referred to as a generation, while the collection of families across generations within a family line is referred to as a dynasty. Note that time is discrete, $t = 0, 1, \dots$. Upon reaching adulthood, an individual allocates his or her earnings y_t at time t on three items. First, the representative individual transfers σ fraction of his/her income to the parent, $t_t = \sigma y_t$. Second, the agent spends vn_t amount of income to raise n_t number of children, where v is the cost per child. Third, the adult spends $k_t \in [0, \bar{k}]$ amount of income to purchase a household public good, which (i) increases the likelihood of survival of each of the n_t number of children (π_{t+1}) from π_0 to $\pi_0(1 + k_t)$ ¹², and (ii) increases the earning capacity of surviving children (y_{t+1}) from y_0 to $y_0(1 + k_t)$.

An individual derives utility in period t from consumption c_t according to a utility function, U_t . We assume that the individual discounts each future period with a constant

¹²Since π_0 is the likelihood of child survival, then its complement, $1 - \pi_0$, is the likelihood of child mortality.

discount factor, $0 < \beta < 1$. The discounted utility of an adult over two time periods given a discount factor, β , therefore is

$$U_t = \log(c_t - \bar{c}) + \beta \log(c_{t+1} - \bar{c}), \quad \beta \in (0, 1), \quad (1)$$

where \bar{c} is a level of subsistence consumption. Since $y_t = y_0(1 + k_{t-1})$, and the adult spends c_t , vn_t , k_t and σy_t respectively on consumption, child rearing, household public goods and transfer, the budget constraint of the adult is

$$y_0(1 + k_{t-1}) = c_t + vn_t + k_t + \sigma y_0(1 + k_{t-1}). \quad (2)$$

Since $\pi_{t+1} = \pi_0(1 + k_t)$ is the likelihood of survival of each of the n children and $y_{t+1} = y_0(1 + k_t)$, the budget constraint of the individual during old age is

$$\pi_{t+1}n_t\sigma y_{t+1} = c_{t+1}, \quad (3)$$

where the amount of transfers (only source of revenue for old age) that an old age will receive from each of his or her surviving child is $t_{t+1} = \sigma y_{t+1}$.

3.2 Equilibrium and Steady State

We solve the utility maximization problem of each adult surviving into adulthood at time t , by maximizing the proposed utility function subject to the two budget constraints, taking agent's earning potential determined by investment undertaken by the parents, k_{t-1} , as given. Substituting the two budget constraints expressed in (2) and (3) into the utility function in (1) by defining c_t and c_{t+1} as a function of other inputs yields

$$\max_{\{k_t, n_t\}_{t=0}^{\infty}} U_t = \log [y_0(1 - \sigma)(1 + k_{t-1}) - vn_t - k_t - \bar{c}] + \beta \log (\pi_{t+1}n_t\sigma y_{t+1} - \bar{c}), \quad (4)$$

where the first term is adult's utility from consumption during adulthood while the second term refers to agent's utility gained over old age period. Maximizing U_t by choosing fertility n_t , the first order condition is given by, with assumption that k_t is provided for the moment

$$\frac{v}{y_0(1 - \sigma)(1 + k_{t-1}) - vn_t - k_t - \bar{c}} = \frac{\beta \pi_{t+1} \sigma y_{t+1}}{\pi_{t+1} n_t \sigma y_{t+1} - \bar{c}},$$

and utility maximizing or optimal fertility level, n_t^* , is defined as

$$n_t^* = \frac{\beta}{(1 + \beta)v} \left[y_0(1 - \sigma)(1 + k_{t-1}) - k_t - \bar{c} \left(1 - \frac{v}{\beta \pi_{t+1} \sigma y_{t+1}} \right) \right]. \quad (5)$$

If we substitute the utility maximizing fertility level, n_t^* , back into the utility function in (4), we derive the maximal discounted utility as

$$U_t(k_t, k_{t-1}) = (1 + \beta) \log \left[y_0(1 - \sigma)(1 + k_{t-1}) - k_t - \bar{c} \left(1 + \frac{v}{\pi_{t+1}\sigma y_{t+1}} \right) \right] + \\ + \beta \log(\pi_{t+1}\sigma y_{t+1}) + \log \left(\frac{1}{1 + \beta} \right) + \beta \log \left[\frac{\beta}{(1 + \beta)v} \right],$$

which is linearly proportional to the weighted average of the log of

$$y_0(1 - \sigma)(1 + k_{t-1}) - k_t - \bar{c} \left(1 + \frac{v}{\pi_{t+1}\sigma y_{t+1}} \right),$$

and the log of

$$\pi_{t+1}\sigma y_{t+1},$$

plus a constant, $\log(1/(1 + \beta)) + \beta \log(\beta/((1 + \beta)v))$. We denote this a maximum $U_t(k_t, k_{t-1})$. Upon choosing the optimal level of fertility, or internalizing the fertility decision, a consumer's utility function or the consumer's maximal attainable utility is defined as a function of investment in household public goods in the following form

$$U_t(k_t, k_{t-1}) = (1 + \beta) \log \left[y_0(1 - \sigma)(1 + k_{t-1}) - k_t - \bar{c} \left(1 + \frac{v}{\pi_0 y_0 \sigma (1 + k_t)^2} \right) \right] + \\ + 2\beta \log(1 + k_t) + (1 + \beta) \log \left(\frac{1}{1 + \beta} \right) + \beta \log \left(\frac{\beta \pi_0 y_0 \sigma}{v} \right). \quad (6)$$

Now if we maximize $U_t(k_t, k_{t-1})$ in (6) by choice of k_t , the first order condition is given by

$$\frac{(1 + \beta) \left[1 - \frac{2v\bar{c}}{\pi_0 y_0 \sigma (1 + k_t)^3} \right]}{y_0(1 - \sigma)(1 + k_{t-1}) - k_t - \bar{c} \left[1 + \frac{v}{\pi_0 y_0 \sigma (1 + k_t)^2} \right]} = \frac{2\beta}{1 + k_t},$$

and we derive the law of motion equation, which illustrates the dynamic relationship between k_t and k_{t-1} , as follows

$$k_{t-1} = g(k_t) = \alpha k_t - \frac{\hat{k}_0}{(1 + k_t)^2} + \tilde{k}_l, \quad (7)$$

where $\alpha = (1 + 3\beta)/(2\beta(1 - \sigma)y_0)$ and $\hat{k}_0 = v\bar{c}/(\beta(1 - \sigma)\pi_0\sigma y_0^2)$ are parameters, and $\tilde{k}_l = \bar{c}/((1 - \sigma)y_0) + (1 + \beta)/(2\beta(1 - \sigma)y_0) - 1$ is a constant. In Appendix A.3, we show that such a relationship always exists in greater detail. Note that $g(\cdot)$ is strictly increasing in k_t , with

$$\frac{\partial g(k_t)}{\partial k_t} = \alpha + \frac{2\hat{k}_0}{(1+k_t)^3} > 0,$$

where $\alpha > 0$ and $\hat{k}_0 \geq 0$. For all $k_{t-1} \in g(\mathbb{R}_+)$, there exist a unique point whose image is k_{t-1} . Since $k_{t-1} \in g(\mathbb{R}_+)$, there exists some k_t such that $g(k_t) = k_{t-1}$. For all $k'_t \neq k_t$, from the strict increasing property of $g(\cdot)$, we must have $g(k'_t) \neq g(k_t)$. So the inverse function $g^{-1}(\cdot)$ exists or it is well-defined. Accordingly, we can write investment in intra-household public goods at any time t given k_{t-1} as

$$k_t = g^{-1}[g(k_t)] = g^{-1}(k_{t-1}) = f(k_{t-1}), \quad (8)$$

where $g^{-1}(\cdot) = f(\cdot)$ is solution to the following cubic equation,

$$\alpha k_t^3 - (k_{t-1} - 2\alpha - \tilde{k}_l)k_t^2 - (2k_{t-1} - \alpha - 2\tilde{k}_l)k_t - (k_{t-1} + \hat{k}_0 - \tilde{k}_l) = 0. \quad (9)$$

