Model-Aided Identification of Policy Effects using RCTs

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Introduction

- RCTs gold standard for treatment effects.
- Evaluation of programs/policies τ on choices/outcomes Y
- Most RCTs are short run (SR): *Limited Duration* RCTs
- Many RCTs have endogenous recruitment (ER)
- If forward-looking, heterogeneous subjects, RCTs with (SR,ER) may not identify ATE(τ).
- Our Paper: Structural Model + RCT to recover ATE(τ).
- Application: Malawi, late 2000s.
  - Short-Run RCT with Endogenous Recruitment.
  - Effects of Conditional Cash Transfers for girls on Schooling

Related Literature

1. Combining Structural Models with RCTs
   - Todd and Wolpin [2023]
   - Galiani and Pantano [2023]
   - Dual Role of (multi-arm) RCTs: Identification + Validation
     - Galiani, Murphy, and Pantano [2015]
2. Large Literature on CCTs
   - Review: Fizbein et al. [2009]
   - Malawi: Baird, McIntosh, and Özler [2011]
3. Smaller Structural Literature on CCTs
   - Bourguignon et al. [2003] ex-ante analysis, static model, Brazil's Bolsa Scola.
   - Todd and Wolpin [2006] PROGRESA, dynamic, Hold Out Treatment group for validation.
   - Attanasio, Meghir, and Santiago [2012] PROGRESA, dynamic, Control + Treatment for Identification.
4. Limited Duration Problem in RCTs
   - Moffitt [1979]

RCTs w/Short-Run Exposure, Endogenous Recruitment I

- τ is a policy of interest.
- $\underline{a}_\tau$: age at which policy exposure starts (e.g. 14)
- $\bar{a}_\tau$: age at which policy exposure ends (e.g. 24)
- $T^{\texttt{pol}} = \bar{a}_\tau - \underline{a}_\tau + 1$: number of years a household will be exposed to the actual policy during its life-cycle (e.g. 10)
- $\underline{a}_i$: recruitment age for experimental household i at which policy exposure starts. (e.g. 14, 16, 17, 19, etc)
- $\bar{a}_i$: age at which policy exposure ends for experimental household i (e.g. 15, 17, 18, etc)
- $T^{\texttt{rct}} = \bar{a}_i - \underline{a}_i + 1$: number of years a household will be exposed to a policy during the experiment (e.g. 2)

RCTs w/Short-Run Exposure, Endogenous Recruitment II

1. Short-Run RCTs (SR):
   - $T^{\mathtt{pol}} > T^{\mathtt{rct}}$
   - households know $T^{\mathtt{rct}}$ when the experiment begins
   - households are forward-looking and their decision problem is dynamic.
2. RCTs with Endogenous Recruitment (ER)
   - $\underline{a}_i > \underline{a}_\tau$
   - eligibility for recruitment into the RCT is based on $Y_{\underline{a}_i}$
   - households are heterogenous in unobserved ways. This heterogeneity affects $Y_{\underline{a}_i}$.

Why SR RCTs hinder identification of $E[Y_a^{\mathtt{pol}} - Y_a^0]$?

- We consider first RCTs with the SR feature but without ER.
- $T^{\mathtt{pol}} > T^{\mathtt{rct}}$
- RCT recruits subjects at ages $\underline{a}_\tau$
- Interest in $Y_{\underline{a}_\tau+s}$ for $s = 0, \ldots, T^{\mathtt{rct}} - 1$
- $Y^{\mathrm{D}}_{i,\underline{a}_\tau+s}$ Potential Outcome for i, s years after $\underline{a}_\tau$ under treatment $D \in \{\mathtt{pol}, \mathtt{rct}, 0\}$
- If $\exists i : Y^{\mathtt{pol}}_{i,\underline{a}_\tau+s} \neq Y^{\mathtt{rct}}_{i,\underline{a}_\tau+s} \implies$ RCT does not identify $E[Y^{\tau}_{\underline{a}_\tau+s} - Y^{0}_{\underline{a}_\tau+s}]$
- Intuition: Decisions and Outcomes by forward looking household i at age $a_\tau + s$ are different when exposed to $\mathtt{pol}$ vs. $\mathtt{rct}$ even for $s < T^{\mathtt{rct}}$

