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Early Life Health Interventions and Childhood Development:

Evidence from Special Care Nursery Assignment in Australia's Northern Territory

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This paper studies the effect of improved early-life health care, through assignment to a special care nursery (SCN), on childhood development and school achievement. We use linked administrative data in the Northern Territory of Australia and exploit the fact that assignment to SCN is largely based on rules of thumb involving low birth weight thresholds. We find large positive effects of SCN assignment on development at age five and some persistent improvements in test scores. Our results suggest that costly early-life health interventions, that are shown to increase survival probabilities of children in the short run, can also substantially boost cognitive and non-cognitive skills.

Keywords: Early-life health treatments, special care nurseries, school achievements, non-cognitive skills, school readiness

JEL classification codes: J13, I14, I18, I24

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Neonatal health is well established as a key component of human capital formation. A large part of the variation in childhood, adolescent, and adult outcomes can be explained by an individual's "initial conditions" (Almond and Currie, 2011; Heckman and Masterov, 2007). Even when comparing outcomes within families, children born at lower birth weights are disadvantaged over the life course relative to their heavier siblings (Figlio et al., 2014; Black et al., 2007). Given these associations, it is not surprising that investments in infant health are linked to long-term benefits.

Health care investments at birth are often determined by clinical rules and recommendations based on physical measurements (e.g. birth weight, gestation) and health assessments (e.g. APGAR scores). Medical professionals have developed thresholds based on these factors used to assign extra care in the form of special care nurseries (SCN) or neonatal intensive care units (NICU). Researchers have recently exploited these thresholds to measure the causal short- and long-term impact of the NICU care provided to infants born around 1500 grams (Almond et al., 2010; Bharadwaj et al., 2013). Using linked administrative data from Australia's Northern Territory—which include novel measurements of early-childhood development through the Australia Early Development Index (AEDI)—we evaluate the impact of assignment to a SCN for newborns below a low birth weight (LBW) threshold of 2500 grams.

The linked, administrative data from the Northern Territory—an Australian territory which has the highest prevalence of low birth weight newborns (Hilder et al., 2014)—allow us to exploit discontinuities in the probability of assignment to a SCN at two different thresholds (below 2300 grams and between 2300 and 2500 grams) to identify a causal effect. We use bands of birth weight as instrumental variables to provide exogenous variation in the special care admission. This method helps us to identify a local average treatment effect of SCN admission, which is representative for children born near the salient thresholds used to assign SCN care.

Our study contributes to the prior literature evaluating benefits from early-life health interventions in a few important ways: First, we estimate effects at a higher threshold of 2500g than prior research which focuses on a 1500g threshold; Second, we are able to observe novel assessments of early-childhood development across five domains (physical, social, emotional, language/cognitive, communication/general knowledge) and school achievement test scores up until age 14; Third, we estimate benefits for extremely disadvantaged children in the Northern Territory, a population of great interest both domestically and internationally.

First, prior studies focus on newborns at risk of death and serious medical complications by evaluating the impact of assignment to a NICU, or additional medical treatment, for newborns born below a very low birth weight (VLBW) threshold of 1500 grams (Almond et al., 2010; Bharadwaj et al., 2013). We provide estimates of the benefits from extra care investment among newborns who are, in general, much healthier than these prior samples. While the return on health investment may not be as large for this population as those with lower initial endowments of health capital, estimates are relevant as SCN is costly, more widely applied, and could have important benefits for certain disadvantaged children. The SCN treatment in the Northern Territory also includes additional support for mothers such as breastfeeding and settling advice. Even without increased medical attention, this extra support and advice could potentially be associated with long-term benefits. Similar to prior literature, we are only able to evaluate the package of interventions associated with SCN assignment. *We hope to use other linked administrative data with the aim to tease out important mechanisms generating benefits such as different medical treatments and parental investments.*

Our second primary contribution derives from our novel measurements of early childhood devel-

opment and follow up measurements in early adolescence. Prior research analyzes the impact of NICU assignment or other early-life treatment for at-risk newborns on short-term survival rates and long-term academic achievement (Brooks-Gunn et al., 1992; Almond et al., 2010; Bharadwaj et al., 2013). We evaluate the effects of additional medical attention on physical, social, emotional, language, cognitive, and communication development at the age of five. Measurements across these developmental domains are shown to perform as well or better than other established instruments used by psychology professionals (such as SDQ, PEDS, PedsQLTM, and PPVT-III) and also are predictors of performance in later-life cognitive assessments (Brinkman, 2012; Brinkman et al., 2013). These early-life measurements of cognitive and noncognitive skills are of interest to both policymakers and researchers, because they can be both shaped through parenting and preschool interventions, and they are strong predictors of a variety of later-life outcomes (e.g. Heckman et al., 2013; Heckman and Kautz, 2012).

Three recent studies offer compelling evidence that early-life medical treatment is associated with short and long-term benefits and are most closely related to this paper. First, Almond et al. (2010) study the effectiveness of extra medical treatment, that is not necessarily associated with NICU admission, for newborns with VLBW using data from the U.S Census 1983-2002. The authors use a regression discontinuity approach that exploits a discontinuity in the probability of being treated across a VLBW (1500g) threshold to identify the causal effect of the extra medical treatment for those newborns just below the threshold. The authors find that this additional medical treatment, which involves a longer hospital stay and 10% higher expenditures, lowers the one-year infant mortality rate by nearly 20%. Second, Bharadwaj et al. (2013) use a similar approach to identify the causal effect of NICU admission for VLBW babies on test scores using Chilean and Norwegian data. The authors find that newborns in Chile below the VLBW threshold, who receive additional treatment, score 0.15 standard deviations higher mathematics and language tests measured at age 18 than newborns above the VLBW cut-off. Slightly larger effects are obtained for Norway (0.22 SD). Third, Breining et al. (2015) use administrative linked data from Denmark and also a regression discontinuity approach, to confirm the findings in the previous literature that children who are slightly below the VLBW cutoff have better short- and long-term health, and higher math test scores in 9th grade. More importantly, they also demonstrate important spillover effects on siblings' academic achievement - although not on their health outcome - which the authors attribute to improved interactions within the family as an important pathway.

Finally, we provide evidence of the returns to early-life health investment in a unique, but important, setting. A large proportion of children born in Australia's Northern Territory face extreme disadvantage and deprivation over the life-course. Aboriginal children in the Northern Territory experience the highest probability in the country for infant mortality, development of chronic illness, malnutrition, and chronic ear infections. Millions of dollars are invested each year on programs and interventions to address basic health care needs and cognitive and non-cognitive deficiencies among disadvantaged children who typically are from an Aboriginal background and live in very remote communities. A night in the SCN or in a Neonatal Intensive Care Unit (NICU) costs between A\$3,000 and A\$4,300 and it is not uncommon that a LBW infant incurs more than A\$200,000 in total expenses before being discharged from the hospital.¹

¹The numbers range between providers. For instance, The Royal Women's hospital in Melbourne, Victoria charges a patient fee of \$2,971 for a night in the SCN, and \$4,293 for a night in the NICU. See <https://www.thewomens.org.au/patients-visitors/patient-fees/>, while Monash Health Centre charges \$2,250 per night at the SCN file:///C:/Users/ssch9002/Downloads/188242_1440390910.pdf. Similar numbers are reported in a 2011 ABC Four Corner report "The Price of Life", 8 November 2011, see <http://www.abc.net.au/4corners/stories/2011/10/14/3339507.htm>.

While our setting is indeed unique, estimates are relevant to children in other settings facing extreme poverty and disadvantage, both in developed and developing areas.