Since $g(\cdot)$ is strictly increasing, we must have $g^{-1}(k'_{t-1}) > g^{-1}(k''_{t-1})$ for any $k'_{t-1} > k''_{t-1}$, so $g^{-1}(\cdot) = f(\cdot)$ is also strictly increasing. It follows directly that an investment equilibrium k^* is a rest point or fixed point to (8) with

$$k^* = f(k^*).$$

With this in mind, a simple application of Brouwer's fixed point theorem (Debreu, 1959) provides the following proposition:

Proposition 1. *If $f(\cdot)$ is continuous, an investment equilibrium exists.*

To this end, (7) implies that given any feasible k_{t-1} , $k_t = f(k_{t-1})$ is

$$\begin{cases} 0 < k_t \leq \bar{k}, & \text{if } \tilde{k}_l - \hat{k}_0 < k_{t-1}; \\ 0, & \text{if } 0 \leq k_{t-1} \leq \tilde{k}_l - \hat{k}_0, \end{cases}$$

where $\tilde{k}_l - \hat{k}_0 = \bar{c}/((1-\sigma)y_0) + (1+\beta)/(2\beta(1-\sigma)y_0) - v\bar{c}/(\beta(1-\sigma)\pi_0\sigma y_0^2) - 1$. This indicates that the k_t schedule has a kink at $\tilde{k}_l - \hat{k}_0$ due to a non-negativity constraint of k_t and the k_t schedule takes strictly positive values beyond the point of inheritance $k_{t-1} = \tilde{k}_l - \hat{k}_0$.

Our findings so far take investment decision of generation $t-1$ as given. Figure 7 depicts the law of motion for investment in intra-household public goods, k_t , defined in (8) under the baseline and two alternative scenarios. The horizontal and the vertical axis respectively denotes the degree of investment in household-level public goods at time $t-1$ and t . The 45° line is the set of all possible steady-state solutions corresponding to

(8). There are two scenarios where non-zero stable fixed point of this dynamic system resides at \bar{k} or optimal investment in the household public good is equal to maximum possible investment level. Begin with the baseline scenario where dynamically stable steady level of investment in household public goods resides at \bar{k} when $f(k_{t-1})$ crosses 45° line at the point of $k_{t-1} = k_t = \bar{k}$ after it reaches the $k_t = \bar{k}$ as numerically illustrated in Figure 7a. Alternatively, depending on parameter values, function k_t intersects 45° line for the second time exactly at \bar{k} . One such scenario or equilibrium is shown in Figure 7b. Notice that, in these first two scenarios, we have k_{t-1} , which is weakly less than \bar{k} , being able to generate \bar{k} in period t . Although there exist these two scenarios where k_t intersects 45° line for strictly positive values of k_{t-1} , it is also possible that the k_t schedule intersects the 45° line only once, at the origin, and never intersects the 45° for any strictly positive values of k_{t-1} that is less than \bar{k} (Figure 7c).

From (8), the investment schedule $f(k_{t-1})$ for inheritance $k_{t-1} \geq \tilde{k}_l - \hat{k}_0$ is both strictly increasing and convex in k_{t-1} ¹³. In baseline scenario, the k_t schedule intersects the 45° line three times, or there are total of three fixed points or equilibria where $k_t = k_{t-1}$. Interior steady states are given by the intersection of the 45° line and the k_t schedule. Since $k_t \geq 0$, $k_t = f(k_{t-1})$ starts from the origin where it intersects the 45° line for the first time. Then k_t function intersects the 45° line at $k^* \in (0, \bar{k})$ for the second time. The investment in the household public good is bounded by construction, $k_t \in [0, \bar{k}]$, therefore, function k_t crosses the 45° line at $k^{**} = \bar{k}$ for the last time. It can be readily verified that the steady states or fixed points k^* and k^{**} exist, and k^* is dynamically unstable or locally repelling, with $|(\partial k_t / \partial k_{t-1})|_{k_{t-1}=k^*}| > 1$, while k^{**} is dynamically stable or locally attracting, with $|(\partial k_t / \partial k_{t-1})|_{k_{t-1}=k^{**}}| < 1$. In each of the three scenarios except for the last one, there are two long-run dynamically stable equilibria (i) at \bar{k} which is strictly greater than the repelling fixed point k^* , and (ii) at the origin which is strictly less than k^* . In particular, if k_{t-1} is less than the unstable equilibrium, the dynamic system will converge to zero. We have thus:

Proposition 2. *In the overlapping generations model with intra-household public goods that are complementary to child mortality, there exist two dynamically stable steady states, including one with zero investment (trivial) and another with investment at maximum possible level (non-zero or non-trivial).*

The result of Proposition 2 strongly suggests that there are two “clusters”, which is supported by the data in the previous section.

¹³To see this, note that $\partial g(k_t) / \partial k_t > 0$ and $\partial^2 g(k_t) / \partial k_t^2 = -6\hat{k}_0(1 + k_t)^{-4} < 0$, which indicates that $g(k_t)$ is strictly concave, and $f(k_{t-1}) = g^{-1}(k_{t-1})$ is strictly convex because an inverse function of strictly increasing and concave function is strictly convex.

3.3 Comparative Statics

Effects of Investment in Intra-Household Public Goods on Fertility: The household makes a trade-off between investment in household-level public goods and fertility decisions as the utility-maximizing fertility level defined in (5) decreases in response to increase in investment in household public goods, assuming that k_{t-1} is given,

$$\frac{\partial n_t^*}{\partial k_t} = -\frac{\beta}{(1+\beta)v} \left[1 + \frac{2v}{\beta\pi_0\sigma y_0(1+k_t)^3} \right] < 0, \quad (10)$$

since $\pi_{t+1} = \pi_0(1+k_t)$ and $y_{t+1} = y_0(1+k_t)$. This provides the following proposition:

Proposition 3. *Households make tradeoffs between investment in intra-household public goods and fertility decisions.*

Effects of Investment in Intra-Household Public Goods on Utility: Taking the total derivative of (6), by implicit function theorem, the change in maximum utility from a change in household investment in household public goods can be written as

$$\frac{dU_t(k_t, k_{t-1})}{dk_t} = \frac{(1+\beta) \left[\frac{2v\bar{c}}{\pi_0 y_0 \sigma (1+k_t)^3} - 1 \right]}{y_0(1-\sigma)(1+k_{t-1}) - k_t - \bar{c} \left[1 + \frac{v}{\pi_0 y_0 \sigma (1+k_t)^2} \right]} + \frac{2\beta}{1+k_t} > 0, \quad (11)$$

for $k_t < (2v\bar{c}/\pi_0 y_0 \sigma)^{1/3} - 1$ since all other terms in (11) are positive. The comparative statics of the maximum $U_t(k_t, k_{t-1})$ with respect to k_t suggests several important policy implications. First, investment in intra-household public goods (or increase in k_t) would directly decrease an individual's utility during the adulthood by reducing his/her disposable income for consumption; however, it can have a positive impact on utility over this period when $k_t < (2v\bar{c}/\pi_0 y_0 \sigma)^{1/3} - 1$ or investment in intra-household public goods is bounded above by some upper bound. This indicates that too much investment in household-level public goods reduces adults' maximum possible utility by lowering the expenditure potential on consumption goods. Second, investment in health-benefiting household public goods increases an individual's utility over an old age period at all times or for all non-negative values of k_t through improving the child's likelihood of survival and resulting increase in intergenerational transfer income or returns to investment in household public goods in the earlier period, i.e.,

$$\frac{\partial \beta \log [\pi_0 y_0 \sigma (1+k_t)^2]}{\partial k_t} = \frac{2\beta}{1+k_t} > 0,$$

since $\beta > 0$ and $k_t \geq 0$. This result is intuitive, given our two-generations setting, because an individual's income and thus consumption during the old age period increases in response to an increase in k_t , and elders do not allocate their income resource to investment in intra-household public goods. Hence, there is no reason that an individual's utility over an old age period to decrease in response to positive investment in k_t .