RCTs with Endogenous Recruitment do not identify $E[Y_a^{\text{pol}} - Y_a^0]$

- We now consider SR RCTs with the additional ER Feature.
- $T^{\text{rct}} > T^{\text{rct}}$
- RCT recruits subjects at ages $\underline{a}_\tau, \underline{a}_\tau + 1, \underline{a}_\tau + 2, ..., \bar{a}_\tau + 1 - T^{\text{rct}}$
- Eligibility for Recruitment into RCT based on Y_a for $a = \underline{a}_\tau, \underline{a}_\tau + 1$, etc.
- $f(k_{\underline{a}_\tau})$ distribution of unobserved household types at age $\underline{a}_\tau$
- If $f(k_{\underline{a}_\tau}) \neq f(k_{\underline{a}_i} | i \texttt{ is rct eligible})$
  - $\implies$ There is dynamic selection and endogenous recruitment.
  - $\implies$ RCT does not identify $E[Y^\tau_{\underline{a}_\tau + s} - Y^0_{\underline{a}_\tau + s}]$

Model-Based Identification of $E[Y_a^{\texttt{pol}} - Y_a^0]$

- Consider RCTs with either SR and/or ER features.
- Formulate Model $M(\theta)$ of choices and potential outcomes.
- $M(\theta)$ allows for forward-looking behavior.
- $M(\theta)$ allows for heterogeneous potential outcomes and treatment effects.
- Estimate Model $M(\theta)$ using some experimental variation.
- Validate Model $M(\theta)$ using remaining experimental variation.
- Identify $E[Y_a^{\texttt{pol}} - Y_a^0]$ by using $M(\theta)$ to evaluate choices and outcomes for full population with and without exposure to `pol`

Empirical Application I

- We build on a RCT developed and studied by Baird, McIntosh, and Özler [2011] "Cash or condition? evidence from a cash transfer experiment" *Quarterly Journal of Economics*
- RCT with 3 arms targeting never-married female adolescents ages 13-22 in Malawi and evaluating the role of conditionality in the effects of cash transfers on school enrollment, fertility and marriage.
- **Short-Run RCT**: 2-year Intervention during 2008 and 2009.
- 3 Rounds of Data Collection
  - Round 1: Oct 2007-Jan 2008 (before randomization)
  - Round 2: Oct 2008-Feb 2009
  - Round 3: Feb 2010-June 2010 (after cash transfers end in December 2009)
- **RCT with Endogenous Recruitment:** girls must be never married and in school to be eligible to participte in RCT.

Empirical Application II

- Basic Design:
  1. Control
  2. UCT Unconditional Cash Transfer
  3. CCT Conditional Cash Transfer
- Idea: Estimate Model with (1)+(2), validate with (3)
  - Models similar to Todd and Wolpin [2006] and Attanasio, Meghir, and Santiago [2012].
  - Difference: We can use experimental variation to *both* estimate *and* validate the model.
  - Validation data not directly used in estimation. Model selection device for non-nested models.

Empirical Application III

- Main RCT Results:
  - CCT enrolls much more in school than Control. Effect is small and not significantly different from zero for UCT.
  - UCT much less likely to marry and get pregnant than Control. No such effects for CCT.
- Puzzle: Results on Marriage and Pregnancy in UTC against conventional wisdom: more human capital for women, like that expected from CCTs, would reduce early fertility and marriage.
- Marriage and fertility results driven by change in behavior of those *never-takers* who dropout of school even when they get the UCT transfer:

School Enrollment, Pregnancy and Marriage in a Dynamic Model: Notation I

- cohorts of girls born between $t = 1986$ and $t = 1995$, ages $a = 13$ to $a = 22$ in $t = 2008$ when RCT recruitment occurs.
- The time unit of the dynamic model is a year.
- s_a is a 0-1 indicator whether girl attends school at age a
- m_a is a 0-1 indicator whether girl marries at age a.
- sp_a is a 0-1 indicator whether girl has a romantic partner at age a.
- $t(a)$ indexes calendar year when girl is age a (affects the availability of UCT/CCT transfers)

School Enrollment, Pregnancy and Marriage in a Dynamic Model: Notation II

- e_a = highest level of education completed by age a
- n_a captures whether the girl has ever been pregnant by age a
- Marriage is absorbing state. Marriage and school are mutually exclusive. Married girls have no romantic partners.
- ms_a ever married indicator at the beginning of age a
  - $ms_a = 0$ if single
  - $ms_a = 1$ if married
  - By Malawi law, we restrict $ms_a = 0$ for $a = 13, 14, 15, 16$.
- y_a parental household income, not including the money that the girl can get from a romantic partner.
- g_a income the girl gets from her romantic partner (if any)
- X_a vector of time-varying and time-invariant girl- and household-level observable characteristics.