Our paper proceeds as follows. In Section 1 we describe the linked administrative data, the outcome variables of interest, and the medical treatment that children receive in the SCN. Section 2 presents the empirical framework which is based on a two-stage least squares estimation model. In Section 3 we present and discuss estimated effects. The implications of our findings are discussed in Section 4.

1 Institutions and Data

1.1 The Northern Territory Data Linkage

The analysis is conducted with data from the Northern Territory (NT) Early Childhood Data Linkage Project, “Improving the developmental outcomes of NT Children: A data linkage study to inform policy and practice across the health, education and family services sectors”, which is funded through a Partnership Project between the National Health and Medical Research Council (NHMRC) and the NT Government. A collaboration between the NT and South Australia (SA) Governments enabled the establishment of the SA NT DataLink facility in 2009, which is responsible for linking datasets from state Government departments (SA NT, 2017).²

We use in this study whole-of-population linked data spanning pregnancy and adolescence (age 15) from 1) the NT perinatal data register, 2) the NT government school student information including teacher reports on the Australian Early Child Development Index (AEDI), and 3) The National Assessment Program - Literacy and Numeracy (NAPLAN) database. Probabilistic record linkage was undertaken by SA-NT DataLink, and involved calculating the probability that records in different datasets belong to the same person, based on concordance of predetermined identifiers (e.g. name, DOB, gender, address). Cut-offs for rejecting or accepting a ‘match’ were pre-set, and then modified during clerical review until the false positive and negative rates were less than 0.05. Matches were assigned a unique linkage key, which was then returned to the respective data custodians, who compiled a de-identified research dataset containing the requested content data and linkage keys. Community-level data such as community size, housing overcrowding and measures of remoteness are also included.

In each year, roughly 4,000 children are born in the NT. Unlike most Australian jurisdictions, the NT’s demographic profile differs substantially from other Australian states and territories in having a much larger percentage of the population who are Aboriginal and/or Torres Strait Islanders. In the 2011 census 27% of the NT population was counted as Aboriginal and/or Torres Strait Islander compared to 4% or less in all other jurisdictions (Australian Bureau of Statistics, 2012). Of the NT born children in this data linkage study, 39% had school enrolments records in which they were identified as Aboriginal and/or Torres Strait Islanders.

²With the support of the Population Health Research Network (PHRN), part of the Australian Government’s National Collaborative Research Infrastructure Strategy (NCRIS), the Education Investment Fund Super Science Initiative, and a range of other stakeholders, the SA NT Datalink was established to support important research to inform many areas of policy and service development within the NT, SA and nationwide.

1.2 Clinical decision rules

We focus on the long-term treatment effects of SCNs instead of NICUs, because in the NT there is no distinction between the two. In general, SCNs are designed for newborns that require extra attention at birth, but who are not sick enough to be admitted to a NICU. In the NT, more intensive care units are nested within the SCN. However, our analysis focuses on newborns who, in other settings, be admitted to a SCN rather than a NICU.³

While the primary aim of a SCN is medical care, there is also a focus on discharge planning and educating the parents of the newborn. Staff are available for advice about caring for newborns including feeding and bathing. Those admitted to a SCN therefore benefit both directly and indirectly from admission. First, they receive medical treatment that should increase survival probabilities and early-life health. Second, these newborns benefit from potentially better informed and prepared parents.

Newborns will be admitted to the SCN primarily if they have low birth weight or if they are premature, although they may also be admitted due to other reasons such as difficulty breathing or very low APGAR scores. According to the *Admission and Discharge Planning For Babies in Neonatal Intensive Care and Maternity Ward RDH Guidelines* provided by the NT Department of Health, newborns should be admitted to the SCN if:⁴

1. They weigh less than 2300g. Newborns between 2200g and 2300g may be transferred to the Maternity Ward after a period of observation in the SCN where they have proven to be thermodynamically stable with stable blood glucose levels.
2. They are born with a birth weight between 2300g and 2500g *and* meet one of the below qualifications:
 - Is born premature, which is defined as less than 36 weeks gestation by confirmed dates.
 - Did not breast feed successfully at birth or where the "Borderline low birth weight newborns admitted to the Maternity Unit Breastfeeding Plan" is unsuccessful.
 - Is at risk of sepsis.⁵
3. Suffers from apnoea, birth asphyxia, a respiratory distress, or hypoglycaemia.

These clinical guidelines emphasize that birth weight and gestational age are not the only factors used to assess newborn health. As a consequence, birth weight is not a perfect predictor of SCN assignment within the borderline (2300-2500g region). Our strategy does not require these birth weight thresholds to perfectly predict assignment, only that the relationship between birth weight and the probability of assignment to change as we cross the 2500g threshold (see

³While in a SCN, newborns are monitored closely by nurses, but less often than in the typical NICU. Each nurse looks after several newborns at a time. In hospitals with both a SCN and NICU facility, the SCN usually contains newborns that were admitted to NICU initially, but after seeing an increase in their health, are discharged from the NICU to a SCN for additional observation. In general, newborns in the SCN are healthier and stronger than newborns admitted to the standard NICU.

⁴From conversations with Northern Territory obstetricians and midwives, we confirmed that these clinical guidelines are being used in all three hospitals of our data and have not substantially changed since 1994. We interviewed Dr Charles Kilburn, Head of Pediatrics at the Royal Darwin Hospital, who provided us with the clinical guidelines from the NT Department of Health. These guidelines are summarized below and will be provided in Appendix X.

⁵For example vaginal birth when mother GBS +ve without adequate antibiotic cover in labour, meconium stained liquor, prolonged ruptured membranes.

Section 2 for a description of the identification strategy).

Importantly, the clinical use of birth weight thresholds around the 2500g and prematurity thresholds around 36 gestation weeks are not necessarily reflecting discontinuities in true biological survival risk. In fact, the 2500g (LBW) threshold has been used since the 1930s, when a Finnish pediatrician advocated it as a critical indicator for adverse neonatal outcomes. Most important to our empirical strategy is that the 2500g and 2300g cutoffs reflect convention rather than strict biological criteria (see Almond et al., 2010, for more discussion of the evolution of these rules of thumbs).

When exploiting these thresholds, one concern is that parents or doctors are manipulating the recorded birth weight to qualify for additional medical treatment as discussed by Almond et al. (2010) and Bharadwaj et al. (2013). In our data, we find little evidence of non-random heaping around the 2300 g threshold below which newborns would be automatically admitted to SCN. Figure 1 depicts the full distribution of birth weight (in 20g bins) for all newborns in our perinatal data. If there was systematic manipulation by doctors, we would see a spike in observations just below the 2300g threshold, which is not the case for both groups of newborns.⁶ This is consistent with findings in Almond et al. (2010) and Bharadwaj et al. (2013) for the 1500g threshold.⁷

1.3 Australian Early Development Index

To measure human capital at age five, we use teacher-assessed data on the child's development collected in the Australian Early Development Index (AEDI). The AEDI is a national developmental census of all Australian children in their first year of schooling. The first national collection was in May 2009. A second full census was collected in 2012.⁸

The AEDI collects a range of demographic and contextual data on each child as well as developmental assessment items. The tool is not intended as an individual assessment (or diagnosis) tool although the data are collected at the individual level. Children are assessed in the context of their demographic, cultural, language and school environment on five developmental domains that are designed to measure aspects of their readiness for schooling.

- Physical Health and Wellbeing: illness or injury, dressed inappropriately, too tired or sick, hungry, well-coordinated, overall physical appearance, daily hygiene, etc.
- Social Competence: plays with various children, cooperative, gets along with peers, respect for adults, accepts responsibility, etc.
- Emotional Maturity: bullies, takes things, restless, temper tantrums, worried, cries a lot, etc.
- Language and Cognitive Skills (school based): numeracy, literacy, music, reads simple

⁶This conclusion does not change when presenting the histogram by 1g bins. There is no visual evidence of heaping around any birth weight threshold. We conducted tests for discontinuities across thresholds based on the extended version of a McCrary density test (Breining et al., 2017). We fail to reject the null of no manipulation around 2300 (p-value=0.291) and 2500g thresholds (p-value=0.263).