4 Welfare Analysis

Each adult makes decisions to maximize his or her welfare, rather than that of the family dynasty. We call this a “holdup problem”. Consider therefore the problem of an adult faced with the decision whether investing in intra-household public goods. The maximal discounted utility of such an adult, as defined in (6) above, is given by

$$U(k^*) = (1 + \beta) \log \left[y_0(1 - \sigma)(1 + k^*) - k^* - \bar{c} \left(1 + \frac{v}{\pi_0 y_0 \sigma (1 + k^*)^2} \right) \right] \\ + \beta \log \left[\pi_0 y_0 \sigma (1 + k^*)^2 \right] + \left\{ \log \left(\frac{1}{1 + \beta} \right) + \beta \log \left[\frac{\beta}{(1 + \beta)v} \right] \right\},$$

where $k_{t-1} = k_t = k^*$. We maximize the utility function with respect to k^* , and the first order condition is given by

$$\frac{(1 + \beta) \left[1 - y_0(1 - \sigma) - \left(\frac{2v\bar{c}}{\pi_0 y_0 \sigma} \right) \frac{1}{(1 + k^*)^3} \right]}{y_0(1 - \sigma)(1 + k^*) - k^* - \bar{c} - \frac{v\bar{c}}{\pi_0 y_0 \sigma (1 + k^*)^2}} = \frac{2\beta}{1 + k^*}.$$

Rearranging the above expression and collecting the terms yield

$$(1 + 3\beta) [1 - y_0(1 - \sigma)] k^{*3} + [2\beta\bar{c} + 7\beta + 3 - 3(1 + 3\beta)y_0(1 - \sigma)] k^{*2} + \\ + [4\beta\bar{c} + 5\beta + 3 - 3(1 + 3\beta)y_0(1 - \sigma)] k^* - \\ - (1 + 3\beta)y_0(1 - \sigma) + 2\beta\bar{c} + \beta + 1 - \frac{2v\bar{c}}{\pi_0 y_0 \sigma} = 0.$$

Then the steady state welfare of an adult can be found solving the above equality for k^* . Once we find the steady state welfare of an adult, we maximize the steady state welfare of the household to define under what condition will such k^* exceed (or fall below or match) the steady state equilibrium found in the previous section. This will be further explored in the future work.

5 Conclusion

This paper presents a dynamic model, which interlinks investment in intra-household public goods with both child mortality or infant survival and fertility decisions. By developing a model in which investment in household-level public goods affects infant survival based on the setup of overlapping generations of economic agents, we show that there is a trade-off between intra-household public goods and fertility decisions. The overlapping generations structure enables us to formulate the intergenerational effects of household public goods (e.g., indoor air pollution, indoor smoking behavior, and child

vaccination) on long-term earning potential of both parents and children and child mortality or inverse of child survival likelihood as well as the potential tradeoffs between intra-household public goods and fertility decisions. We empirically motivate the key features of our model by leveraging multiple waves of a nationally representative household survey data.

We contribute to at least two distinct economic literature, with several extensions in some subfields in various directions. First, this paper adds to economic literature on household public goods by exploring the interaction between decisions about household public goods other than children, which has been considered as the main household public goods in the current literature, and the number of children or fertility. We model the household public good as it affects child mortality or survival using standard tools from the neoclassical growth theory of the consumer. Considering that indoor air pollution as the key component of intra-household public goods that have been undertaken, we argue that the present study contributes to the economic subfield of energy and fuel use models. In addition to endogenizing the investment in household public goods, second, we extend the economic literature on the model of fertility and household fertility decisions by endogenizing the fertility choice and showing that household investment in intra-household public goods is negatively associated with fertility rate.

Upon optimally choosing an investment in intra-household public goods or maximizing an indirect utility function with respect to household-level public goods, we show that the dynamic relationship of investment in household public goods exists. Notably, we find that there are two dynamically stable equilibrium outcomes both at the boundaries (instead of interior solutions) and non-zero dynamically stable steady-state equilibrium is uniquely determined at the upper bound of household investment in intra-household public goods.

References

- Abay, Kibrom A., Garrick Blalock, and Guush Berhane.** 2017. "Locus of Control and Technology Adoption in Developing Country Agriculture: Evidence from Ethiopia." *Journal of Economic Behavior & Organization*, 143: 98–115.
- Alem, Yonas, Abebe D. Beyene, Gunnar Köhlin, and Alemu Mekonnen.** 2016. "Modeling Household Cooking Fuel Choice: A Panel Multinomial Logit Approach." *Energy Economics*, 59: 129–137.
- Apte, Komalkirti, and Sundeep Salvi.** 2016. "Household Air Pollution and Its Effects on Health." *F1000Research*, 5.
- Arthur, Maria de Fátima S.R., Craig A. Bond, and Bryan Willson.** 2012. "Estimation of Elasticities for Domestic Energy Demand in Mozambique." *Energy Economics*, 34(2): 398–409.
- Barro, Robert J., and Gary S. Becker.** 1989. "Fertility Choice in a Model of Economic Growth." *Econometrica*, 57(2): 481–501.
- Basu, Arnab K., Tsenguunjav Byambasuren, Nancy H. Chau, and Neha Khanna.** 2020. "Cooking Fuel Choice, Indoor Air Quality and Child Mortality in India." IZA Discussion Paper No. 13295.
- Becker, Gary S.** 1960. "An Economic Analysis of Fertility." In *Demographic and Economic Change in Developed Countries*.: Princeton University Press, 209–240.
- Becker, Gary S.** 1965. "A Theory of the Allocation of Time." *The Economic Journal*, 75(299): 493–517.
- Becker, Gary S., and H. Gregg Lewis.** 1973. "On the Interaction between the Quantity and Quality of Children." *Journal of Political Economy*, 81(2): S279–S288.
- Behrman, Jere R.** 1997. "Intrahousehold Distribution and the Family." In *Handbook of Population and Family Economics*, 2nd edition. eds. by Mark R. Rosenzweig, and Oded Stark, Amsterdam: North-Holland, 125–187.
- Beltramo, Theresa, Garrick Blalock, David I. Levine, and Andrew M. Simons.** 2015a. "Does Peer Use Influence Adoption of Efficient Cookstoves? Evidence from a Randomized Controlled Trial in Uganda." *Journal of Health Communication*, 20(sup1): 55–66.
- Beltramo, Theresa, Garrick Blalock, David I. Levine, and Andrew M. Simons.** 2015b. "The Effect of Marketing Messages and Payment Over Time on Willingness to Pay for Fuel-Efficient Cookstoves." *Journal of Economic Behavior & Organization*, 118: 333–345.
- Bergstrom, Theodore C.** 1997. "A Survey of Theories of the Family." In *Handbook of Population and Family Economics*, 2nd edition. eds. by Mark R. Rosenzweig, and Oded Stark, Amsterdam: North-Holland, 21–79.
- Boldrin, Michele, and Larry E. Jones.** 2002. "Mortality, Fertility, and Saving in a Malthusian Economy." *Review of Economic Dynamics*, 5(4): 775–814.
- Bruce, Nigel, Eva Rehfuss, Sumi Mehta, Guy Hutton, and Kirk Smith.** 2006. "Indoor

