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# The impact of antiretroviral treatment and child-focused unconditional cash transfers on child mortality

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ABSTRACT

Although there is sufficient evidence in the epidemiological literature that antiretroviral treatment (ART) reduces child mortality, there is limited evidence of its effect in the socio-economic determinants of child mortality literature. Furthermore, evidence on the effect of child focused unconditional cash transfers (UCTs) on child mortality is limited, especially in the African context. Using South Africa's provincial level data over the period 2001 to 2019, we evaluate the effect of ART and child focused UCTs on child mortality. We use the two-stage instrumental variable mean group estimator. We find that ART reduces child mortality. Moreover, we find an inverted U-shaped non-linear relationship between UCTs and child mortality that is contingent to the level of cash transfer coverage. Our analyses also reveal that UCTs improve the effect of ART on child mortality by enhancing access and adherence to treatment. While the focus of our analyses was on the child mortality effects of ART and UCTs, our findings reaffirm the well-documented impacts of factors such as public health expenditure, HIV/AIDS, female education, and health worker density on child mortality. Collectively, the combination of high ART and UCTs coverage, increased public health expenditure, enhanced female education, and improved health worker density, represents value for money for policymakers and funders. These areas should be prioritised to improve child well-being.

## 1. Introduction

Elevated level of child mortality in a country reflects limited access to basic health and socio-economic services such as HIV care and treatment, vaccinations, adequate nutrition, and clean water (Rademeyer, 2019). Although there is sufficient evidence in the epidemiological literature that antiretroviral treatment (ART) reduces child mortality (Bule & Wade, 2019; Johnson et al., 2020; Schue, Van Dijk, Hamangaba et al., 2021; Shabangu, Beke, Manda, & Mthethwa, 2017), there is limited evidence of its effect in the socio-economic determinants of child mortality literature. Understanding the influence of ART on child mortality is essential since it is a primary intervention in the management of HIV/AIDS.

Furthermore, previous studies have demonstrated that cash transfers (CTs) lead to a reduction in child mortality through the child nutrition and health care service utilisation channels (Aransiola et al., 2023; Rasella, Aquino, Santos, Paes-Sousa, & Barreto, 2013; Richterman et al., 2023). However, the effects of CT programmes vary based on design and implementation characteristics (Bastagli et al., 2019; Kilburn, Handa, Angeles, Mvula, & Tsoka, 2017). Most of the existing evidence is based on conditional cash transfers (CCTs) from Latin America (Novignon et al., 2022). Within Africa, there is limited evidence on the effect of child focused unconditional cash transfers (UCTs) on child mortality. Actually, evidence linking UCTs to child mortality is emerging (Richterman et al., 2023). This underscores an important avenue that requires further examination within an African context.

South Africa's child support grant (CSG) stands as a pivotal social protection tool in the battle against child poverty and malnutrition (Zembe-Mkabile, Sanders, Ramokolo, & Doherty, 2022). CSG is a targeted UCT provided to parents or caregivers of children under the age of 18 years and whose income is below a specified threshold to address child poverty and malnutrition (Hall, Proudlock, & Budlender, 2023). In 2019, parents and caregivers received a cash payment of R430 (US$24) per month (National Treasury, 2023a). However, this monthly grant was considerably below the prevailing food poverty line of R624 (US$34) in 2019 (Hall, 2023).

We argue in this paper that in the case of UCTs, the impact of CTs on child mortality may not be that straight forward. This ambiguity may

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also be aggravated in a setting characterised by CT amount that is beneath the food poverty line since malnutrition may remain persistent. Richterman et al. (2023) have pointed out that CTs with limited coverage or low transfer amounts may prove ineffective in reducing population-level mortality rates. Emerging non-causal evidence suggests that CSG may not be sufficient to alleviate malnutrition in South Africa (Zembe-Mkabile et al., 2022).

Although existing literature suggests that CTs reduce child mortality through the child nutrition and health care utilisation channels (Bastagli et al., 2019; Zembe-Mkabile, Surender, Sanders, Jackson, & Doherty, 2015), a third channel establishing a non-linear relationship is plausible in the case of a child focused UCTs. In this mechanism, UCTs may not necessarily lead to improvements in food security, ART adherence and children's well-being. This alternative channel suggests that child mortality may also rise if the CT is not directed towards improving food security and to cover the transportation costs that can facilitate improvements in health care utilisation. In other words, UCTs' impact on child mortality depends on parental or caregiver's decision-making (Kilburn et al., 2017). In South Africa, parents and caregivers of CSG recipients have reported experiencing greater financial independence and decision-making autonomy regarding the utilisation of the grant (Chakraborty et al., 2024). Since parents and caregivers decide how the grant money should be spent, it is possible that they can also use the money towards their individual needs and not necessarily on the basic food needs of the child and this may hamper ART adherence. As pointed out by Weiser et al. (2014), food insecurity represents a significant potential obstacle to the efficacy of ART programmes in resource-constrained settings. Therefore, this paper closes this void in the literature by evaluating the hypothesis that the relationship between UCTs and child mortality could be non-linear, contingent on the extent of CT coverage especially in a setting characterised by CT that is below the food poverty line.

Against this background, our paper relates to two strands of the literature. The first strand is the literature on the socio-determinants of child mortality while the second strand is the literature on the impact of CTs on health outcomes and nutrition. We contribute to these strands by examining the impact of ART and child focused UCTs on child mortality in South Africa.

The first strand of the literature that our paper contributes to is the literature on socioeconomic determinants of child mortality. In this literature, most studies have evaluated the effect of health expenditure (Akinkugbe & Mohanoe, 2009; Akinlo & Sulola, 2019; Anyanwu & Erhijakpor, 2009; Bidzha, Greyling, & Mahabir, 2017; Hlafa, Sibanda, & Hompashe, 2019; Moreno-Serra & Smith, 2015; Novignon, Olakojo, & Nonvignon, 2012; Rahman, Alam, & Khanam, 2022). Most of these studies provide evidence that health spending reduces child mortality. In this literature, several studies have also explored the impact of HIV/AIDS on child mortality (Akinlo & Sulola, 2019; Hlafa et al., 2019; Novignon et al., 2012; Rahman et al., 2022; Salahuddin, Vink, Ralph, & Gow, 2020).[1] Majority of these studies found that HIV/AIDS increases child mortality. Despite the increasing attention to the influence of HIV/AIDS on child mortality, as far as we are aware, no study has explored the impact of ART in this literature.

We argue in this paper that in a high HIV/AIDS prevalence setting like South Africa with widespread rollout of ART, omission of the ART variable may exaggerate the child mortality effects of health expenditure, HIV/AIDS, and other socio-economic variables. We anticipate an inverse causal relationship between ART and child mortality.

Our paper is also connected to the literature that investigates the impacts of CTs on child health outcomes and nutrition (Barham, 2010; Rahman & Pallikadavath, 2018; Rasella et al., 2013; Renzaho et al., 2019; Richterman et al., 2023). Majority of these studies have employed outcome variables such as healthcare service utilisation, dietary diversity, and anthropometric measures including stunting, wasting, and underweight (Bastagli et al., 2019; Rahman & Pallikadavath, 2018; Renzaho et al., 2019). In our view, this approach of using intermediate mechanisms or mediators as proxies for distal outcomes of health does not contribute to conceptual clarity as pointed out by Sun, Huang, Hudson, and Sherraden (2021). Malnutrition and hunger not only have detrimental effects on growth and development of children but also contribute to child mortality (Zembe-Mkabile et al., 2022).