⁷The literature has further discussed the potential misclassification of low birth weight due to conversion from two units of measurement, ounce and grams, which is relevant in the US health care system context, but not in the Australian context (see Barreca et al., 2011; Umbach, 2000). We will provide formal tests for potential manipulation and heaping biases in a subsequent draft.

⁸In the Northern Territory there was a smaller collection in certain remote communities in 2010 to ameliorate data quality issues at several sites.

words, reads sentences, writing voluntarily, interested in math, interested in number games, etc.

- Communication Skills and General Knowledge: knowledge about the world, curious, follows simple instructions, etc.

The first domain is a proxy for health capital, although it also includes a notion of whether the child is neglected. The second and third domains refer to the concept of socio-emotional skills, while the last two domains capture standard cognitive skills, although not task-based but teacher-assessed. *A full list of questions underlying the each of the five AEDI domains is presented in Table XX in the Online Appendix (to be added).*

The AEDI data—and in particular repeated collections—can inform policy makers on the types of early childhood circumstances and programs that delay (or enhance) a child's readiness for school. The data can help identify the cohorts of children most at risk of developmental delay and poor school outcomes, informing the allocation of resources, funding and interventions. The Australian Government uses this data to identify schools and areas where children are most developmentally vulnerable, i.e. the proportion of children who score below the 10th percentile on a specific domain. Children scoring between the 10th and 25th percentiles are assessed as "developmentally at risk" while all other children are "developmentally on track". In this study, we use the full score in each domain, standardized to a mean of zero and a standard deviation of one.

The accuracy of the data collection depends on the teachers completing the assessment [Brinkman et al. \(2007\)](#). Prior researchers have validated its use with indigenous children [Silburn et al. \(2009\)](#). Recent research demonstrates that some domains of the AEDI—Social Competence, Language and Cognitive Development and Communication Skills and General Knowledge—are good predictors of both cognitive and behavioural outcomes. Further to that, the AEDI performs as well as or better than established instruments such as the SDQ, PEDS, PedsQLTM and PPVT-III ([Brinkman, 2012](#)).

In study in Western Australia using data from 2002, [Brinkman et al. \(2013\)](#) found that all five of the AEDI domains predicted literacy and numeracy outcomes for children as measured by the National Assessment Program Literacy and Numeracy (NAPLAN) in years three, five and seven. The Language and Cognitive Development, and Communication Skills and General Knowledge domains of the AEDI at age five were the best predictors of scores on the NAPLAN assessments. The strengths of these relationships were very stable over time despite the continuing development of the children ([Brinkman et al., 2013](#)).

1.4 School achievement

Our data includes information on students' performance in the National Assessment Program: Literacy and Numeracy (NAPLAN) tests, a standardised school achievement test battery. It is an annual assessment for students in Years 3, 5, 7 and 9, when the child is between 8 and 14 years of age, which has been an everyday part of the school calendar since 2008. NAPLAN tests skills that are essential for every child to progress through school and life, such as reading, writing, spelling and numeracy. The assessments are undertaken nationwide, every year, in the second full week in May. NAPLAN is made up of tests in the four domains of: (1) reading; (2) writing; (3) language conventions (spelling and grammar); and (4) numeracy. NAPLAN tests skills in literacy and numeracy that are developed over time through the school curriculum.

In the benchmark model, we use a summary measure of the NAPLAN test scores that is averaged across all grades and components. In additional analyses, we use the sub-component scores and grade-specific scores as outcome variables.

1.5 Estimation sample

The perinatal administrative records capture the population of 74,419 newborns between 1994 and 2013. The population of newborns per annum increased in these 20 years by 15%, from 3,526 born in 1994, and 4,061 in 2013. Less than 1% of babies were still born (689) or died in the hospital immediately following birth (262). For approximately 10% of newborns we have no information on whether or not they were admitted to a special care nursery, and therefore we drop these observations.⁹ We also drop 1,094 newborns which were transferred to another acute hospital since we do not have indication of whether treatment in the receiving hospital included admission to a SCN. The analysis is further restricted to children born in the Royal Darwin Hospital, a public teaching hospital, the Darwin Private hospital, or the Alice Springs Hospital, all of which have SCNs, and which administered the majority of births (82%) in the Northern Territory.

In the AEDI administrative records, we start out with 7,120 children who were assessed in 2009 (3,183), 2010 (467), and 2012 (3,470). Among those assessed, data is missing on at least one domain for 506 children (7%), who are excluded from our estimation sample.¹⁰ In the case of the 20 children for whom two AEDI assessments are available, we only kept the second assessment.

Of the 6,594 eligible children in the AEDI we were able to match perinatal and AEDI records for 4,630 children (70%).¹¹ Previous reports demonstrated that the pattern of linkage and the shifts in the demographics of the linked data demonstrate the expected pattern but some effects are greater than anticipated. Indigenous children have a higher rate of linkage (particularly to the perinatal data where their proportion increases from 47 to 59%). This reflects the greater interstate mobility of non-indigenous children as well as their higher representation in the NT non-government school sector (McKenzie and Silburn, 2014). When restricting this sample to the children born in Darwin or Alice Springs, we are left with 3,683 children. Restricting the sample further to children born between 1500g and 3500g, we are left with 1,109 children of indigenous background and 1,198 children of non-indigenous background.¹²

From the NAPLAN data, we are able to match over X% of the children with the perinatal data. Restricting the sample to observations that have at least one assessment available across the four assessment years (Years 2003, 2005, 2007, and 2009), we are left with a sample of 12,001 person-year observations, or between 3,652 and 4,132 individuals observations in a specific assessment year.

Table 1 presents descriptive statistics on perinatal information for the base estimation sample and compares these to children fitting our sample restrictions in the perinatal database.¹³

⁹Need to check, but I think this was mostly an issue of this indicator being missing for a few years?

¹⁰We will check that all results are robust to their inclusion in models including outcomes for which these children are assessed.

¹¹Data linkage is based on the child's First Name and Surname, Sex, Country of Birth, Date of Birth, School name, and the Unique Record Number.

¹²There are four children we dropped from the sample because they were born with less than 2300g but who were not admitted to a special care nursery.

¹³Note that children not linked primarily include those born in years in which we do not have AEDI or NAPLAN assessment data. Also included would be those who meet our criteria, but are not matched to AEDI or NAPLAN

2 Empirical Strategy

Our empirical strategy exploits the highly non-linear relationship between special care nursery admission and birth weight seen in Figure 2. Identification comes from controlling for smooth functions of birth weight and attributing any remaining nonlinearities to the causal effect of special care nursery admission.

If we assume the effects of SCN are constant and that the relationship between human capital and birth weight can be represented by a natural logarithmic curve (as is standard in economic literature evaluating the effects of birth weight (e.g. see Figlio et al., 2014)), we can write the following model for our human capital outcome k (HC_i^k):

$$HC_i^k = \beta_0 + \tau SCN_i + \beta_1 \ln(BW_i) + X_i' \gamma + u_i, \quad (1)$$

where SCN_i represents an indicator for SCN admission (as indicated in the perinatal birth records), $\ln(BW_i)$ is the natural log of the weight recorded at birth, and X_i is a vector containing a wide range of controls from school and medical records. Most importantly, these controls include information that is also used in the SCN decision: gestation (prematurity), APGAR scores at one and five minutes, and indicators for any labor or medical complications during birth. We also control for gender and ethnicity, and assessment-specific information to capture differences in the age of assessment, year of assessment, and school heterogeneity (school fixed effects). Since these health challenges at birth are correlated with SCN admission and could have longer-term effects on developmental outcomes, we expect a downward bias in our estimate of τ without the inclusion of these controls. In an extension to these baseline controls, we include demographic and maternal characteristics including a quadratic polynomial of mother age, number of total prior pregnancies for the mother (gravidity), number of antenatal visits, indicators for maternal smoking or drinking behavior during pregnancy, and indicators for hospital of birth.