- Air Pollution." In *Disease Control Priorities in Developing Countries, 2nd edition*. eds. by Joel G. Breman Dean T. Jamison, Anthony R. Measham et al. Washington, DC: The World Bank, 793–815.
- Carré, Julie, Nicolas Gatimel, Jessika Moreau, Jean Parinaud, and Roger Léandri.** 2017. "Does Air Pollution Play a Role in Infertility?: A Systematic Review." *Environmental Health*, 16(1): 82–82.
- Caudill, Steven B., and Franklin G. Mixon.** 1995. "Modeling Household Fertility Decisions: Estimation and Testing of Censored Regression Models for Count Data." *Empirical Economics*, 20(2): 183–196.
- Chambwera, Muyeye, and Henk Folmer.** 2007. "Fuel Switching in Harare: An Almost Ideal Demand System Approach." *Energy Policy*, 35(4): 2538–2548.
- Chaudhuri, Shubham, and Alexander Pfaff.** 2002. "Economic Growth and the Environment: What Can We Learn from Household Data?." Mimeo, Columbia University.
- Chen, Le, Nico Heerink, and Marrit van den Berg.** 2006. "Energy Consumption in Rural China: A Household Model for Three Villages in Jiangxi Province." *Ecological Economics*, 58(2): 407–420.
- Chiappori, Pierre-Andre, and Yoram Weiss.** 2001. "Marriage Contracts and Divorce: An Equilibrium Analysis." Mimeo, Tel Aviv University.
- Chiteji, Ngina.** 2010. "Time Preference, Noncognitive Skills and Well Being Across the Life Course: Do Noncognitive Skills Encourage Healthy Behavior?" *American Economic Review: Papers & Proceedings*, 100(2): 200–204.
- Cobb-Clark, Deborah A., Sonja C. Kassenboehmer, and Stefanie Schurer.** 2014. "Healthy Habits: The Connection between Diet, Exercise, and Locus of Control." *Journal of Economic Behavior & Organization*, 98: 1–28.
- Das, Sukanya, Hugo De Groote, Bhagirath Behera et al.** 2014. "Determinants of Household Energy Use in Bhutan." *Energy*, 69: 661–672.
- Debreu, Gerard.** 1959. *Theory of Value: An Axiomatic Analysis of Economic Equilibrium.*: Yale University Press.
- Doepke, Matthias.** 2005. "Child Mortality and Fertility Decline: Does the Barro-Becker Model Fit the Facts?" *Journal of Population Economics*, 18(2): 337–366.
- Duflo, Esther, Michael Greenstone, and Rema Hanna.** 2008. "Indoor Air Pollution, Health and Economic Well-being." *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society*, 1(1).
- Edwards, John H.Y., and Christian Langpap.** 2005. "Startup Costs and the Decision to Switch from Firewood to Gas Fuel." *Land Economics*, 81(4): 570–586.
- Farsi, Mehdi, Massimo Filippini, and Shonali Pachauri.** 2007. "Fuel Choices in Urban Indian Households." *Environment and Development Economics*, 12(6): 757–774.
- Gupta, Gautam, and Gunnar Köhlin.** 2006. "Preferences for Domestic Fuel: Analysis with Socio-economic Factors and Rankings in Kolkata, India." *Ecological Economics*,

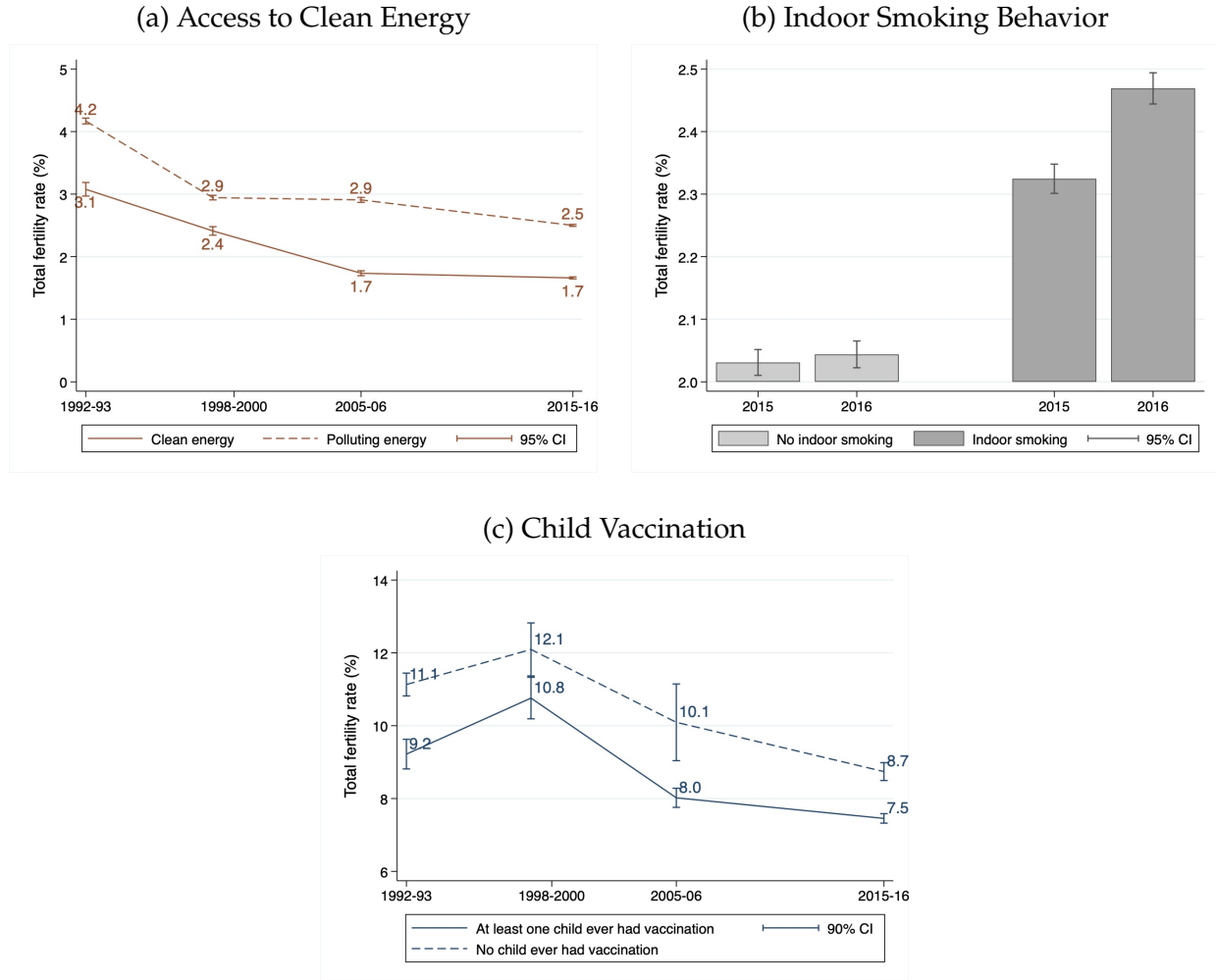
57(1): 107–121.

- Heckman, James J., Jora Stixrud, and Sergio Urzua.** 2006. "The Effects of Cognitive and Noncognitive Abilities on Labor Market Outcomes and Social Behavior." *Journal of Labor Economics*, 24(3): 411–482.
- Heckman, James J., and James R. Walker.** 1990. "The Relationship between Wages and Income and the Timing and Spacing of Births: Evidence from Swedish Longitudinal Data." *Econometrica*, 58(6): 1411–1441.
- Heltberg, Rasmus.** 2004. "Fuel Switching: Evidence from Eight Developing Countries." *Energy Economics*, 26(5): 869–887.
- Heltberg, Rasmus.** 2005. "Factors Determining Household Fuel Choice in Guatemala." *Environment and Development Economics*, 10(3): 337–361.
- Heltberg, Rasmus, Thomas Channing Arndt, and Nagothu Udaya Sekhar.** 2000. "Fuelwood Consumption and Forest Degradation: A Household Model for Domestic Energy Substitution in Rural India." *Land Economics*, 76(2): 213–232.
- Huang, Zhexue.** 1997. "A Fast Clustering Algorithm to Cluster Very Large Categorical Data Sets in Data Mining." In *KDD: Techniques and Applications*. eds. by H. Motoda H. Lu, and H. Luu, Singapore: World Scientific, 21–39.
- Huang, Zhexue.** 1998. "Extensions to the k-Means Algorithm for Clustering Large Data Sets with Categorical Values." *Data Mining and Knowledge Discovery*, 2(3): 283–304.
- Kelly, Frank J.** 2003. "Oxidative Stress: Its Role in Air Pollution and Adverse Health Effects." *Occupational and Environmental Medicine*, 60(8): 612–616.
- Kishore, Avinash, and Dean Spears.** 2014. "Having a Son Promotes Clean Cooking Fuel Use in Urban India: Women's Status and Son Preference." *Economic Development and Cultural Change*, 62(4): 673–699.
- Kowsari, Reza, and Hisham Zerriffi.** 2011. "Three Dimensional Energy Profile: A Conceptual Framework for Assessing Household Energy Use." *Energy Policy*, 39(12): 7505–7517.
- van der Kroon, Bianca, Roy Brouwer, and Pieter J.H. van Beukering.** 2013. "The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis." *Renewable and Sustainable Energy Reviews*, 20: 504–513.
- van der Kroon, Bianca, Roy Brouwer, and Pieter J.H. van Beukering.** 2014. "The Impact of the Household Decision Environment on Fuel Choice Behavior." *Energy Economics*, 44: 236–247.
- Kumar, K.S. Kavi, and Brinda Viswanathan.** 2007. "Changing Structure of Income Indoor Air Pollution Relationship in India." *Energy Policy*, 35(11): 5496–5504.
- Kuo, Ying-Min, and Mehtabul Azam.** 2019. "Household Cooking Fuel Choice in India, 2004-2012: A Panel Multinomial Analysis." IZA Discussion Paper No. 12682.
- Lay, Jann, Janosch Ondraczek, and Jana Stoever.** 2013. "Renewables in the Energy Transition: Evidence on Solar Home Systems and Lighting Fuel Choice in Kenya." *Energy Economics*, 40: 350–359.