Few studies have assessed the effects of CTs using key indicators of children's health, such as infant and child mortality (Aransiola et al., 2023; Barham, 2010; Rasella et al., 2013; Richterman et al., 2023). However, most of these studies have examined the effect of CCTs on child mortality in Latin America while our focus is on the effect of child focused UCTs [2] on child mortality within a low- and middle-income African context.

In the African context, numerous studies have explored the effects of UCTs on a range of outcomes, including health, education, food security, and nutrition. Empirical studies conducted in countries such as Kenya (Huang et al., 2017; Kilburn, Thirumurthy, Halpern, Pettifor, & Handa, 2016), Malawi (Angeles et al., 2019; Lambon-Quayefio et al., 2024), South Africa (Luthuli, Haskins, Mapumulo, & Horwood, 2022), and multiple sub-Saharan African countries including Ghana, Malawi, and Zimbabwe (Handa, Otchere, Sirma, & on behalf of the Evaluation Study Team, 2022), as well as Uganda (Mills et al., 2018; Weiser et al., 2014), have shed light on the multifaceted impacts of UCTs on various demographic groups and household welfare. Despite this extensive body of research, none of these studies have specifically examined the influence of UCTs on child mortality.

Although existing evidence suggests that CTs produce positive health effects (Richterman et al., 2023; Sun et al., 2021), the outcomes exhibit multiple complexities and variations. As argued by Handa et al. (2022), Kilburn et al. (2017) and Novignon et al. (2022), CCTs and UCTs may not affect child outcomes through the same mechanisms given their differences in design and implementation features.

As far as we are aware, no empirical study has assessed the impact of child focused UCTs on child mortality in an African country. By providing more evidence from Africa, we contribute to the global understanding of health disparities and the effectiveness of interventions. Our study is closely related to a recent study by Richterman et al. (2023) who examined the effects of both CCTs and UCTs on child and adult mortality in developing countries. In their study, Richterman et al. (2023) found that both CCTs and UCTs reduce child mortality. While Richterman et al. (2023) utilised data from diverse countries, South Africa was not included in their sample. Furthermore, Richterman et al. (2023) used CCTs and UCTs data that are inclusive of all major CT programmes in each country to assess their impacts on both adult and child mortality while we use child focused UCTs in an African country where evidence is limited. We argue in this paper that South Africa offers a unique context in that it allows us to evaluate the child-mortality effects of CTs using a large-scale child-focused UCTs in a high HIV/AIDS prevalence setting characterised by a large-scale rollout of ART.

Health care alone cannot sufficiently enhance overall health or reduce health inequalities without addressing the upstream social determinants of health, such as living conditions and access to resources (Braveman, Egerter, & Williams, 2011). In this paper, we analyse the impact of ART and CSG on under-five mortality rates, while controlling for the effects of increased public health expenditure, HIV/AIDS prevalence, enhanced female education, improved health worker density,

[1] Rahman et al. (2022) has provided a detailed survey of the literature on the HIV/AIDS-child mortality nexus.

[2] Bastagli et al. (2019) has shown that 61% of the empirical studies have focused on the CT programmes in Latin America while 29% of the studies are in sub-Saharan Africa focusing mainly on UCTs. Actually, none of the studies reviewed by Bastagli et al. (2019) have used child mortality as an outcome variable.

better access to safe drinking water, expanded immunisation programmes, and urbanisation. These socioeconomic interventions have been found to contribute to the reduction of child mortality (Akinkugbe & Mohanoe, 2009; Akinlo & Sulola, 2019; Bärnighausen, Bloom, Canning, & O'Brien, 2008; Braveman et al., 2011; Rahman et al., 2022). Furthermore, the selection of these control variables is influenced by data availability and the necessity to mitigate potential collinearity issues among them.

Research indicates that mothers with higher levels of education tend to adopt healthier lifestyles and make decisions that positively impact their children's health (Rademeyer, 2019; Rahman et al., 2022; Rasella et al., 2013). Additionally, the presence of essential health workers, such as nurses and physicians, enhances healthcare services, which is beneficial for children's health (Akinkugbe & Mohanoe, 2009; Anyanwu & Erhijakpor, 2009; Rahman et al., 2022). Moreover, increased vaccination coverage among children has been a significant factor in the decline of child mortality rates in South Africa (Bärnighausen et al., 2008; Rademeyer, 2019). In this paper, we also consider urbanization as a control variable, as it facilitates access to healthcare services, particularly in developing countries (Bidzha, Ngepah, & Greyling, 2024; Rademeyer, 2019; Salahuddin et al., 2020).

We contend that our paper makes contributions to both the literature on socio-economic determinants of child mortality and the literature examining the effects of CTs on child health outcomes and nutrition in the following ways. Firstly, as far as we are aware, this is the first study in the extensive literature examining the effects of socio-economic factors on child mortality and the literature assessing the effects of CTs on child health outcomes to investigate the role of ART and child focused UCTs on child mortality using econometric methods.

Second, we demonstrate that the relationship between child focused UCTs and child mortality may be non-linear in a setting characterised by high grant coverage and CTs that are below the food poverty line. In doing so, we assess the emerging hypothesis that the CSG's monetary value may be too low to positively impact health status by reducing child mortality through the child nutrition channel. We believe these approaches improve our understanding of the precise mechanisms involved on how child focused UCTs affect child mortality. Furthermore, our approach of examining the child mortality effects of CTs is consistent with the suggestion by Bastagli et al. (2019) who recommended that future research should focus on the higher order outcomes such as child health status that are of ultimate policy interest.

Lastly, we examine the mediating role of child focused UCTs on the relationship between ART and child mortality. The inclusion of both ART and CSG in our analyses allows us to investigate their joint effects on child mortality given that there has been a significant increase in the implementation of these policies over the last two decades to address child-wellbeing in South Africa. This approach allows us to explore the health care service utilisation channel through which child focused UCTs may affect child mortality.

Using provincial level data spanning from 2001 to 2019, we explore the effect of ART and child focused UCTs on child mortality in South Africa.[3] In this paper, we employ under five mortality rate as a measure of child well-being, recognising the significance of the first four years in a child's life in shaping health outcomes later in life. We also exploit the HIV incident data that is relevant to the transmission of HIV/AIDS in children by Johnson and Dorrington (2023). In the analysis, we use both linear and nonlinear econometric approaches.

The subsequent sections of this paper are structured as follows: Sections 2 and 3 offer an exposition of the data and the empirical methodology employed. Section 4 presents the empirical findings, while Section 5 provides a detailed discussion of these results. Finally, Section 6 concludes with the authors' remarks.

[3] Data and variables are discussed in detail in Section 2.