Even after controlling for birth weight, a proxy for underlying neonatal health, and all of the above observable characteristics listed, SCN is likely to be correlated with other omitted determinants of human capital because there is some discretion involved in assignment. If admission to a SCN is a function of unobservable characteristics u_i that also influence developmental outcomes, then our OLS estimation of Eq. (1) would produce biased estimates of τ .¹⁴ Since SCN assignment is more likely for newborns with other unobserved health challenges, it is likely that the OLS estimate of τ downward biased.

To address the health-related endogeneity in SCN admission, we use an instrumental variable approach.¹⁵ We exploit clinical decision rules, based predominantly on the birth weight of a

data data due to moving out of the NT before entering school.

¹⁴Possible candidates for these unobservable factors are maternal pre- and post-natal investment in the child's health. Maternal health behaviors during pregnancy, such as drinking and smoking, will have strong demonstrated effects on birth weight, and consequently the probability of being admitted to a SCN. It is also likely that mothers who engage in risky health behaviors are less likely to invest in their children's health and cognitive development. The latter will affect children's long-term educational outcomes.

¹⁵Our strategy is similar to the modelling strategy used in Clark and Del Bono (2016) who estimated the causal effect of assignment to private schooling on later-life outcomes including education, income and fertility. Clark and Del Bono (2016) exploited a strict formula, which was a highly nonlinear function of assignment scores, according to which primary students were admitted to elite schools.

newborn, which medical professionals use to decide whether a newborn baby requires additional medical attention. In Figure 2 we demonstrate that the relationship between birth weight and admission to SCN changes around birth weights of 2300g and 2500g. For newborns heavier than the LBW threshold of 2500g, we find that newborns are increasingly likely to be assigned to a SCN as they are closer to the 2500g threshold. This increase in probability of admission is not likely due to birth weight, but to other health factors such as prematurity or low APGAR scores. Children born within the 2300g and 2500g window have a strong and increasing probability of being admitted to special care, ranging between 50 and 90%. Below 2300g, all children in our sample are admitted to a SCN. Thus, the defining characteristic of this "first-stage" relationship is that the fitted probability of treatment increases sharply over the marginal area. These patterns are consistent with the clinical rules previously described.

We exploit this change in gradient of the relationship between birth weight and SCN admission at the LBW threshold of 2500g and again at the threshold of 2300g as instrumental variables. We can use these instrumental variables in a two-stage least squares (2SLS) model. The first stage is as follows:

$$\begin{aligned} \text{SCN}_i = & \gamma_0 + \gamma_1 \mathbb{1}[\text{BW}_i \leq 2300] + \gamma_2 \mathbb{1}[2300 < \text{BW}_i \leq 2500] + \\ & \gamma_3 \mathbb{1}[\text{BW}_i \leq 2300] \times \ln(\text{BW}_i) + \gamma_4 \mathbb{1}[2300 < \text{BW}_i \leq 2500] \times \ln(\text{BW}_i) \\ & + \gamma_5 \ln(\text{BW}_i) + X_i' \gamma_6 + \epsilon_i \end{aligned} \quad (2)$$

The first instrument is an indicator variable that takes the value of one if the individual has a birth-weight that lies below 2300g ($\mathbb{1}[\text{BW}_i \leq 2300]$). The second instrumental variable is an indicator variable that takes the value 1 if the baby has a birth-weight that lies within 2300g and 2500g ($\mathbb{1}[2300 < \text{BW}_i \leq 2500]$), which we refer to as the borderline region. In addition, interactions of these indicator variables with the natural log of birth weight also serve as instrumental variables for the endogenous SCN assignment. These four instruments have strong predictive power in the probability of SCN admission. Tests of the hypothesis that the excluded instruments had no explanatory power generated F-statistics of almost 49 in the AEDI sample, and 189 in the larger NAPLAN sample.¹⁶

We must also make the assumption that the instruments are not correlated with unobserved determinants of HC_i^k . This assumption implies that the instruments have an effect on developmental outcomes only through their effect on the probability of being admitted to the SCN. For the 2SLS estimation to generate consistent results, the natural log of birth weight must capture the underlying relationship between our outcomes and birth weight after conditioning on all other observed health and demographic factors. We note that our strategy is similar to a regression kink design as described in Dong (2016), but we apply stronger parametric assumptions on the human capital-birth weight relationship across a wide range of birth weight values (1500g to 3500g) since we have small samples and two "kinks" that are relatively close to each other.¹⁷

If treatment effects are heterogeneous, we expect our strategy to identify treatment effects for those born just below and within the borderline region. These are the newborns for whom

¹⁶The strength of the instruments is important in a statistical sense, because if our instruments are weak, then we are likely to introduce large estimation biases of unknown magnitudes (Bound et al., 1995).

¹⁷These are similar issues in Clark and Del Bono (2016). We will test for alternative specifications, including a regression kink design framework, in a robustness check [*not yet completed for this draft*]

admission to SCN is influenced by the value of the four instruments. Apart from strength and validity, the IVs must ensure monotonicity. Monotonicity requires that the IVs affect the probability of SCN admission only in one direction. In our setting this means that, conditional on other covariates, the newborns with lower birth-weights are always more likely to receive SCN admission. To meet this assumption we drop all newborns below the very low birth-weight (VLBW) threshold of 1,500g since these individuals may die prior to admission to a SCN, be transferred to another hospital, or receive care outside of the hospital's SCN. In each of these cases, we would observe the newborns to be less likely to be admitted to a SCN. We also drop those born over 3,500g, as some newborns may be admitted to SCN units for health reasons associated with being heavy (Eriksen, 2014).¹⁸

Finally, we cannot exclude the possibility that the treatment in SCN affects post-hospitalization medical treatments and parental investment. Thus, the interpretation of the treatment effect of SCN includes the possible role of parental and subsequent medical inputs into the human capital production function. The subsequent inputs could either increase or decrease the treatment effect of SCN (see Bharadwaj et al., 2013, for similar argument). Furthermore, SCN admission is associated with additional treatment among not only the newborns, but also their mothers who typically spend extended periods in the hospital. During these spells, mothers will receive guidance on feeding-, settling-, and hygiene routines, in addition to general parenting advice provided by the midwives. This advice may influence the mother's child investment behavior in the long-run and their demand for future medical care.¹⁹

3 The long-term effect of special care nursery admission

The AEDI measure is an early-childhood measure of human capital formation, measuring child development around five years of age. Each measure is continuous in nature, but AEDI statistics are reported in terms of the proportion of children in the population that are developmentally vulnerable. Developmental vulnerability is defined as ranking in at least two domains in the lowest 10th percentile of the national AEDI distribution. High values of developmental vulnerability are associated with lower levels of human capital. School achievement is measured by NAPLAN test scores, averaged across all five domains. Higher values of NAPLAN test scores are associated with higher levels of human capital.

Figures 3 depict the relationship between birth weight and AEDI vulnerability or average NAPLAN scores which are not explained by other medical factors. Outcomes are standardized to mean zero and standard deviation one. Each of the circles in these figures represent the average residuals from a regression on AEDI vulnerability or NAPLAN test score on the basic control variables specified in Section 2 within 100g birth weight bins. The solid lines represent the expected outcomes based on the observed birth weight. Without indicators for the regions below the LBW threshold and interactions of these indicators with birth weight, the expected outcomes are represented by the dashed gray line. This provides a visual of the counterfactual outcomes without a change in neonatal health care (the probability of SCN admission) at the birth weight thresholds.