- Leibowitz, Arleen.** 1974. "Home Investments in Children." *Journal of Political Economy*, 82(2): 111–131.
- Levine, David I., Theresa Beltramo, Garrick Blalock, Carolyn Cotterman, and Andrew M. Simons.** 2018. "What Impedes Efficient Adoption of Products? Evidence from Randomized Sales Offers for Fuel-Efficient Cookstoves in Uganda." *Journal of the European Economic Association*, 16(6): 1850–1880.
- Lodovici, Maura, and Elisabetta Bigagli.** 2011. "Oxidative Stress and Air Pollution Exposure." *Journal of Toxicology*, 2011.
- Luoto, Jill, Minhaj Mahmud, Jeff Albert, Stephen Luby, Nusrat Najnin, Leanne Unicomb, and David I. Levine.** 2012. "Learning to Dislike Safe Water Products: Results from a Randomized Controlled Trial of the Effects of Direct and Peer Experience on Willingness to Pay." *Environmental Science & Technology*, 46(11): 6244–6251.
- MacQueen, James et al.** 1967. "Some Methods for Classification and Analysis of Multivariate Observations." In *Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability*. eds. by Lucien Marie Le Cam, and Jerzy Neyman 281–297, Berkeley, CA: University of California Press.
- Madajewicz, Malgosia, Alexander Pfaff, Alexander Van Geen, Joseph Graziano, Iftikhar Hussein, Hasina Momotaj, Roksana Sylvi, and Habibul Ahsan.** 2007. "Can Information Alone Change Behavior? Response to Arsenic Contamination of Groundwater in Bangladesh." *Journal of Development Economics*, 84(2): 731–754.
- Manning, Dale T., and J. Edward Taylor.** 2014. "Migration and Fuel Use in Rural Mexico." *Ecological Economics*, 102: 126–136.
- Masera, Omar R., Barbara D. Saatkamp, and Daniel M. Kammen.** 2000. "From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model." *World Development*, 28(12): 2083–2103.
- Melkersson, Maria, and Dan-Olof Rooth.** 2000. "Modeling Female Fertility using Inflated Count Data Models." *Journal of Population Economics*, 13(2): 189–203.
- Meredith, Jennifer, Jonathan Robinson, Sarah Walker, and Bruce Wydick.** 2013. "Keeping the Doctor Away: Experimental Evidence on Investment in Preventative Health Products." *Journal of Development Economics*, 105: 196–210.
- Miller, Grant, and A. Mushfiq Mobarak.** 2014. "Learning about New Technologies through Social Networks: Experimental Evidence on Nontraditional Stoves in Bangladesh." *Marketing Science*, 34(4): 480–499.
- Muller, Christophe, and Huijie Yan.** 2018. "Household Fuel Use in Developing Countries: Review of Theory and Evidence." *Energy Economics*, 70: 429–439.
- Ngui, Dianah, John Mutua, Hellen Osiolo, and Eric Aligula.** 2011. "Household Energy Demand in Kenya: An Application of the Linear Approximate Almost Ideal Demand System (LA-AIDS)." *Energy Policy*, 39(11): 7084–7094.
- Nguyen-Dinh, Huan.** 1997. "A Socioeconomic Analysis of the Determinants of Fertility: The Case of Vietnam." *Journal of Population Economics*, 10(3): 251–271.
- Nieuwenhuijsen, Mark J., Xavier Basagaña, Payam Dadvand, David Martinez, Marta**

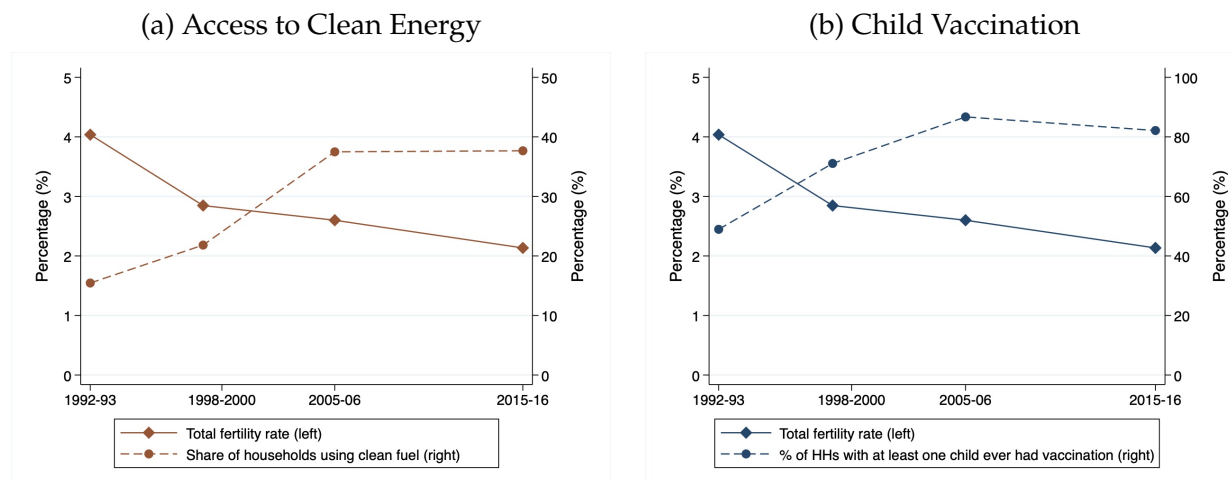
- Cirach, Rob Beelen, and Bénédicte Jacquemin.** 2014. "Air Pollution and Human Fertility Rates." *Environment International*, 70: 9–14.
- Njong, A.M., and T.A. Johannes.** 2011. "An Analysis of Domestic Cooking Energy Choices in Cameroon." *European Journal of Social Sciences*, 20(2): 336–347.
- Olsen, Randall J., and Kenneth I. Wolpin.** 1983. "The Impact of Exogenous Child Mortality on Fertility: A Waiting Time Regression with Dynamic Regressors." *Econometrica*, 51(3): 731–749.
- Ouedraogo, Boukary.** 2006. "Household Energy Preferences for Cooking in Urban Ouagadougou, Burkina Faso." *Energy Policy*, 34(18): 3787–3795.
- Pfaff, Alexander S.P., Shubham Chaudhuri, and Howard L.M. Nye.** 2004. "Household Production and Environmental Kuznets Curves—Examining the Desirability and Feasibility of Substitution." *Environmental and Resource Economics*, 27(2): 187–200.
- Rao, M. Narasimha, and B. Sudhakara Reddy.** 2007. "Variations in Energy Use by Indian Households: An Analysis of Micro Level Data." *Energy*, 32(2): 143–153.
- Rasul, Imran.** 2000. "Children as a Household Public Good." Mimeo, London School of Economics.
- Sah, Raaj K.** 1991. "The Effects of Child Mortality Changes on Fertility Choice and Parental Welfare." *Journal of Political Economy*, 99(3): 582–606.
- Schindler, Mirjam, Geoffrey Caruso, and Pierre Picard.** 2017. "Equilibrium and First-Best City with Endogenous Exposure to Local Air Pollution from Traffic." *Regional Science and Urban Economics*, 62: 12–23.
- Strauss, John, Germano Mwabu, and Kathleen Beegle.** 2000. "Intrahousehold Allocations: A Review of Theories and Empirical Evidence." *Journal of African Economies*, 9(Supplement 1): 83–143.
- Vizcaíno, Miguel A. Checa, Mireia Gonzalez-Comadran, and Benedicte Jacquemin.** 2016. "Outdoor Air Pollution and Human Infertility: A Systematic Review." *Fertility and Sterility*, 106(4): 897–904.
- Wang, Weiren, and Felix Famoye.** 1997. "Modeling Household Fertility Decisions with Generalized Poisson Regression." *Journal of Population Economics*, 10(3): 273–283.
- Weiss, Yoram, and Robert J. Willis.** 1985. "Children as Collective Goods and Divorce Settlements." *Journal of Labor Economics*, 3(3): 268–292.
- Wolpin, Kenneth I.** 1984. "An Estimable Dynamic Stochastic Model of Fertility and Child Mortality." *Journal of Political Economy*, 92(5): 852–874.