## 2. Data and variables

The data employed in this paper encompass nine provinces in South Africa, spanning the period from 2001 to 2019. During this period, there was a remarkable increase in ART and CSG rollout. We restrict our sample to this period since provincial level data for ART and CSG are unavailable prior to 2001 and this also applies to most control variables. Furthermore, provincial level HIV/AIDS prevalence data is unreliable post 2019 since the crucial antenatal survey data which are the basis for these estimates were not available after 2019 (Johnson & Dorrington, 2023).

In this paper, we use under five mortality rate as a measure of child health outcome since it captures the socio-economic development of a country as well as health equity and access (Rademeyer, 2019). Data on under-five mortality rate as our dependent variable are sourced from Johnson and Dorrington's (2023) Thembisa model version 4.6. For our variable of interest ART, we use the proportion of HIV positive children younger than 15 years who are on treatment. Data on these estimates are obtained from Johnson and Dorrington (2023). For the child focused UCTs, we use the CSG coverage in children younger than five years. However, we also use the overall CSG coverage for children younger than 18 years to check robustness of our estimated results. Data on CSG coverage are sourced from SASSA (2023) while the related population data are obtained from Stats SA (2023).

For the HIV/AIDS prevalence as one of our control variables, we use the mother to child transmission (MTCT) of HIV data by Johnson and Dorrington (2023). The MTCT of HIV data are inclusive of both maternal acquisition of HIV during pregnancy and breastfeeding. In accordance with Johnson et al. (2020), a substantial share of new HIV infections in children in South Africa stems from vertical transmission during breastfeeding. Data on female education which is measured by mean years of schooling are sourced from the Subnational Human Development Database by Smits and Permanyer (2021). On the other hand, data on the health worker density and immunisation coverage in children are obtained from the Health Systems Trust (2023). With regards to access to portable water, we source these data from the Stats SA's (2023) General Household Survey.

Data on urban ratio are obtained from Stats SA's (2023) annual General Household Survey estimates. Public health expenditure data are sourced from the National Treasury(2023)b while the related uninsured population data are sourced from Stats SA (2023). Data on our chosen external instruments child poverty and household unemployment are sourced from Hall's (2023) Children Count database. Lastly, data on HIV tests which is an external instrument for ART are obtained from Johnson and Dorrington (2023). Table 1 presents the descriptive statistics of the variables employed in this study.

## 3. Empirical strategy

This paper employs the Grossman's (1972) health production function, incorporating the conceptual model by Mosley and Chen (1984), to investigate the impact of ART and CSG on child mortality. To examine these effects, we use the two-stage instrumental variable mean group (2SIV-MG) estimator. This approach allows us to control for potential endogeneity emanating from reverse causality and unobserved province-specific characteristics, cross-sectional dependence, and heterogeneity. The 2SIV-MG estimator is well-suited for static linear panels with a small number of individuals (small N) and a large number of time periods (large T). It is preferable, as there is no need to search for external instruments, given that the instruments are transformed regressors (Cui, Norkute, Sarafidis et al., 2022).

In this paper, we use child poverty rate and household unemployment rate as additional external instruments for CSG. Additionally, we incorporate the level of HIV testing in children as an extra instrument for ART. We expect these external instruments to be strongly correlated with the endogenous variables ART and CSG and indirectly correlated

**Table 1**
Summary statistics.

| | Abbreviations | Obs | Mean | Std.Dev. | Min | Max |
|---|---|---|---|---|---|---|
| **Dependent variable** | | | | | | |
| Under five mortality rate | U5_MR | 171 | 54.6 | 25.9 | 15.3 | 112.1 |
| **Independent variables** | | | | | | |
| ART coverage in children (%) | ART_U15 | 171 | 24.5 | 20.4 | 0.2 | 58.5 |
| CSG coverage in children under 5 years (%) | CSG_U5 | 171 | 77.3 | 24.2 | 15.7 | 99.8 |
| MTCT of HIV (%) | MTCT_HIV | 171 | 16.6 | 12.2 | 3.3 | 43.9 |
| Female education | Educ_Female | 171 | 8.9 | 1.3 | 5.2 | 11.5 |
| Access to water (%) | ATW | 171 | 68.5 | 21.0 | 23.9 | 95.6 |
| Immunisation coverage (%) | Immunisation | 171 | 76.8 | 10.7 | 54.3 | 99.0 |
| Health worker density | HW_Density | 171 | 123.9 | 26.2 | 76.2 | 186.2 |
| Urbanisation (%) | Urban_ratio | 171 | 59.3 | 26.7 | 10.6 | 98.2 |
| Public health expenditure (% of GDP) | PHEXP | 171 | 4.8 | 2.5 | 1.0 | 12.4 |
| **Instrumental variables** | | | | | | |
| Child poverty (%) | Child_Poverty | 171 | 69.3 | 14.5 | 22.9 | 91.0 |
| Household unemployment (%) | Household_Unemp | 171 | 34.1 | 13.2 | 7.5 | 59.7 |
| HIV Tests (%) | HIV_Tests | 171 | 45.3 | 20.3 | 10.3 | 77.7 |

with our dependent variable under five mortality rate. We also expect these instruments to satisfy the exogeneity conditions and this will be confirmed by the Hansen J statistic in the 2SLS-IV-FE model.

As noted by Bidzha et al. (2024), neighbouring provinces are often highly linked, making it implausible to assume that there is no cross-sectional dependence in our data. We also control for heterogeneity since it is plausible to assume that provinces differ in their levels of development and natural resource endowment (Bidzha et al., 2024). Moreover, Johnson, Dorrington, and Moolla (2017) also observed that HIV/AIDS epidemic exhibits significant heterogeneity across provinces in South Africa.

To account for potential non-linearity in the relationship between CSG and under-five mortality, we incorporate the squared term of CSG consistent with the approach of previous studies (Asiedu, Jin, & Kanyama, 2015; Bidzha et al., 2024). Our variables are in natural logs to simplify interpretation. To estimate our results, we set up our baseline model as follows:

$$ln\ U5\_MR_{it} = \beta_0 + \beta_1\ ln\ ART_{it} + \beta_2\ ln\ CSG_{it} + \beta_3\ ln\ CSG^2_{it} + \beta_4\ ln\ PHEXP_{it} + \beta_5 ln\ MTCT\_HIV_{it} + \beta_6\ ln\ Educ_{it} + \beta_7\ ln\ HW\_Density_{it} + \beta_8\ ln\ ATW_{it} + \beta_9\ ln\ Immunisation_{it} + \beta_{10}\ ln\ Urban_{it} + \mu_{it} \quad (1)$$

the natural log of urbanisation. $\mu_{it} = \gamma_i^{'} f_t + \epsilon_{it}$ which encompasses underlying common factors $f_t$ as well as heterogenous factor loading $\gamma_i^{'}$. We account for these effects by using the 2SIV-MG model that transforms regressors into valid and relevant instrumental variables (Cui, Norkutė, Sarafidis, & Yamagata, 2022). $\epsilon_{it}$ is the idiosyncratic error term.