School Enrollment, Pregnancy and Marriage in a Dynamic Model: Notation III

- ε_a^u vector girl- and household-level unobserved preferences for s, sp and m when the girl is age a.
- $\Omega_a = \{a, e_a, n_a, ms_a, y_a, X_a, t(a)\}$ observed (to the econometrician) state variables at age a (unrelated to the RCT)
- Z is the random assignment group
  $$\begin{pmatrix} \text{C} = \text{Control} \\ \text{UCT} = \text{Unconditional Cash Transfer} \\ \text{CCT} = \text{Conditional Cash Transfer} \end{pmatrix}$$
- τ^Z is the transfer that the household receives.
- $\chi = \{Z, \tau^Z\}$ collects state variables associated with the experimental assignment.

School Enrollment, Pregnancy and Marriage in a Dynamic Model: Notation IV

- The CCT/UCT offer arrives as a surprise in 2008.
- At age $a = 25$ the household collects a terminal value function $V_{25}(\Omega_{25})$
- $\varepsilon_a^u = \{\varepsilon_a^m, \varepsilon_a^s\, \varepsilon_a^{sp}\}$
- $\varepsilon_a = \{\varepsilon_a^u, \varepsilon_a^y, \varepsilon_a^g\}$

School Enrollment, Pregnancy and Marriage in a Dynamic Model: Notation V

- There are 5 mutually exclusive choices in every period for never married girls to make

d	m_a	s_a	sp_a
1	1	0	0
2	0	1	1
3	0	0	1
4	0	1	0
5	0	0	0

Table: Discrete Choices

Optimal Household Decisions I

Before 2008, the household solves

$$\max_{\{m_a, s_a, sp_a\}_{a=13}^{25}} \left\{ E\left[\sum_{a=13}^{25} \delta^{a-13} U\left(c_a, s_a, m_a, sp_a; X_a, e_a, n_a, ms_a, \varepsilon_a^u\right) \right.\right.$$
$$\left.\left. + \delta^{25-13} V_{25}(\Omega_{25}) \right] \right\}$$

subject to

$$\begin{aligned} c_a &= y_a + g_a sp_a \\ y_a &= g_y(X_a, \varepsilon_a^y) \\ g_a &= g_g(a, s_a, e_a, n_a, X_a, \varepsilon_a^g) \\ \Pr\left(n_{a+1} = 1\right) &= \pi_n\left(a, s_a, m_a, e_a, ms_a, n_a, X_a, sp_a \mid n_a = 0\right) \\ &\text{given } \Pr(X_{a+1} | X_a, d_a) \end{aligned}$$

Optimal Household Decisions II

The recursive representation is given by:

$$
\begin{aligned}
V_d(\Omega_a, \varepsilon_a) = {} & U_d(c_a, s_a, m_a, sp_a, \Omega_a, \varepsilon_a^u) \\
& + \delta E_{\Omega_{a+1}, \varepsilon_{a+1}} \left[V\left(\Omega_{a+1}, \varepsilon_{a+1}\right) \middle| d, \Omega_a \right]
\end{aligned}
$$

subject to the constraints, income functions and state variable evolutions

The value function is simply the maximum of the alternative-specific value functions

$$
V\left(\Omega_a, \varepsilon_a\right) = \max_{\{m_a, s_a, sp_a\}} \{V_d(\Omega_a, \varepsilon_a)\}
$$

Re-write alternative-specific value functions as follows:

$$
\begin{aligned}
V_d(\Omega_a, \varepsilon_a) = {} & U_d(c_a, s_a, m_a, sp_a, \Omega_a, \varepsilon_a^u) \\
& + \delta E_{\Omega_{a+1}} \left[E_{\varepsilon} \left[\max_j \{V_j(\Omega_{a+1}, \varepsilon_{a+1})\} \right] \middle| d, \Omega_a \right]
\end{aligned}
$$