Figure 1: Trend of Total Fertility Rate associated with Household Public Goods



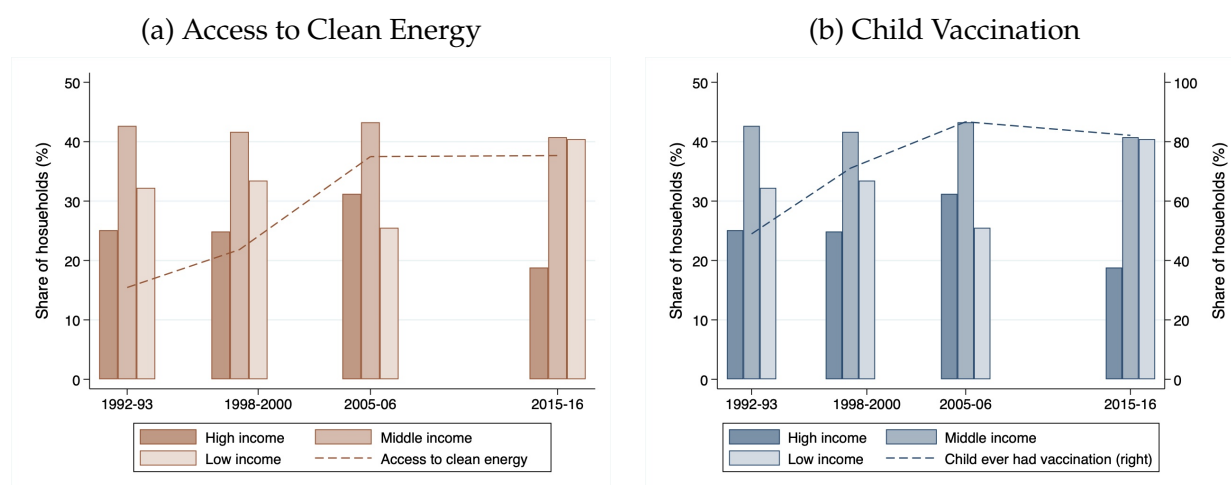
Notes: Based on India's DHS datasets 1992–93, 1998–2000, 2005–06, and 2015–16. The figure presents the time trend of the total fertility rate (TFR) in India in association with intra-household public goods, including the types of fuels used for cooking (panel (a)), whether there is any household member smoking inside the house (panel (b)), and whether any one of the children is ever had vaccination (panel (c)). An indicator for household members' indoor smoking behavior is constructed based on a variable of the frequency of smoking by anyone of the family members in the house, which was only asked in the DHS-4 (2015–16). Despite this, we still can show the time trend of TFR in association with household members' indoor smoking behavior because a single wave of the DHS covers multiple years, 2015 and 2016 for DHS-4, for example. A binary variable of whether indoor smoking takes the value 1 if household members never smoke inside the house in household h , in village v , in district d of state s , in survey year t , and 0 otherwise. All four rounds of DHS collect data on vaccination of every under-five child of interviewed women, and we define a dummy variable indicating whether at least one of the children ever had a vaccination. The TFR for households at least one child ever treated with vaccination is different from that for those without any child ever received vaccination at the 95% level except for 1998–2000, where the two are significantly different at the 90% level.

Figure 2: Trends of Investment in Household Public Goods and Total Fertility Rates



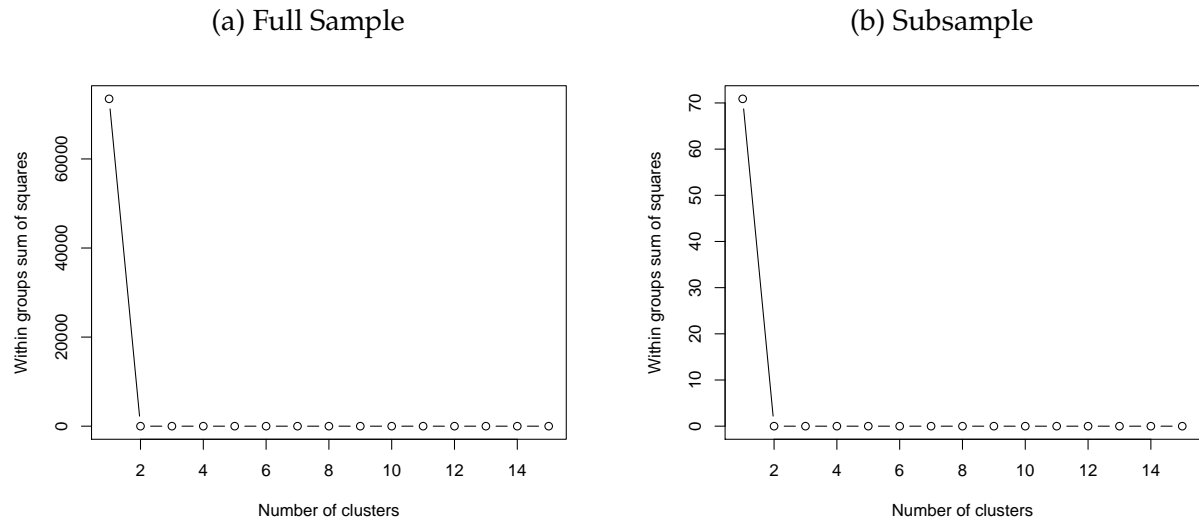
Notes: The figure shows the co-movement of the tendency to invest in household public goods and total fertility rate over time, based on India's DHS data sets, in the examples of the use of clean fuels for cooking (left panel) and child vaccination (right panel). Panel (a) suggests that fertility has been continuously declining, while the share of households using clean fuels for cooking has been growing with level-off over the past ten years before DHS-4 (2015–16). Panel (b) similarly shows that child vaccination grows while fertility rate declines over the period before DHS-3 (2005–06), although share of households with at least one child ever had vaccination slightly drops during a decade between 2005–06 and 2015–16. We thus generally see that there is a negative relationship between fertility and investment in the household public goods. One may expect that intra-household public goods provision and fertility rates should be positively correlated, arguing that parents would prefer to have child and raise their children in a better or cleaner environment. However, it could be the opposite, i.e., the two are negatively associated because the decision to invest in household public goods makes households or individuals to work more instead of staying at home to afford clean fuels and vaccination and further leads to fertility drop.