From epidemiological studies (Bule & Wade, 2019; Johnson et al., 2020), coefficient of ART is expected to be negative since it has been shown to reverse adverse effects of HIV/AIDS. In line with the hypothesis, we postulated under Section 2.2 on the effect of child focused UCTs, child mortality increases due to the persistent high levels of malnutrition at lower levels of CSG coverage when the monetary value of the CT is below the food poverty line. In this instance, $\beta_2 > 0$ while $\beta_3 < 0$ at higher levels of CSG coverage. On the other hand, control variables such as female education, health worker density, access to water, urbanisation, immunisation, are expected to have a negative sign while coefficient of HIV/AIDS prevalence is expected to be positive consistent with previous studies (Akinkugbe & Mohanoe; 2009; Akinlo & Sulola, 2019; Anyanwu & Erhijakpor, 2009; Bidzha et al., 2017; Novignon et al., 2012; Rahman et al., 2022). To analyse the joint effect of ART and CSG on child mortality, we modify Equation (1) by replacing the squared term on CSG with an interaction term between ART and CSG and estimate the following equation:

$$ln\ U5\_MR_{it} = \beta_0 + \beta_1\ ln\ ART_{it} + \beta_2\ ln\ CSG_{it} + \beta_3\ ln\ PHEXP_{it} + \beta_4(ln\ ART_{it} * ln\ CSG_{it}) + \beta_5 ln\ MTCT\_HIV_{it} + \beta_6\ ln\ Educ_{it} + \beta_7\ ln\ HW\_Density_{it} + \beta_8\ ln\ ATW_{it} + \beta_9\ ln\ Immunisation_{it} + \beta_{10}\ ln\ Urban_{it} + \mu_{it} \quad (2)$$

where $lnU5\_MR_{it}$ is the natural log of under-five mortality rate in province $i$ in year $t$; $ln\ ART_{it}$ is the natural log of ART, $ln\ CSG_{it}$ is the natural log of CSG, $ln\ CSG^2_{it}$ is the square of the CSG, $ln\ PHEXP_{it}$ denotes the natural log of public health expenditure, $ln\ MTCT\_HIV_{it}$ is the natural log of HIV/AIDS prevalence, $ln\ Educ_{it}$ is the natural log of female education, $ln\ HW\_Density_{it}$ is the natural log health worker density, $ln\ ATW_{it}$ is the natural log of access to portable water, $ln\ Immunisation_{it}$ is the natural log of immunisation coverage in children, and $ln\ Urban_{it}$, is

In light of our assertion that the relationship between CSG and under-five mortality rate is contingent upon the CSG coverage level, we expand our analyses of this study by utilising a panel threshold model by Hansen (1999). We use this estimator to determine the threshold level of CSG coverage and to confirm the existence of threshold effects. We estimate the following panel threshold model in this paper:

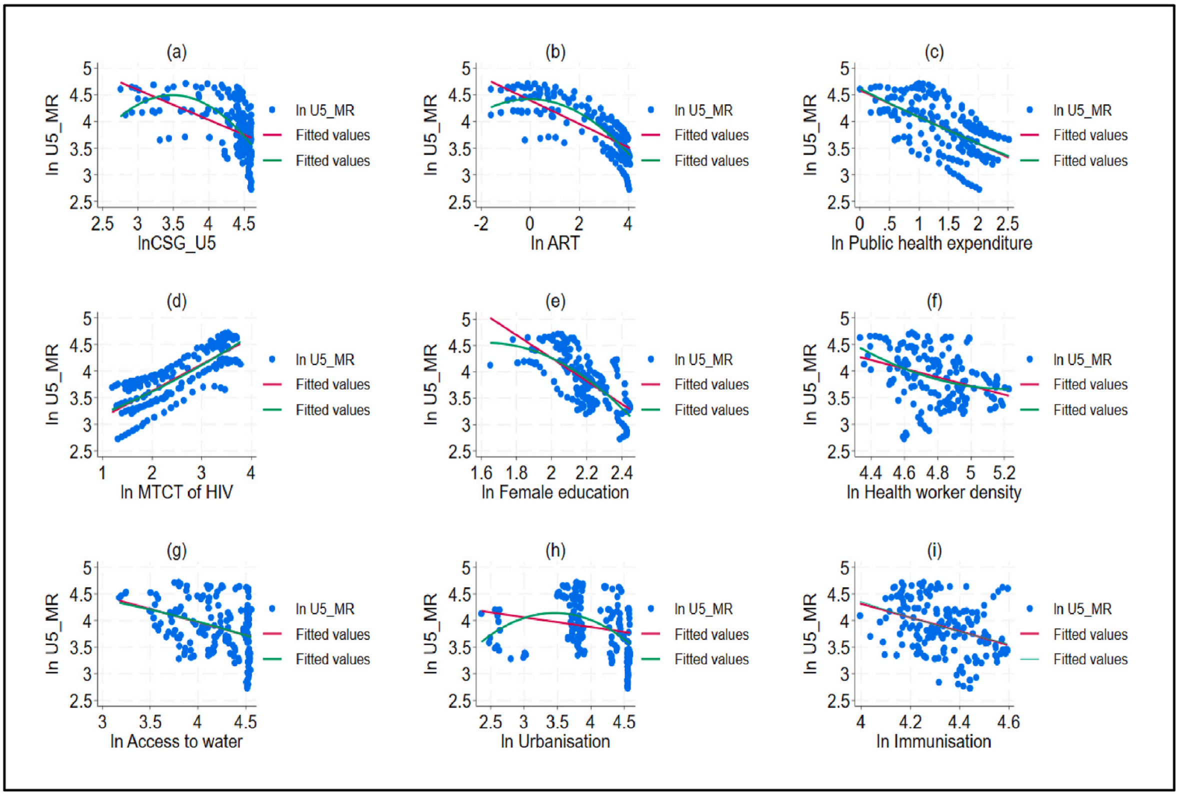


**Fig. 1.** Correlations between under five mortality rate and various explanatory variables.
Source: Own computation

$$ln\ U5\_MR_{it} = \mu_i + \alpha_1[(ln\ CSG_{it})I(CSG_{it} \le \gamma)] + \alpha_2[(ln\ CSG_{it})I(CSG_{it} > \gamma)] + \theta Z_{it} + \varepsilon_{it} \quad (3)$$

where $\mu_i$ represents individual-specific fixed effects, $I(.)$ specifies regime, $\gamma$ represents threshold level dividing our model in Equation (3) into two regimes. These regimes have $\alpha_1$ and $\alpha_2$ as coefficients. $CSG_{it}$ is the threshold variable, $Z_{it}$ is a vector of controls, and $\varepsilon_{it}$ is the error term.

## 4. Results

### 4.1. Correlation analysis

Fig. 1 provides the strength of association between the dependent variable and explanatory variables. In general, the signs of variables conform to *a priori* expectations. For example, panel (a) in Fig. 1 shows a moderate negative relationship between CSG and under-five mortality with a potential inverted u-shaped non-linear relationship consistent with our postulated hypothesis. Along the same lines, panel (b) shows a relatively strong relationship between ART and under five mortality rate. Panel (c) also shows a strong negative relationship between public health expenditure and under five mortality rate. On the other hand, panel (d) shows a strong positive relationship between HIV/AIDS and under-five mortality rate. As noted by Akinlo and Sulola (2019), these correlations should be interpreted with caution since correlation does not imply causation. However, we demonstrate later that most of the associations we observe in Fig. 1 are robust to different model specifications and estimation techniques.