In general, above the LBW threshold, decreases in birth weight are associated with an increase

¹⁸ We will explore whether or not we can exploit a change in the probability of being admitted at the 3,500g threshold to estimate effects among heavier children.

¹⁹ We hope to explore these alternative mechanisms once other administrative records on child protection, hospitalization, and general practice use are matched to our data.

in AEDI vulnerability and a decrease in NAPLAN test scores. This relationship is consistent with prior literature investigating the causal impact of birth weight on later-life outcomes (Figlio et al., 2014; Black et al., 2007). The two figures provide visual evidence of a change in the relationship between both human capital outcomes and birth weight around the key thresholds and evidence of human capital improvements associated with SCN admission.

Figures 4 depict the same changes in relationship for the various domains of the AEDI (left panel) and NAPLAN test scores. Note, that here both outcomes are increasing in human capital, and therefore we expect a positive relationship between birth weight and human capital.

These visual patterns are consistent with regression results presented in Table 2. Each row indicates a separate regression model in which one of the five AEDI (upper panel) or NAPLAN (lower panel) domains is the outcome. Column 1 reports OLS results (with basic control variables), and columns 2 and 3 report 2SLS estimates with basic and extended control variables, respectively. All specifications include the natural log of birth weight. The basic control variables include fixed attributes such as gender and aboriginal status, birth outcomes, which are being used in the clinical decision rules to assign newborns to special care, and age and school of outcome assessment. Extended control variables include information on the mother, her health behaviors during pregnancy and hospital fixed effects.

Column 1 of Table 2 demonstrates that the average child admitted to a SCN after birth, is neither worse nor better off than those who are not admitted to a SCN in terms of its human capital development between 5 and 14 years later. In stark contrast, once controlling for the health-related endogeneity in SCN admission, we find positive treatment effects on human capital (column 2). Newborns at the margin of admission are 0.27 SD less likely to be developmentally vulnerable at age 5 (upper panel), an effect that is statistically significant at the 5% level. This treatment effect is particularly strong for the socioemotional dimensions of development. The marginal child scores 0.47 SD higher on physical health/wellbeing, 0.41 SD higher on social competence, and 0.53 SD higher on emotional maturity. These treatment effects are statistically significant at least at the 10% level for social competence, and statistically significant at the 5% and 1% level for physical health/wellbeing and emotional maturity, respectively. We find no significant treatment effects for cognitive skills at age 5.

The lower panel of Table 2 shows that for the marginal child we find no statistically significant treatment effect for the average school achievement score at later ages (8 to 14), but there are important heterogeneities across the domains of the NAPLAN tests. The marginal child scores 0.21 SD higher on the writing domain, an effect that is statistically significant at the 1% level.

The relevant treatment effects are not sensitive to the inclusion of maternal and demographic control variables, as can be seen from column 3 in Table 2.

3.1 Heterogeneity in the treatment effect of SCN

In this section we explore the possible heterogeneity in the treatment effect of SCN for the marginal child. Table 3 treatment effects by sex (columns 1 and 2), and by Indigenous status. Indigenous status reflects in our context socioeconomic inequalities and geographic remoteness. The treatment effects on AEDI vulnerability is mainly driven by male and/or indigenous sample members. For instance, the marginal male child admitted to SCN is 0.45 percentage points less likely to be developmentally vulnerable (significant at the 1% level), an effect that is more than twice as large as the treatment effect for the marginal female child (0.2, not significant). Boys

admitted to a SCN after boys score almost 0.6 SD higher on physical health/wellbeing, 0.5 SD higher on social competence, and 0.81 SD higher on emotion maturity. They also score 0.43 SD higher on cognitive and language skills. Due to smaller samples we obtain relatively large standard errors for these estimates, so we have less certainty whether these differences are statistically meaningful, although they are economically meaningful.

Column 3 shows that the treatment effect on AEDC vulnerability is almost 0.3 percentage points, while the positive treatment effects on physical health/wellbeing, social competence and emotional maturity for the marginal indigenous child are 0.72 SD, 0.73 SD, and 0.85 SD, respectively. The marginal indigenous child also seems to benefit from SCN in terms of cognitive skills (almost 0.4 SD), although these estimates are imprecise. This is also the group of children who benefit from SCN in terms of school achievement at later ages (lower panel). Their NAPLAN writing scores are 0.34 SD larger (significant at 1% level), while their spelling and grammar scores are 0.13 and 0.16 SD larger (Significant at the 10% level). In stark contrast, the treatment effects for non-indigenous children on human capital development between ages 5 and 14 are at best indistinguishable from zero, or even negative.

As we have longitudinal data for NAPLAN test scores (Year 3, 5, 7, and 9), we are able to explore whether the treatment effects changing over the years of assessment. Table 4 displays these results for the average NAPLAN test score (first row) and each NAPLAN domain (rows 2 to 6).²⁰ The treatment effects of SCN for the marginal child are strongest in Year 9, whereby they are weakest in Year 3. There are two reasons why this may be the case. One reason is that initially small gains to non-cognitive skills at age 5 add up over the years and lead to large gains cumulatively at later stages of child development. Another explanation is that of selective school dropout: The children who had benefitted the most from SCN are most likely to remain in school until Year 9, and their achievements gains are also the strongest. [Note, we will further investigate possible explanations for this observation.]

3.2 Robustness Checks

We conducted various robustness checks to our baseline 2SLS specification which include narrowing of the birth weight distribution and alternative specifications of the non-linearities in the relationship between SCN/human capital development and birth weight.

Table 5 shows that using a linear specification or quadratic or polynomials of birth weight do not alter the treatment effect of interest.

Figure 5 provides evidence that our estimates are not driven by the range of birth weights (1500g-3500g) we use to define our primary sample. The estimated treatment effects on developmental vulnerability or NAPLAN test scores are comparable when using samples that stretch a birth weight interval of 1000g-4000g and sample that include birth weight values of between 2000g-3000g.

Finally, we also tested for discontinuities in important maternal observable characteristics such as maternal age or number of antenatal visits. We need to exclude the possibilities that doctors assign newborns around the 2300 and 2500g threshold to SCN care because of observable characteristics of their parents. Table 7 demonstrates that there are no discontinuities in these maternal characteristics at the relevant thresholds. [Note: We will do the same analysis for

²⁰Due to drop-out from the school system, our sample numbers are dropping by three quarters between Year 3 and 9. The numbers are respectively: 4,934, 4,539, 3,386, 1,897.

maternal health behaviors during pregnancy]

4 Discussion and conclusion

As shown in Section 3, we find a significant and robust treatment effect of SCN admission on physical health, emotional maturity, and social competence at age 5 and gains in Writing skills up until age 14 for the marginal child in our Northern Territory administrative data. These effects are driven by male children, and/or by Indigenous children. The treatment effects are sizeable by any means. Our treatment effects on age-5 non-cognitive skill assessments are comparable to the estimated treatment effects on cognitive skills of highly disadvantaged children from the most famous parenting and pre-school interventions – the Abecedarian (0.8 SD) and Perry Preschool Projects (1.0 SD) (see [Duncan and Magnuson, 2013](#), for a review). Yet, no developmental benefits are detected for children of non-indigenous backgrounds at age five. In this section we discuss possible explanations for why we find such heterogeneous benefits of SCN treatment, before we finally conclude.