Figure 3: Trends of Household Public Goods Provision and Household Earnings



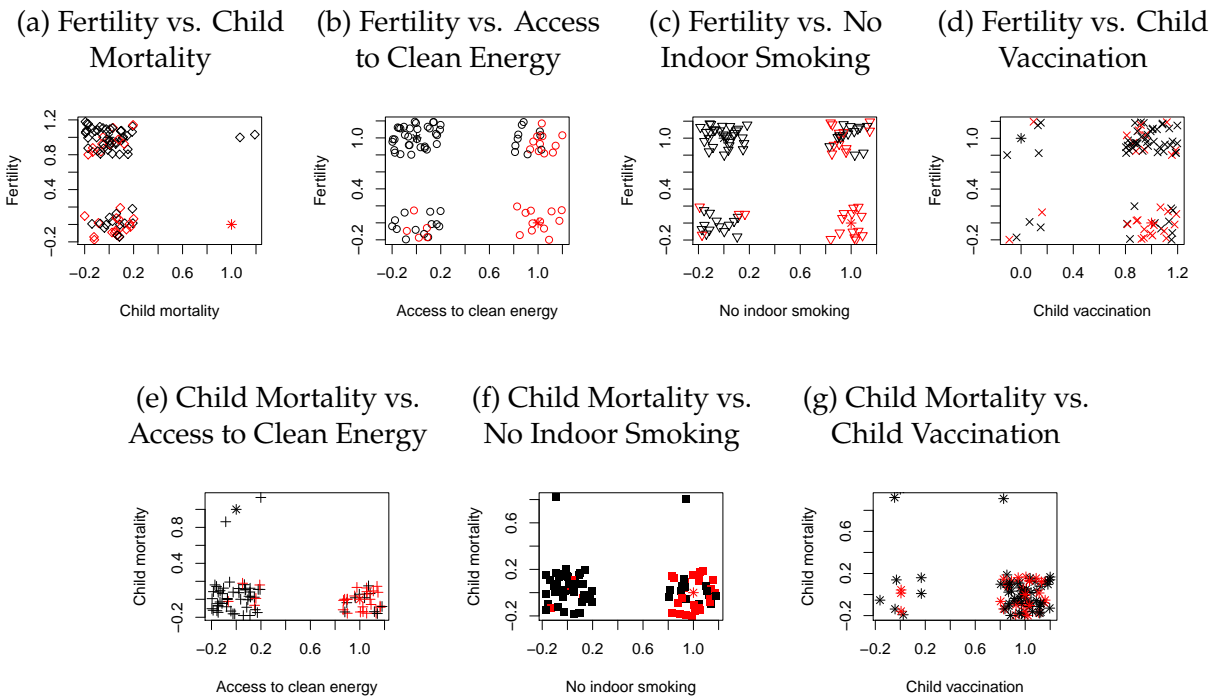
Notes: The figure shows the co-movement of household public goods provision and household wealth (described by the household wealth index) over time, based on India's DHS data sets. We observe that the share of middle-income households stabilizes at around 40% since the early 1990s. The share of high-income households has been growing over the considered period, while the share of low-income households has been declining since 1992–93, except for periods from 2005–06 to 2015–16. During a decade between 2005–06 and 2015–16, in contrast, the share of high-income households plummeted, whereas the share of low-income households shrinks down sharply. Hence, we see that a higher level of investment in the household public goods in the examples of household investment in clean fuel (left panel) and child vaccination (right panel) is associated with greater household earnings over the periods of first three rounds of DHS (from 1992–93 to 2005–06).

Figure 4: Scree Plot



Notes: The figure depicts the scree plot to determine the optimal number of clusters. Panel (a) shows the scree plot based on the K -modes clustering performed on full sample of India's DHS-4 (2015–16) that consists of $N = 84,286$ ever-married women. Panel (b) similarly shows the scree plot of the K -modes clustering analysis using 0.1 percent of the full sample (i.e., $N = 84$ ever married women), which is used for the K -modes clustering visualized in Figure 5. The number of objects is five (i.e., $M = 5$), and fertility, child mortality, household fuel choice, indoor smoking behavior, and child vaccination status are included.

Figure 5: The K -Modes Clustering for Fertility, Child Mortality, and Household Public Goods ($K = 2$)



Notes: Based on a subsample of $N = 84$ (0.1 percent of the full sample) randomly drawn from India's DHS dataset 2015–16 for clearer illustration. Given that we have categorical data, the figure depicts the results from a 5-dimensional ($M = 5$) cluster analysis of fertility, child mortality, and considered three examples of intra-household public goods (including access to clean energy, indoor smoking behavior, and child vaccination) clustering using the K -modes algorithm ($K = 2$). The clusters are visualized with some jitter or random displacement for an illustration purpose.

Figure 6: The K -Modes Clustering for Fertility, Child Mortality, and Household Public Goods, $K \in \{1, 5\}$