### 4.2. Preliminary diagnostic tests

Before we conduct regression analyses on the effects of CSG and ART on child mortality, we test for multicollinearity to ensure that we estimate our models in Equations (1)–(3) with precision. Table A1 of the Appendix reports the variance inflation factor (VIF) of the explanatory variables. Table A1 shows that the VIF for ART, MTCT_HIV and public health expenditure variables are 18.58, 17.13 and 12.77, respectively in our baseline model that includes all the control variables. This implies that our model may suffer from multicollinearity problem given that the VIFs of these variables are greater than 10. However, we demonstrate under Section 4.3 that the estimated coefficients on key variables such as ART and CSG are not affected by potential multicollinearity problem.

Burdisso and Sangiácomo (2016) caution that although non-stationarity is inherent in time-series data, long panel data analysis should also address this problem. We use the Levin, Lin, and Chu (2002) panel unit root test which is relevant to our data dimensions. The test results are provided in Table A2 of the Appendix and results show that all variables are stationarity. The Wooldridge (2002) test as shown by Table A3 of the Appendix shows that our data suffer from serial auto-correlation. In the Appendix, Table A4 provides enough evidence to suggest that there is cross-sectional dependence and heterogeneity in the data. Lastly, the joint endogeneity tests for ART and CSG in the two stage least squares fixed effects instrumental variable (2SLS-FE-IV) models show that these variables are endogenous evidenced by the p-values of zero. To account for endogeneity, serial autocorrelation, cross-sectional dependence, and heterogeneity, we use the 2SIV-MG estimator.

### 4.3. The effect of ART and CSG on child mortality

In this section, we examine and show the effects of ART and CSG on under five mortality. With regards to CSG, we evaluate the hypothesis that the relationship between child focused CTs and child mortality is non-linear, and this depends on the CSG coverage level. In doing so, we examine the child nutrition and health care service access channels through which CTs affect child mortality. Table 2 provides our main results using different estimation techniques such as Driscoll and Kraay

**Table 2**
Baseline results of the impact of ART provision to children and CSG on child mortality.

| Dependent variable: Under five mortality rate | Homogenous slopes | | Heterogenous slopes | |
|---|---|---|---|---|
| Independent variables | FE-Driscoll & Kraay SE (1) | 2SLS-FE-IV (2) | 2SIV-MG (3) | DCCE-MGIV (4) |
| ART coverage | −0.044*** | −0.054*** | −0.061** | −0.044* |
| | (0.017) | (0.016) | (0.019) | (0.040) |
| CSG coverage | 0.799*** | 4.507*** | 0.841*** | 1.056* |
| | (0.309) | (1.133) | (0.196) | (0.531) |
| CSG coverage squared | −0.085** | −0.564*** | −0.098*** | −0.112** |
| | (0.041) | (0.164) | (0.026) | (0.068) |
| Public health expenditure | −0.083* | 0.107 | −0.001 | −0.098 |
| | (0.052) | (0.096) | (0.091) | (0.153) |
| MTCT_HIV | 0.379*** | 0.396*** | 0.379*** | 0.333*** |
| | (0.043) | (0.051) | (0.060) | (0.082) |
| Female education | −0.116 | −0.236 | −0.347** | −0.538** |
| | (0.175) | (0.239) | (0.163) | (0.240) |
| Access to water | 0.141*** | 0.235*** | −0.027 | −0.038 |
| | (0.031) | (0.079) | (0.107) | (0.144) |
| Health worker density | −0.054** | −0.128** | −0.150** | −0.053 |
| | (0.022) | (0.048) | (0.074) | (0.104) |
| Immunisation | −0.014 | −0.041 | −0.001 | −0.001 |
| | (0.039) | (0.058) | (0.001) | (0.098) |
| Urbanisation | 0.093*** | 0.121* | −0.056 | −0.068 |
| | (0.042) | (0.072) | (0.151) | (0.144) |
| R-squared | 0.99 | 0.97 | 0.99 | 0.99 |
| Hansen J statistic | | 0.086 | 0.000 | |
| | | [0.770] | [1.000] | |
| Number of instruments | | 3 | 24 | 3 |
| CD Statistic | | | | 3.41 |
| | | | | [0.000] |
| Observations | 171 | 162 | 162 | 153 |
| Number of lags/ Factors | 2 | | 3 | 3 |

Note: *, ** and *** are levels of significance at 10%, 5% and 1%, respectively. Figures in parentheses are standard errors and p values. HIV tests in children and child poverty used as external instruments for ART and CSG, respectively.

estimator with fixed effects, 2SLS-FE-IV, 2SIV-MG, and the DCCE-MGIV. In Table 2, models in column (1) and (2) assume slope homogeneity while models in column (3) and (4) relax this assumption. As already explained in Section 3, we use the 2SIV-MG model to interpret our estimated results.

Table 2 provides baseline results estimated using Equation (1) that we outlined in Section 3. As expected, the coefficient of ART is negative and statistically significant in all the models suggesting robustness to different estimation techniques. In the 2SIV-MG model, ART is significant at 5% level. The ART coefficient is −0.061 on the 2SIV-MG model implying that a 1 percentage point increase in ART coverage reduces under five mortality by 0.06 per cent. Our result suggests that ART provision in children reduces under five mortality consistent with the previous epidemiological studies (Johnson, et al., 2020; Schue et al., 2021; Shabangu et al., 2017). Our finding is also consistent with the scatter plot correlation observed in Section 4.1. Since this is the first study to the best of our knowledge to estimate the effect of ART on child mortality within the socio-economic determinants of child mortality literature, it is somewhat difficult to contextualise the size of the impact.

From Table 2, we also find that the CSG and squared term are statistically significant at 1% level and have a positive and negative sign, respectively in all the models. This finding lends support to the earlier observation of an inverted u-shaped non-linear relationship between CSG and under five mortality under Section 4.1 where we analysed correlations using scatter plots. This result provide further evidence to support our hypothesis that the relationship between child focused UCTs and child mortality is non-linear when the cash amount is below the food poverty line since higher levels of coverage is needed to reduce child mortality. In other words, CSG increases under five mortality at low levels of coverage due to persistent malnutrition given the low cash amount. However, increase in CSG coverage improves households' overall income leading to improvement in child nutrition and the subsequent reduction in child mortality. To confirm the non-linear relationship and to estimate the threshold value, we utilise the panel threshold model in Section 4.5.