Optimal Household Decisions III

In 2008, upon recruitment into RCT households assigned into UCT/CCT re-optimize for two years by solving

$$\max_{\{m_a, s_a, sp_a\}_{a(2008)}^{25}} \left\{ E\left[\sum_{a=a(2008)}^{25} \delta^{\tilde{a}} U\left(c_a, s_a, m_a, sp_a; X_a, e_a, n_a, ms_a, \varepsilon_a^u, \right) + \delta^{25-a(2008)} V_{25}(\Omega_{25}) \right] \right\}$$

where $\tilde{a} = a - a(2008)$ and subject to the income functions, transitions processes and a modified budget constraint that accounts for UCT and CCT transfers:

$$\begin{aligned} c_a &= y_a + sp_a g_a \\ &\quad + \tau_a^{\text{uct}} \times \mathbb{1}\{Z = \text{uct}\} \times \mathbb{1}\{t_a \in \{2008, 2009\}\} \\ &\quad + \tau_a^{\text{cct}} \times \mathbb{1}\{Z = \text{cct}\} \times \mathbb{1}\{t_a \in \{2008, 2009\}\} \times s_a \end{aligned}$$

Optimal Household Decisions IV

- After solving the model we obtain the optimal school attendance, romantic partner choice and marriage decisions by the girl, which are a function d of the state variables $(\Omega_a, \varepsilon_a, \chi)$
  1. For $t \leq 2007$ and $t \geq 2010$ the policy function is given by

$$(m_a^*, s_a^*, sp_a^*) = d_a(\Omega_a, \varepsilon_a)$$

  2. For $t \in \{2008, 2009\}$ the policy function is given by

$$(s_a^*, m_a^*, sp_a^*) = d_a(\Omega_a, \chi, \varepsilon_a)$$

Data

- $N = 2284$ baseline school girls sampled to be in one of the three groups.
- Z_i Random assignment group
- τ^{Z_i} Transfer Amount received.
- $s_{i,a(t)}$ School Enrollment Decisions of girl i at age $a(t)$ for years $t = 2008, 2009, 2010$.
- $m_{i,a(t)}$ Marriage Decision for girl i when she is of age $a(t)$ in years $t = 2008, 2009$
- $n_{i,a(t)}$ whether girl i has ever been pregnant by year t when she is age $a(t)$.
- $X_{i,a(t)}$ girl and household characteristics when the girl is age $a(t)$ in year t:

Estimation I

- Functional forms for utility functions and transition probabilities.
- Discrete distribution of unobserved types $k = 1, ..., K.$ with p_k probability that a household is of type k.
- The joint distribution of the random vector ε is assumed to be multivariate normal $\varepsilon \sim N(0, \Sigma)$.

Estimation II

- Parameters to be estimated are

$$\theta = \{\{\alpha_k\}_{k=1}^K, \lambda^b, \lambda^{sp}, \phi^y, \phi^g, \beta, \psi, \Gamma, p_k\}$$

  - $\{\alpha_k\}_{k=1}^K$: type-specific utility function
  - λ^n: pregnancy probability function
  - ϕ^y: parental income
  - ϕ^g: income and gifts from romantic partner
  - β: terminal value function
  - ψ: transition probability for X
  - Γ: Cholesky Decomposition of Σ, the variance-covariance matrix of the ε
  - p_k: unobserved type probabilities for $k = 2, 3, ..., K$ where $p_1 = 1 - \sum_{k=2}^K p_k$

Estimation III

- For each vector θ of parameters proposed in the estimation routine we
  - solve the model by backwards recursion
  - forward-simulate population of households from different cohorts (i.e. 1986-1995) such that the girls in those households are between the ages of 13 to 22 in 2008.
  - compute simulated moments.
  - compare simulated moments to analogous empirical moments from the data.
- $\hat{\theta}$ is the vector of parameters that minimizes the distance between the empirical (m^{data}) and model-simulated ($m(\theta)$) moments:

$$\hat{\theta} = \arg\min_{\theta} \left\{ \left[m^{\text{data}} - m(\theta) \right]' W \left[m^{\text{data}} - m(\theta) \right] \right\}$$

where W is a weight matrix.

Estimation IV

- Key Set of Moments to Match: Control and UCT groups.