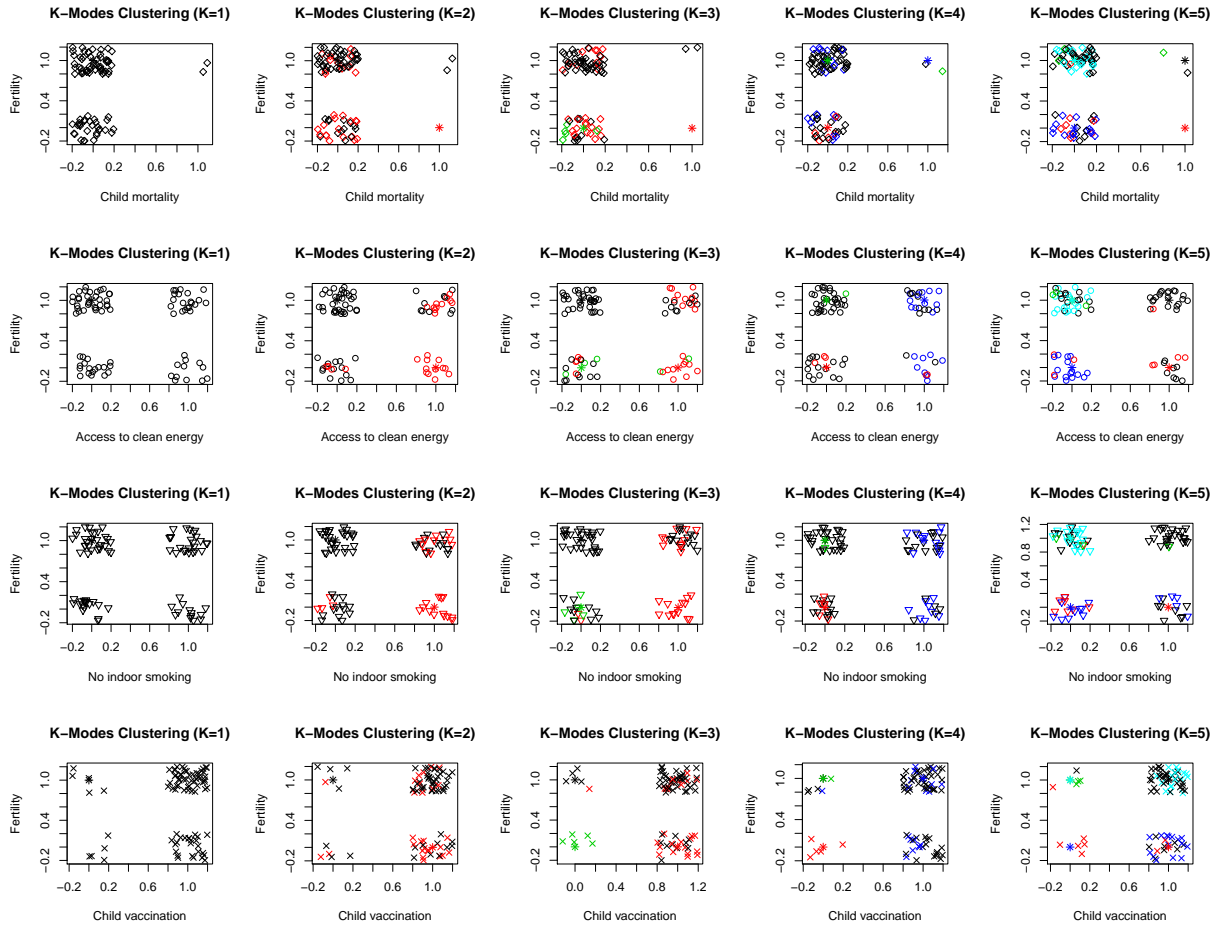
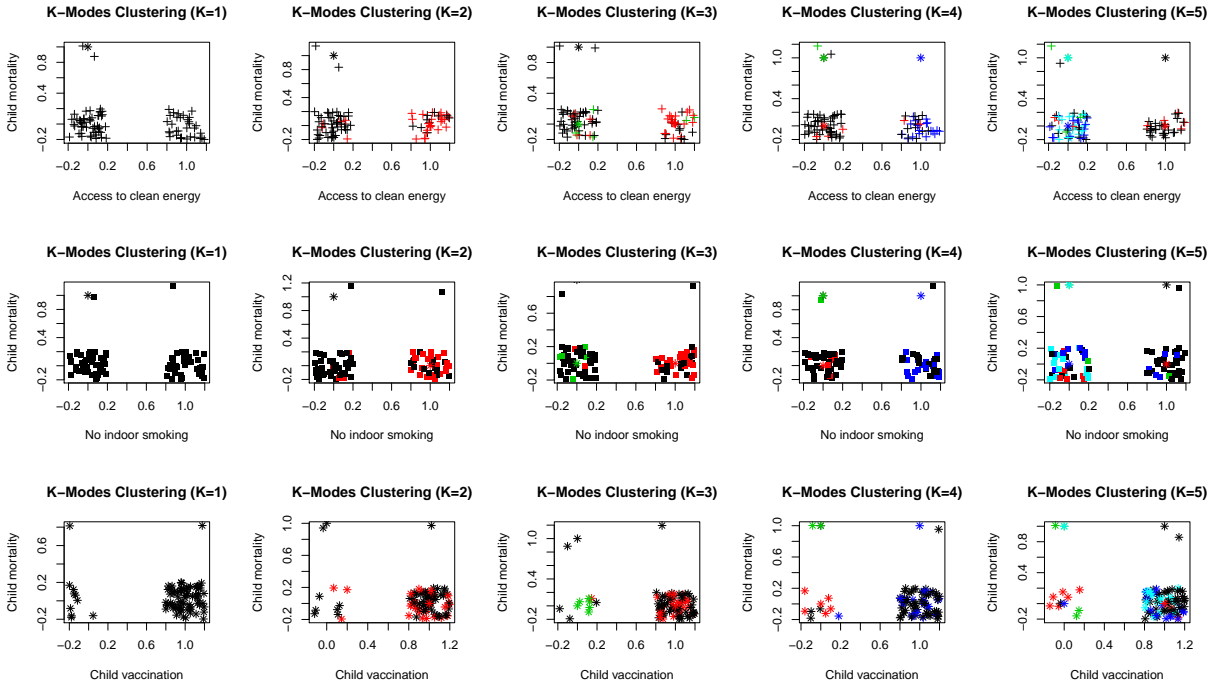
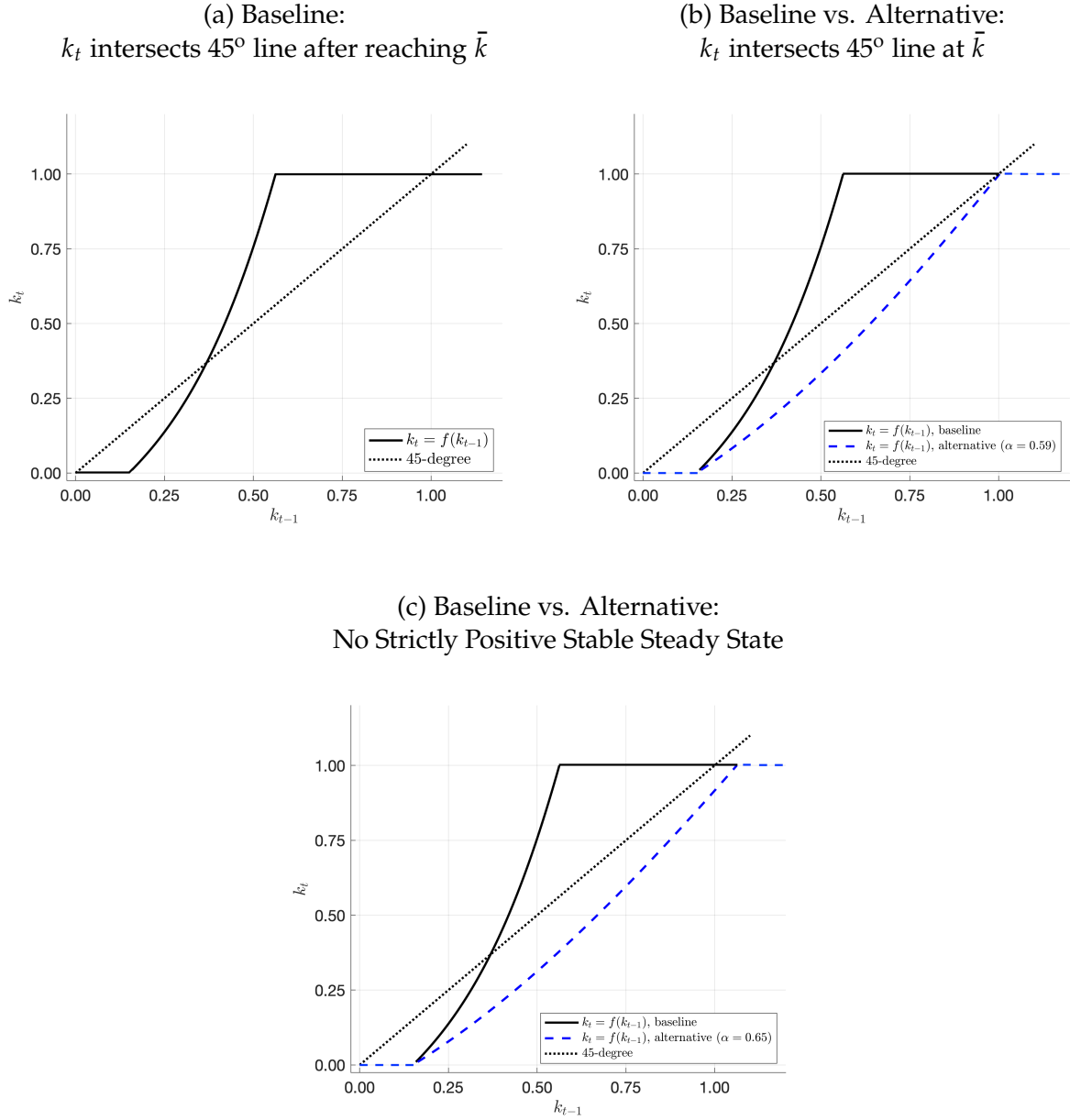


Figure 6: (Continued)



Notes: Based on a subsample of $N = 84$ (0.1 percent of the full sample) randomly drawn from India's DHS-4 (2015–16) dataset. The figure presents results from the K -modes clustering analysis for five objects of our interest ($M = 5$) and predetermined different numbers of clusters, $K \in \{1, 5\}$.

Figure 7: The Law of Motion for k_t



Notes: Based on expression in Equation (7), this figure plots the law of motion for investment in intra-household public goods, k_t , under the baseline (panel (a)) and two alternative scenarios (panels (b) and (c)). The baseline parameter calibration are $\alpha = 0.15$, $\bar{k} = 1$, $\hat{k}_0 = 0.35$, $\hat{k}_l = 0.5$, and the point where k_t crosses the $k_t = 0$ line is thus $\hat{k}_l - \hat{k}_0 = 0.15$.