**Table 3**
The mediating role of CSG on the effect of ART on child mortality.

| Dependent variable: Under five mortality rate | Homogenous slopes | | Heterogenous slopes | |
|---|---|---|---|---|
| Independent variables | FE-Driscoll & Kraay SE (1) | 2SLS-FE-IV (2) | 2SIV-MG (3) | DCCE-MGIV (4) |
| ART coverage in children | −0.046** | −0.034*** | −0.046** | −0.054** |
| | (0.024) | (0.012) | (0.024) | (0.021) |
| CSG coverage | −0.009 | −0.278*** | 0.027 | 0.032 |
| | (0.047) | (0.089) | (0.069) | (0.089) |
| ART coverage*CSG coverage | −0.061*** | −0.139*** | −0.061*** | −0.056** |
| | (0.016) | (0.026) | (0.017) | (0.024) |
| Public health expenditure | −0.098* | 0.006 | −0.027 | −0.002 |
| | (0.048) | (0.059) | (0.082) | (0.069) |
| MTCT_HIV | 0.334*** | 0.344*** | 0.234** | 0.360*** |
| | (0.044) | (0.032) | (0.110) | (0.056) |
| Female education | −0.191* | −0.270* | −0.352** | −0.456* |
| | (0.124) | (0.146) | (0.174) | (0.253) |
| Access to water | 0.137*** | 0.121** | 0.009 | 0.016 |
| | (0.028) | (0.054) | (0.085) | (0.098) |
| Health worker density | −0.068*** | −0.105*** | −0.056* | −0.052 |
| | (0.019) | (0.034) | (0.087) | (0.101) |
| Immunisation | −0.022 | −0.008 | −0.0001 | −0.039 |
| | (0.042) | (0.046) | (0.001) | (0.078) |
| Urbanisation | 0.081** | 0.097* | 0.001 | −0.071 |
| | (0.025) | (0.051) | (0.002) | (0.141) |
| R Squared | 0.99 | 0.99 | 0.99 | 0.99 |
| Hansen J statistic | | 0.159 | | |
| | | [0.690] | | |
| Number of instruments | | 3 | 22 | 5 |
| CD Statistic | | | | 3.97 |
| | | | | [0.000] |
| Observations | 171 | 162 | 162 | 153 |
| Number of cross-sectional lags/ Factors | 2 | | 3 | 3 |

Note: Figures in parentheses are standard errors and p values, respectively.

Among the control variables, results of our chosen 2SIV-MG model in column (3) of Table 2 show that HIV/AIDS, female education, and health worker density are statistically significant with the expected signs. This finding implies that these factors have contributed to reduction in child mortality over the last two decades in South Africa. Other control variables are not statistically significant although they have the expected signs.

The lack of statistical significance we find in Table 2 for the public health expenditure variable may be due to its high collinearity with the MTCT of HIV variable. This is not surprising given that the growth in public health spending during our sample period was largely driven by the need to respond to rising HIV/AIDS prevalence by expanding the prevention of mother to child transmission (PMTCT) and ART programmes. To test this view and validate observations we made in Section 4.2 regarding this collinearity, we re-estimated Equation (1) after dropping the MTCT_HIV variable and found that public health expenditure is highly significant. We do not report these results in this paper due to space limitations.

### 4.4. *The mediating role of CSG on the ART-child mortality relationship*

In this section we re-estimate Equation (1) by substituting the CSG coverage squared term with the interaction term between ART coverage

**Table 4**
Non-linearity of the CSG-child mortality relationship.

| Dependent variable: Under five mortality rate | Fixed effect panel threshold model | | |
|---|---|---|---|
| | Baseline model (1) | Model using total CSG coverage (2) | Model using ART coverage in adult females (3) |
| Estimated threshold value of CSG coverage ($\gamma$) | 80.6%** | 75.0%*** | 80.6%** |
| 95% confidence interval | [79.8–80.9] | [74.9–76.0] | [79.8–80.9] |
| **Effect of CSG coverage** | | | |
| CSG coverage ($\alpha_1$) | 0.185*** | 0.409** | 1.359*** |
| | (0.021) | (0.164) | (0.265) |
| CSG coverage ($\alpha_2$) | −0.014* | −0.041* | −0.143*** |
| | (0.032) | (0.024) | (0.033) |
| **Control variables** | | | |
| ART coverage | −0.044*** | −0.034*** | −0.068*** |
| | (0.009) | (0.009) | (0.013) |
| Public health expenditure | −0.063* | −0.072* | −0.060* |
| | (0.045) | (0.041) | (0.045) |
| MTCT_HIV | 0.393*** | 0.346*** | 0.342*** |
| | (0.028) | (0.026) | (0.030) |
| Female education | −0.068 | 0.016 | −0.089 |
| | (0.117) | (0.114) | (0.116) |
| Access to water | 0.177*** | 0.090* | 0.194*** |
| | (0.057) | (0.053) | (0.057) |
| Health worker density | −0.048* | −0.049* | −0.086*** |
| | (0.029) | (0.027) | (0.029) |
| Immunisation | −0.011 | −0.029 | −0.026 |
| | (0.038) | (0.035) | (0.038) |
| Urbanisation | 0.060 | 0.023 | 0.060 |
| | (0.048) | (0.045) | (0.049) |
| R Squared | 0.99 | 0.99 | 0.99 |
| Observations | 171 | 171 | 171 |
| Bootstrap | 300 | 300 | 300 |
| Bootstrap p-value | 0.090 | 0.000 | 0.040 |

Notes: *, ** and *** denotes significant levels at 10%, 5% and 1%.

**Table 5**
Impact of CSG and ART on child mortality without external instruments.

| Dependent variable: Under five mortality rate | 2SIV-MG (Heterogenous slopes) | | |
|---|---|---|---|
| | Baseline model (1) | Model using total CSG coverage (2) | Model using ART coverage in women (3) |
| ART coverage | −0.061*** | −0.032** | −0.074* |
| | (0.019) | (0.014) | (0.049) |
| CSG coverage | 0.831*** | 1.115*** | 0.965*** |
| | (0.193) | (0.124) | (0.292) |
| CSG coverage squared | −0.098*** | −0.138*** | −0.109*** |
| | (0.026) | (0.018) | (0.029) |
| Public health expenditure | −0.006 | 0.026 | 0.028 |
| | (0.090) | (0.060) | (0.154) |
| MTCT_HIV | 0.379*** | 0.392*** | 0.368*** |
| | (0.060) | (0.046) | (0.092) |
| Female education | −0.360** | −0.261** | −0.343* |
| | (0.157) | (0.115) | (0.226) |
| Access to water | −0.031 | −0.115 | 0.041 |
| | (0.109) | (0.155) | (0.179) |
| Health worker density | −0.141* | −0.168*** | −0.085 |
| | (0.073) | (0.049) | (0.133) |
| Immunisation | −0.048 | −0.005 | −0.071 |
| | (0.064) | (0.054) | (0.123) |
| Urbanisation | −0.052 | 0.005 | 0.096 |
| | (0.150) | (0.175) | (0.181) |
| R Squared | 0.99 | 0.99 | 0.99 |
| Observations | 162 | 162 | 162 |
| Number of instruments | 20 | 10 | 20 |
| Maximum factors | 3 | 3 | 3 |

Notes: *, ** and *** denotes significant levels at 10%, 5% and 1%.

and CSG coverage to assess the mediating role of UCTs on ART-child mortality relationship. Results of the marginal effects of CSG and ART are provided in Table 3 and show that the interaction term between ART and CSG is negative and statistically significant in the four estimation techniques. In our chosen 2SIV-MG model in column (3), CSG enhances the reducing effect of ARTon child mortality thereby confirming the hypothesis that CTs facilitates health care service utilisation leading to a reduction in child mortality.