First, the returns to early-life health treatments may be higher for indigenous children because they typically start at a lower level of health capital at birth. It is well documented that women and children of an indigenous background are disadvantaged relative to non-indigenous women and children across maternal and infant health outcomes ([Kildea et al., 2016](#); [Hilder et al., 2014](#)). Perinatal characteristics of our birth cohorts confirm these patterns. As can be seen in [Table 1](#) indigenous children are twice as likely to be of LBW or born premature than babies of non-indigenous background. They are also more likely to have mothers who are flagged to be smoking and drinking during pregnancy. From [Table 1](#), almost 50% of the mothers of indigenous children smoke at the first antenatal visit, almost 40% still smoke at week 36, and almost 10% drink at Week 36.

Second, newborns of indigenous background may receive more intense medical attention and different treatments when admitted to the SCN, especially if their mothers live in (very) remote communities. Almost a quarter of indigenous birthing mothers live in remote communities (24% versus 1.8% of non-indigenous mothers). These remote areas have reduced services and extremely high rates of poverty ([Kildea et al., 2016](#)). Doctors may choose to delay the discharge from the SCN for these newborns to conduct follow-up examinations which are too costly once the infant returns home. In contrast, non-indigenous babies, and those living near the hospital, may have increased opportunity to receive follow-up care, and therefore the babies are discharged earlier. Thus, the initial investment after-birth for these children living nearby may not be as large or as critical for development.²¹

Third, mothers of indigenous children may also receive more intensive treatment or services while their newborns are in SCN. Indigenous mothers from remote communities are usually flown into Darwin or Alice Springs to give birth.²² Being flown into the metropolitan areas,

²¹ We will further explore these pathways and mechanisms once we have more detailed information on the residential location of the families and what type of medical services are available early in life. We will also have early-life hospitalizations and primary care appointment information linked for later drafts.

²² This is a unique Northern Territory neonatal policy, which is not only costly, but also highly controversial. On average, Aboriginal women would prefer to give birth in their communities amidst their extended families and support system, and many mothers leave the hospital with their newborns against the advice of the clinical staff. Currently discussions are underway to establish midwife services in remote areas to enable, what is called, the "Birthing on Country" policy. See [Kildea et al. \(2016\)](#) for an overview and preliminary evaluations.

these mothers often stay for weeks away from their communities. Midwives and nurses consult the mothers on breastfeeding, bathing and settling routines, hygiene, and other aspects of creating a safe environment for the newborn baby. If a newborn is admitted to the SCN, her mother may spend more time at the hospital and this may provide more time for this type of information to be communicated to the mothers.²³

From a policy perspective, these findings imply that, although costly, early-life health interventions may have many benefits that extend beyond increasing survival probabilities of at-risk newborns. Early-life medical interventions potentially reduce widely-documented development and academic achievement gaps between indigenous and non-indigenous children. Similar arguments have been made for the narrowing of the Black-White achievement gaps in the US with improvements in the early-life health care provided to disadvantaged communities (Chay et al., 2009).

An important consideration for policy makers is the question of whether medical treatment for at-risk newborns is cost effective, or whether resources should be diverted into prevention of low birth weights. In the past fifteen years an academic and public discussion has emerged on the cost-efficacy of newborn treatments in NICU and SCN. Although this discourse is mainly targeted at very low birth weight babies — e.g. “Should every baby be saved?” (see Lantos, 2001; Muraskas and Parsi, 2008) — neonatology is one of the top ten cost items of hospital expenditures. In Australia, one day in a SCN costs the public health insurance provider (Medicare) A\$3,000. In our data, the marginal baby born to an indigenous mother stays on average 9 days in a SCN, which adds \$27,000 to Medicare expenditure. Since improved school readiness is associated with higher levels of academic achievement, such investment may have important long-term benefits in terms of better developmental, schooling, and labor market prospects that should be considered in cost-benefit evaluations.

One of the most celebrated parenting interventions, the Abecedarian program, cost \$70,000 (in 2002 US\$) per child and achieved similar gains in cognitive skills for very disadvantaged children. The Perry Preschool program, that lead to similar gains in cognitive skills, cost \$18,000 per child (in 2002 US\$) (see Duncan and Magnuson, 2013), a number that is comparable to the SCN expenditure in our data. The Infant Health and Development Program (IHDP), a randomized controlled trial that evaluated extra treatment for LBW newborns (Brooks-Gunn et al., 1994, 1992), cost approximately 18,500 \$ per child (in 2005 US \$) and was found to have an effect around 0.3 SD for certain disadvantaged subgroups (low-education mothers).

Although our back-of-the envelope cost calculation is by no means comprehensive or representative of the full Australian at-risk newborn population, it emphasizes that early-life health interventions can have *unanticipated positive externalities* on human capital formation, at a cost that is lower or at least not exceeding the cost of successful parenting or pre-school interventions. Similar positive spill-over effects of a medical treatment on human capital formation were found by Miguel and Kremer (2004). Deworming programs in Kenya did not only significantly reduce the proportion of moderate to heavy infections by around 25 percentage points — which was its primary objective — they also increased primary school participation by over 7.5%, resulting in a gain 0.14 years of education. Although the literature on the unintended positive consequences of early-life medical interventions is very small so far, such studies can provide policy makers with a comprehensive picture of the likely benefits of otherwise very costly

²³So far, there is little documentation on the exposure of indigenous mothers to more intense parental counselling, and thus this pathway is at best speculative. We have discussed these issues with physicians (Dr. Charles Kilburn) and midwives (Sharon Haste, Josie Carr) in the Northern Territory during various research visits.

interventions.

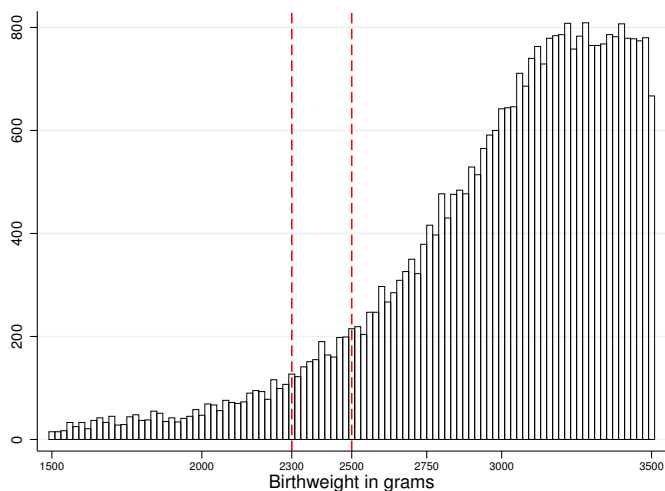


Figure 1: Distribution of birth weight

Figure based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This figure represents the birth weight distribution of the full perinatal data set. We do not observe any clear patterns of heaping or manipulation associated with the SCN thresholds, but subsequent drafts will formerly test for any manipulation or heaping near the LBW thresholds.

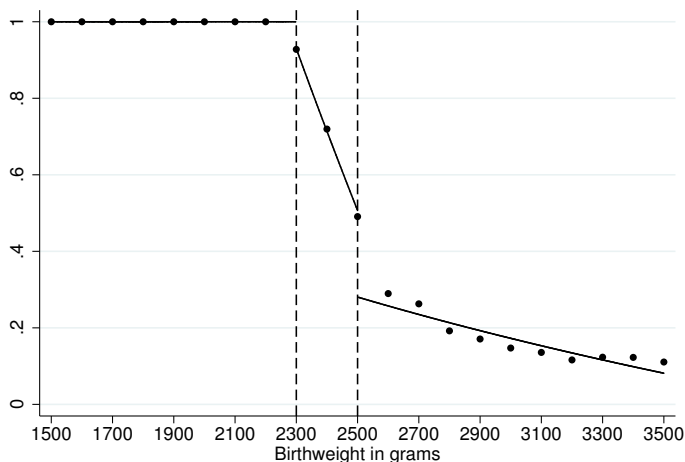


Figure 2: Birth weight and the probability of assignment to a SCN

Figure based on our final sample of children matched between the perinatal and outcome database (see Section 1).