Table: Small Effect of UCT on School Enrollment

	2008	2009	2010
UCT Effect	1.8	3.3	0.1
Control Mean	85.2	70.4	59.6

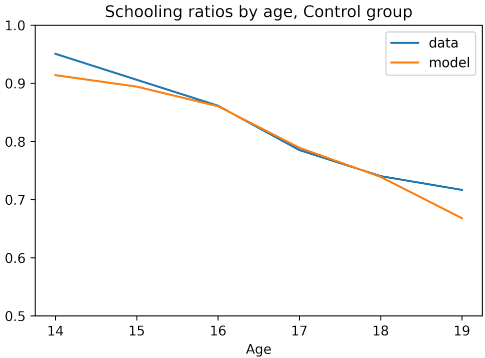
Model Fit in Estimation Sample: Schooling

No big effects of UCT on School Enrollment

Table: Model Fit for School Enrollment - Control vs. UCT Groups

Schooling		2008	2009	2010
Control	Data	85.2	70.4	59.6
	Model	82.1	71.5	59.5
UCT	Data	87.0	73.7	59.7
	Model	82.7	72.3	60.7

Model fit in Estimation Sample: Control Group Schooling By Age



Out-of-Sample Validation

- Key Set of Moments to Evaluate for Out-of-Sample Validation: CCT group.

Table: Bigger Effect of CCT on School % Enrollment

	2008	2009	2010
CCT Effect	6.1	11.3	5.8
Control Mean	85.2	70.4	59.6

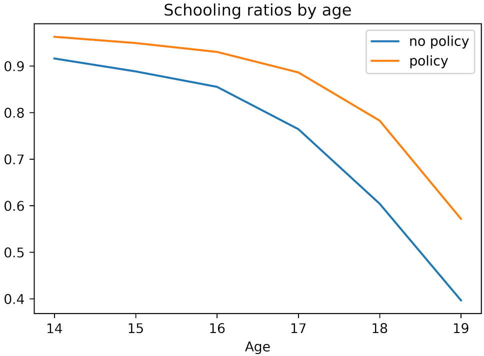
Out-of-Sample Validation: CCT Schooling

Table: Moderate Effect of CCT on School Enrollment

Schooling		2008	2009	2010
Control	Data	85.2	70.4	59.6
	Model	82.1	71.5	59.5
CCT	Data	91.3	81.4	65.4
	Model	90.5	77.6	63.6

Recovering Full-Duration Policy Effects of CCTs

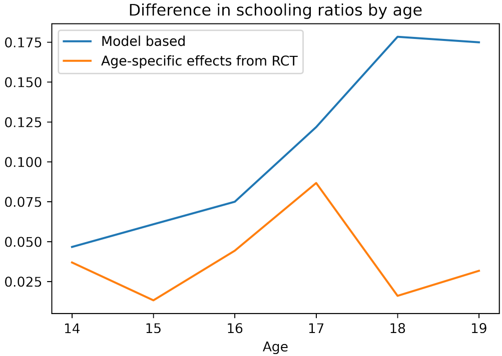
- We simulate one cohort of girls starting from age 13
- Analyze school enrollment with vs without the full multi-year CCT commitment guaranteed up-front.



Recovering Full-Duration Policy Effects of CCTs

Model-Based vs. Age-specific RCT Effects

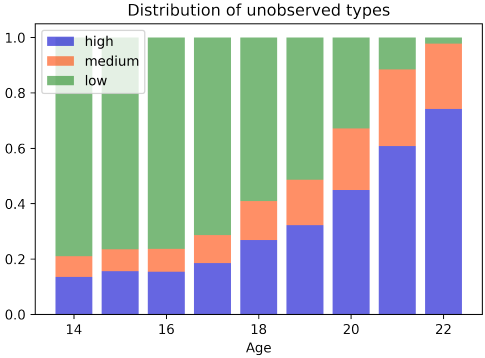
- Compare model-based policy effects vs RCT-based age-specific experimental Treatment Effects.
- Model-based approach accounts for (SR,ER) features of RCT.



Dynamic Selection and Endogenous Recruitment

- Three unobserved types: Low, Medium, High
- Types characterize intensity of household preferences for having the girl attend school.

Figure: Distribution of Unobserved Types by Age Conditional on eligibility for RCT Recruitment



Next Steps

- Next Steps:
  - Decompose Sources of Bias
  - Importance of Limited Duration
  - Importance of Endogenous Recruitment

Conclusions

- Consider RCTs which:
  - are “Short-Run” or “Limited Duration” in nature
  - have Endogenous Recruitment
- Interest in Policy Effects.
- Effects not Identified from RCT directly.
- Develop and Estimate Structural Model using the RCT with dual purpose:
  - identification
  - validation
- Obtain model-aided identification of policy effects.

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