### 4.5. Robustness checks

To confirm the non-linear relationship between CSG and under five mortality we observed in Section 4.3 and to estimate the threshold value, we use Equation (3) that employs the fixed effect panel threshold model. We do this by re-estimating our baseline model that uses CSG coverage in children below five years of age. We also add a model that uses CSG coverage in children aged 0–17 years of age and another model that uses ART coverage in females aged 15 and above. In these models, we use CSG coverage as a threshold variable. Table 4 provides results of the non-linear model.

Results in Table 4 confirm the inverted u-shaped non-linear relationship between CSG and under five mortality that we found in Section 4.1 and 4.3. Column (1) of Table 4 shows that CSG is positively correlated with under five mortality when CSG coverage is beneath 80.6%. CSG is negatively associated with under five mortality when CSG coverage is above 80.6%. Therefore, in a setting where the CT amount is low or below the food poverty line, the relationship between child focused UCTs and child mortality can either be positive or negative contingent on the level of CT coverage.

To ensure validity and robustness of our main findings in Table 2, we also use the 2SIV-MG model without adding external instruments. This will assess if our results are not biased due to the addition of external instruments in the estimation approach. Table 5 provides estimated results of the impact of CSG and ART using the 2SIV-MG estimation approach without adding external instruments.

Our results in Table 5 exhibit both qualitative and quantitative similarities to the results observed in Table 2. To test whether our results are not affected by the inclusion of a highly collinear variable such as public health expenditure, we exclude this variable from our baseline model and compare the results. Table A5 of the Appendix suggests that multicollinearity is not a problem when estimating variables of interest excluding public health expenditure variable.

## 5. Discussion

ART coverage has a robust negative relationship with under five mortality suggesting that ART led to reduction in child mortality in South Africa over the last two decades by reversing detrimental effects of HIV/AIDS. The effect of ART on child mortality is robust to different estimation techniques and different model specifications. Our results lend support to previous findings of epidemiological studies (Bule & Wade, 2019; Johnson et al., 2020; Schue et al., 2021; Shabangu et al., 2017). As observed by Mutanga et al. (2019), children missed by PMTCT programmes face a higher risk of mortality because they often present to the hospital late, already in an immunocompromised state. This finding lends support to the view that ART rollout to children should be prioritised, and resources should be availed for early HIV testing and diagnosis in children.

Consistent with the emerging views that UCTs' impact on child mortality depends on parental or caregiver's decision-making and the monetary value of the grant, our results show that CSG has a non-linear relationship with child mortality. Actually, we find an inverted u-shaped relationship between CSG and under-five mortality rate. Our results also demonstrates that the influence of CSG on child mortality is contingent on the number of poor children reached by the grant. Therefore, our finding suggests that the parental or caregiver's autonomy in decision-making regarding the utilisation of the grant and the monetary value of the grant are crucial in shaping the relationship between UCTs and child mortality. In instances where parents or caregivers redirect the grant away from essential food items crucial for child nutrition, and the amount of the cash transfer is insufficient to improve child nutrition, a higher cash transfers coverage would be necessary for UCTs to effectively reduce child mortality rates.

Unlike Rasella et al. (2013) and Richterman et al. (2023) who found a linear relationship between CTs and child mortality, our finding suggests a nonlinear relationship influenced by parental or caregiver's autonomy in decision-making regarding the utilisation of the grant and the monetary value of the grant. However, our finding is consistent with observations by Richterman et al. (2023) that CT programmes have larger effects on child mortality if they cover a larger share of the population and have larger transfer amounts. In fact, below the threshold level of 80.9%, the coefficient on the CSG indicates a positive and statistically significant relationship. This suggests that the grant is unable to reverse the adverse effects of malnutrition, and this leads to an increase in child mortality. Our findings align with the perspective that the effectiveness of a CT programme depends on its overall coverage, the local context, and the transfer amount.

Unlike most CTs in Latin America, the CSG has no condition attached to it and caregivers have discretion on how to use the money from the grant. This means that caregivers can divert funds to non-food items that are not essential for child's nutrition. In this instance, malnutrition is likely to persist despite high CSG coverage. Another plausible explanation of our finding that there is a positive relationship between CSG and child mortality below the threshold level of 80.9% suggest that the monetary value of the grant may be too low and unable to reverse detrimental effects of malnutrition. Hence a higher level of CSG coverage is required for CSG to reduce child mortality in a setting where the child focused UCTs are too small to improve child nutrition.

However, our finding is consistent with the emerging view in South Africa that the CSG's monetary value is too low to reduce malnutrition and subsequent child mortality. In this view, it is often argued that the monetary value of the CSG is insufficient to shield poor children from hunger, malnutrition, and stunting (Hall et al., 2023; Luthuli et al., 2022; Zembe-Mkabile et al., 2022). Actually, Zembe-Mkabile et al. (2022) found that the small amount of the grant constraints food choices for CSG recipients leading to insufficient dietary diversity to reduce malnutrition in children. Hence a higher level of CSG coverage is required to reduce child mortality through the child nutrition channel as we have demonstrated in this study. Therefore, our finding of a non-linear relationship between CSG and under-five mortality supports the hypothesis that child-focused UCTs' impact on child mortality depends on the extent of its coverage, local context, and the transfer amount. Our findings suggest that theoretical predictions of CTs' impact on child mortality may depend on whether the transfer is conditional or unconditional since the mediating role of household income may differ. In cases of UCTs, increases in household income from CTs do not guarantee improvements in health care utilisation and increase in nutritional choices for children. Our results lend support to the view of Novignon et al. (2022) that the impacts of CCTs and UCTs on health outcomes should be disaggregated.

Our results have also shown that UCTs, similar to CTs, can reduce child mortality by improving food security, which in turn enhances adherence to ART. This finding aligns with the conclusions of Weiser et al. (2014), who found that food security is associated with improved ART adherence. Additionally, our results support the assertion made by Novignon et al. (2022) that UCTs can enhance health-seeking behaviour during illness by reducing constraints such as transportation costs. This finding provides further evidence for the health care utilisation channel through which CTs can impact child mortality, as noted by Rasella et al. (2013).

Overall, our findings offer additional support for the notion that improving access to essential health care services, such as ART and adequate child nutrition can improve child well-being and overall health, ultimately reducing child mortality. As highlighted by Moreno-Serra and Smith (2015), socio-economic and health system inequities that may impede reduction in child mortality are reversible through improvements in access to better health. Furthermore, strategies to tackle child mortality equitably must also include social protection through income support for children. In this regard, children who are well-nourished and have access to crucial medical care and treatment are in a better position to live beyond childhood and contribute to the economy when they are older (Hall et al., 2023).

With regard to other control variables, we find HIV/AIDS, maternal education, and health worker density to be the most influential factors affecting child mortality. Furthermore, we also find sufficient evidence to suggest that public health expenditure reduces child mortality although its effect is not robust to the inclusion of a highly collinear HIV/AIDS variable in the estimated models. Therefore, interventions aimed at enhancing PMTCT programmes, improving maternal education, increasing the number of health care workers especially physicians and nurses can substantially reduce child mortality. Furthermore, increasing public health expenditure will facilitate achievement of these interventions.

## 6. Conclusion

This paper adds to the body of literature on socioeconomic determinants of child mortality and the broader literature on the effect of CTs on child health and wellbeing. We do this by examining the effects of ART and CSG on the under-five mortality in South Africa spanning the period 2001 to 2019 using the 2SIV-MG and the fixed-effect panel threshold econometric approaches.