Each circle represents the fraction of newborns in each cell that were assigned to a Special Care Nursery (SCN). Cells are defined over 100 grams of the birth weight. The solid lines represents the probability of SCN assignment using the first stage model described in the text.

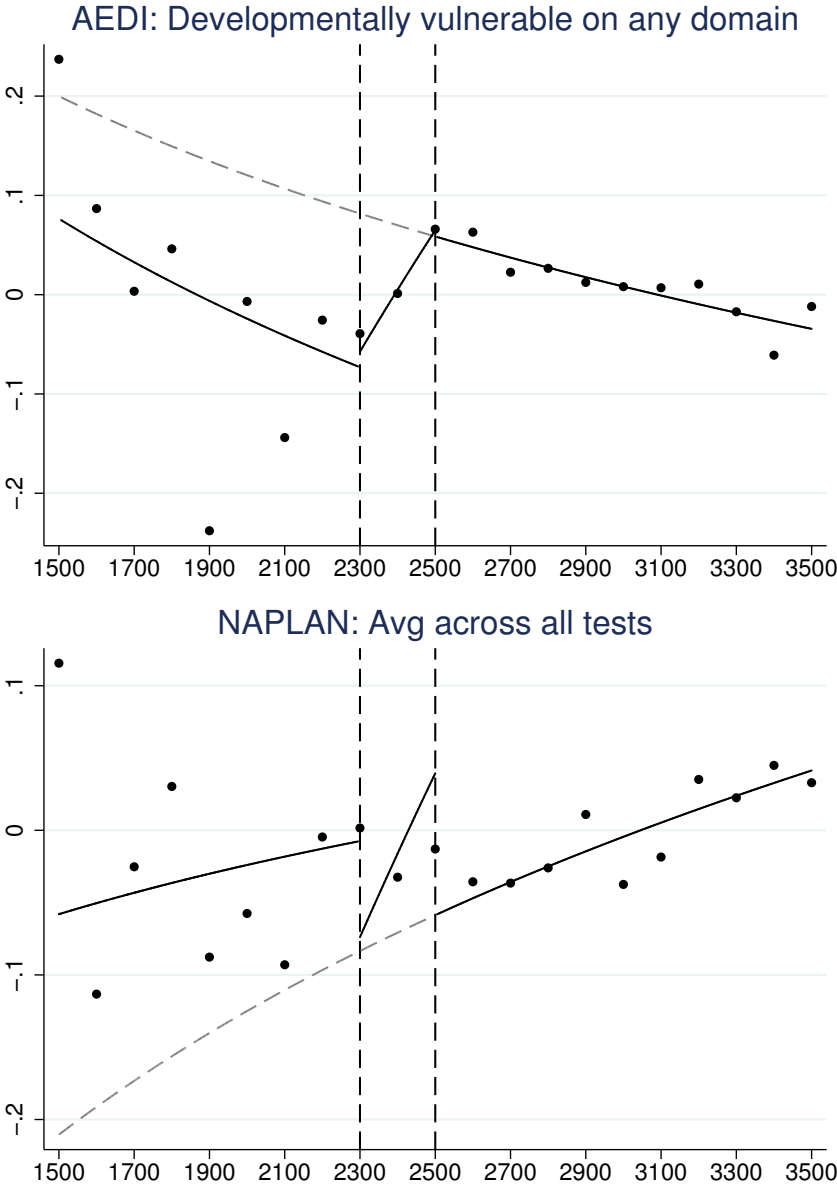


Figure 3: Birth weight and AEDI/NAPLAN summary measures

Figure based on our final sample of children matched between the perinatal and outcome database (see Section 1).

Each circle represents means of the residuals from a regression on the outcome on the basic set of control variables which could also affect assignment to a special care nursery (gestation, apgar scores, labour complications, birth year, hospital of birth, child gender, indigenous status). Cells are defined over 100 grams of the birth weight. The solid lines represent the predicted outcomes after fitting the first-stage model described in the text. Without indicators for the regions below the LBW threshold and interactions of these indicators with birth weight, the expected outcomes are represented by the dashed gray line. This provides a visual of the counterfactual outcomes without a change in neonatal health care (the probability of SCN admission) at these thresholds.

A child is considered developmentally vulnerable in an AEDI domain if the child scores below the 10th percentile of the national AEDI population. The summary NAPLAN score is created using a simple average across all NAPLAN test scores (*note, we will modify this to create a summary index as in ?.*)

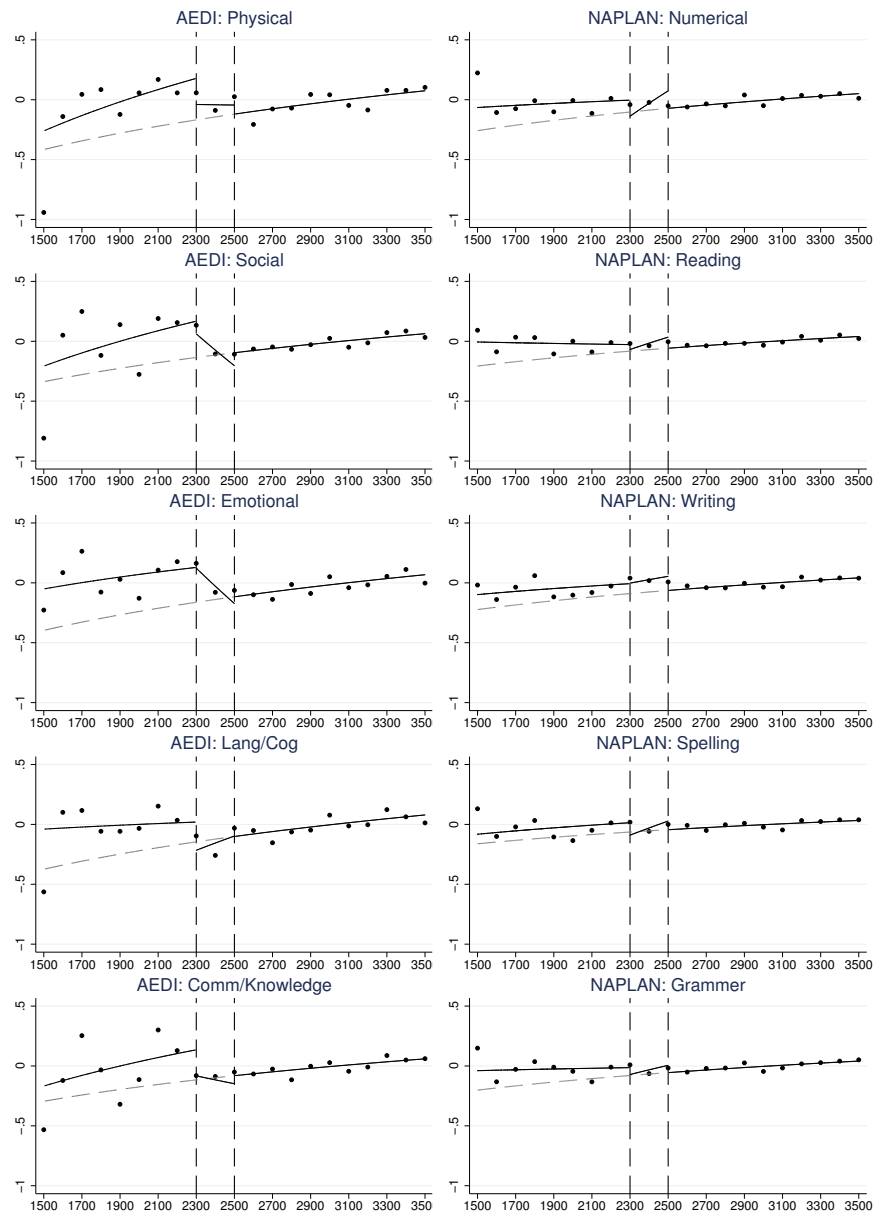


Figure 4: Birth weight and AEDI/NAPLAN Domains

Figure based on our final sample of children matched between the perinatal and outcome database (see Section 1).