Levels of child mortality in South Africa have decreased over the period 2001 to 2019 and much of this can be attributed to the impact of ART as evidenced by our results. This means that ART has over the last two decades reversed the detrimental effects of the HIV epidemic on child mortality. Our results provide further evidence that ART provision is important to children living with HIV. There is a need for early detection and treatment of HIV in children to reduce child mortality. Therefore, child health care services, encompassing HIV prevention, diagnosis, and treatment should be strengthened.

Over the sample period, our results provide evidence to the hypothesis that child focused cash transfers have a non-linear relationship with child mortality. This non-linear relationship is contingent on the level of CT coverage. In terms of the policy options to enhance CSG's impact on child mortality, policy makers have two options. The first option is to ensure that the CSG coverage among children under five years is above the threshold value of 80.6% across all provinces. Another option is to ensure that the monetary value of the grant is increased to above the prevailing food poverty line to ensure that essential nutritional needs of children are met. Given the limited resources, the proposed increase in cash transfer should prioritise children below the age of five since the school-going age children's nutritional needs are partially catered by the existing school nutrition programmes.

We acknowledge the limitations of this study. Data is obtained from a single country, and this may restrict generalisability of our estimated results. Despite this, some of the recommended policies can be useful in contexts where there is a high HIV/AIDS prevalence and child poverty. We recommend future research to include multiple countries over a longer period to assess the joint effects of ART and child focused UCTs on child mortality. An additional limitation of our study is that it does not capture the potential impact of indirect cash transfers on the child mortality effects of ART and UCTs due to unavailability of data. The effects of ART and UCTs on child mortality may be more pronounced, particularly if supplemented by other forms of indirect cash transfers, such as reimbursements for transportation, treatment, and care expenses.

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## CRediT authorship contribution statement

**Mashudu Lucas Bidzha:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Nicholas Ngepah:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Talita Greyling:** Conceptualization, Methodology, Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no competing interests.

## Data availability

Data will be made available on request.


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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2024.101671.

## Appendix A

**Table A.1**
Test for multicollinearity.

| VIF statistic | Inclusive Model (1) | Model excluding MTCT_HIV (2) | Model excluding PHEXP and MTCT_HIV (3) |
|---|---|---|---|
| ART_U15 | 18.58 | 11.63 | 5.65 |
| CSG_U5 | 5.28 | 3.84 | 4.20 |
| MTCT_HIV | 17.13 | – | – |
| PHEXP | 12.77 | 7.47 | – |
| Educ_Female | 5.79 | 5.30 | 4.48 |
| ATW | 4.16 | 3.46 | 2.74 |
| HW_Density | 2.08 | 2.00 | 1.74 |
| Immunisation | 1.57 | 1.54 | 1.49 |
| Urbanisation | 4.23 | 3.80 | 3.70 |
| **Mean VIF** | **7.98** | **4.88** | **4.34** |

**Table A.2**
Levin-Lin-Chu panel unit root test.

| | Adjusted t | |
|---|---|---|
| | Without time trend | With time trend |
| Under five mortality rate | −5.856*** | −7.461*** |
| ART_U15 | −23.954*** | −33.754*** |
| CSG_U5 | −13.337** | −14.436*** |
| MTCT_HIV | −8.799*** | −1.166* |
| PHEXP | −9.132*** | −2.007** |
| Educ_Female | −2.519*** | −7.488*** |
| ATW | −2.734*** | −4.617*** |
| HW_Density | −4.654*** | −1.578* |
| Immunisation | −2.4824*** | −3.431*** |
| Urbanisation | −6.351*** | −4.437*** |

**Table A.3**
Testing for autocorrelation.

| | Baseline model (1) | Model using total CSG coverage (2) | Model using ART coverage in females (3) |
|---|---|---|---|
| *Wooldridge test for autocorrelation in panel data* | | | |
| F-Statistic | 377.984 | 827.897 | 107.921 |
| p-value | (0.000) | (0.000) | (0.000) |

**Table A.4**
Homogeneity and Pesaran (2021) CD test.

| | Baseline model (3) | Model using total CSG coverage (2) | Model using ART coverage females (3) |
|---|---|---|---|
| *Homogeneity tests* | | | |
| Delta | 3.642 | 3.552 | 3.501 |
| p-value | (0.000) | (0.000) | (0.007) |
| Adjusted delta | 5.999 | 5.852 | 5.768 |
| p-value | (0.000) | (0.000) | (0.000) |
| *Pesaran (2021) cross-sectional dependence test* | | | |
| CD-Statistic | 5.332 | 5.835 | 7.700 |
| p-value | (0.000) | (0.000) | (0.000) |
| *Breusch-Pagan LM test of independence (Ho: No cross-sectional dependence)* | | | |
| Chi-Square | 116.788 | 122.262 | 123.482 |
| p-value | (0.000) | (0.000) | (0.000) |

**Table A.5**
Child mortality effects of ART and CSG without public health expenditure.

| Dependent variable: Under five mortality rate | Homogenous slopes | | Heterogenous slopes | |
|---|---|---|---|---|
| Independent variables | FE-Driscoll & Kraay SE (1) | 2SLS-FE-IV (2) | 2SIV-MG (3) | DCCE-MGIV (4) |
| ART coverage in children | −0.046** | −0.048*** | −0.066*** | −0.058*** |
| | (0.019) | (0.016) | (0.023) | (0.021) |
| CSG coverage | 0.820** | 4.152*** | 0.957*** | 1.728** |
| | (0.373) | (0.945) | (0.249) | (0.912) |
| CSG coverage squared | −0.090* | −0.516*** | −0.114*** | −0.196* |
| | (0.050) | (0.117) | (0.037) | (0.114) |
| MTCT_HIV | 0.422*** | 0.354*** | 0.361*** | 0.366*** |
| | (0.029) | (0.024) | (0.050) | (0.045) |
| Female education | −0.137 | −0.201 | −0.491*** | −0.464* |
| | (0.189) | (0.237) | (0.182) | (0.262) |
| Access to water | 0.188*** | 0.183** | 0.035 | 0.055 |
| | (0.042) | (0.083) | (0.115) | (0.114) |
| Health worker density | −0.075** | −0.099** | −0.127* | −0.071* |
| | (0.026) | (0.048) | (0.068) | (0.089) |
| Immunisation | −0.005 | −0.045 | −0.050 | −0.019 |
| | (0.042) | (0.055) | (0.061) | (0.081) |
| Urbanisation | 0.086** | 0.131* | 0.026 | 0.068 |
| | (0.004) | (0.073) | (0.138) | (0.155) |
| R Squared | 0.99 | 0.97 | 0.99 | 0.99 |
| Hansen J statistic | | 0.478 | | |
| | | [0.7872] | | |
| Number of instruments | | 5 | 18 | 6 |
| CD Statistic | | | | 3.00 |
| | | | | [0.003] |
| Observations | 171 | 162 | 162 | 153 |
| Number of cross-sectional lags/Factors | | | 3 | 3 |

Note: Results are estimated using CSG coverage in children under 5 years. There were no external instruments used to estimate results in column (3).

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