Each circle represents means of the residuals from a regression on the outcome on the basic set of control variables which could also affect assignment to a special care nursery (gestation, apgar scores, labour complications, birth year, hospital of birth, child gender, indigenous status). Cells are defined over 100 grams of the birth weight. The solid lines represent the predicted outcomes after fitting the first-stage model described in the text. Without indicators for the regions below the LBW threshold and interactions of these indicators with birth weight, the expected outcomes are represented by the dashed gray line. This provides a visual of the counterfactual outcomes without a change in neonatal health care (the probability of SCN admission) at these thresholds.

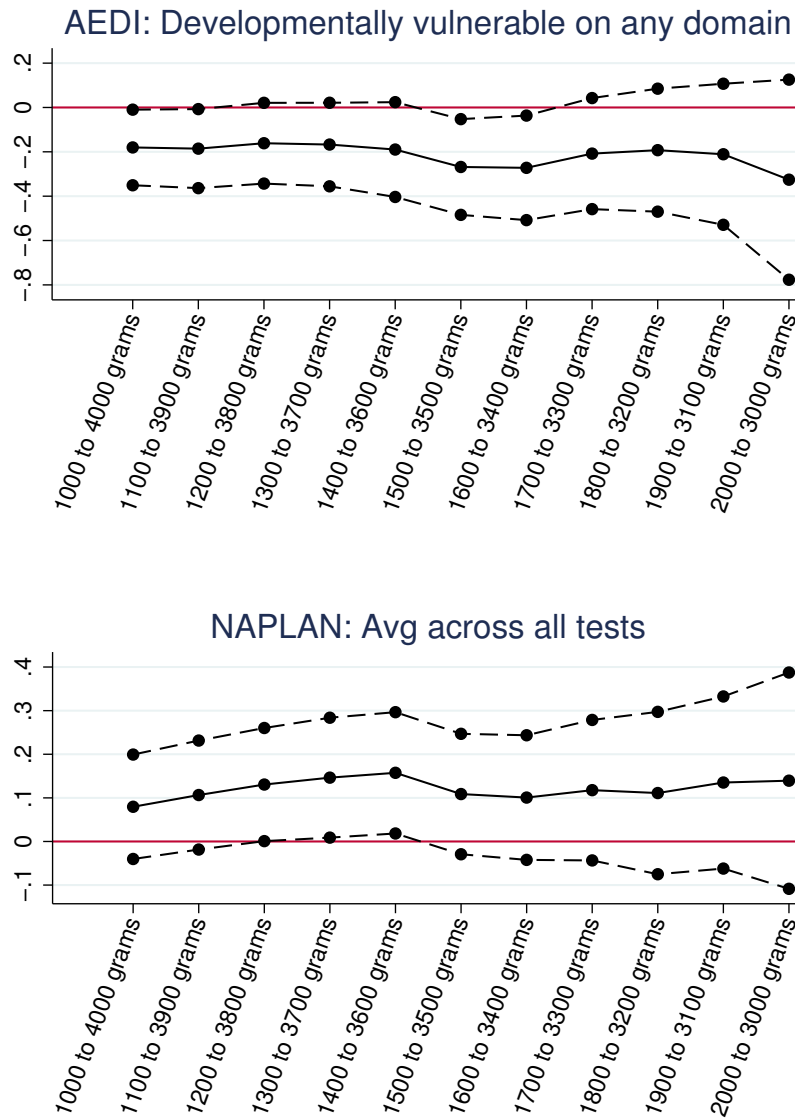


Figure 5: Robustness of effects to birth weight range

Figure based on our final sample of children matched between the perinatal and outcome database (see Section 1).

A child is considered developmentally vulnerable in an AEDI domain if the child scores below the 10th percentile of the national AEDI population. The summary NAPLAN score is created using a simple average across all NAPLAN test scores (*note, we will modify this to create a summary index as in ?.*)

This figure displays estimates of the 2SLS regression with extended controls varying the birth weight range used to estimate effects.

Table 1: Summary Statistics

	Perinatal Data	AEDI-matched	NAPLAN-matched
Perinatal Data			
Special care nursery (SCN) admission	0.206 (0.404)	0.209 (0.406)	0.242 (0.428)
Baby days in hosp.	5.345 (15.505)	5.682 (15.492)	5.836 (23.640)
Birthweight (grams)	3298.303 (598.154)	3285.813 (598.123)	3261.420 (595.222)
Birthweight < 2300g	0.051 (0.219)	0.050 (0.218)	0.054 (0.227)
Birthweight 2300g-2500g	0.033 (0.179)	0.039 (0.195)	0.037 (0.190)
Gestation (weeks)	38.774 (2.024)	38.705 (2.028)	38.768 (2.017)
Prematurity (gestation < 37 weeks)	0.095 (0.294)	0.103 (0.304)	0.102 (0.303)
APGAR 5 minute	9.003 (2.149)	8.997 (0.711)	8.985 (2.177)
Female	0.484 (0.500)	0.485 (0.500)	0.490 (0.500)
Indigenous	0.353 (0.478)	0.439 (0.496)	0.444 (0.497)
Birth year	2004.733 (5.204)	2004.961 (1.558)	2000.964 (2.863)
Age of mother	27.662 (6.242)	27.586 (6.421)	26.655 (6.350)
Antenatal visits	8.946 (4.508)	9.657 (4.339)	8.554 (5.066)
Mother smoking or drinking week 36	0.186 (0.389)	0.262 (0.440)	0.276 (0.447)
AEDI Outcomes (standardized)			
AEDI: Developmentally vulnerable on any domain		0.371 (0.483)	
AEDI: Physical health and wellbeing		-0.018 (1.004)	
AEDI: Social competence		-0.039 (1.026)	
AEDI: Emotional maturity		-0.022 (1.029)	
AEDI: Language and cognitive skills		-0.021 (1.018)	
AEDI: Comm. skills and general knowledge		-0.011 (1.012)	
NAPLAN Outcomes (standardized)			
NAPLAN: Avg across all tests			-0.041 (0.867)
NAPLAN: Avg Numerical Score			-0.061 (0.939)
NAPLAN: Avg Reading Score			-0.046 (0.953)
NAPLAN: Avg Writing Score			-0.041 (0.964)
NAPLAN: Avg Spelling Score			-0.039 (0.947)
NAPLAN: Avg Grammer Score			-0.020 (0.939)
Observations	52927	3683	12001

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

Table 2: Impact of SCN assignment on AEDI and NAPLAN

	OLS	2SLS	2SLS
Early Childhood Development Outcomes (AEDI)			
Developmentally Vulnerable (any domain)	0.016 (0.023)	-0.270** (0.112)	-0.268** (0.110)
Physical health and wellbeing	-0.009 (0.067)	0.471** (0.227)	0.488** (0.226)
Social competence	-0.034 (0.070)	0.405* (0.225)	0.412* (0.222)
Emotional maturity	-0.044 (0.073)	0.528*** (0.196)	0.531*** (0.193)
Language and cognitive skills	-0.021 (0.058)	0.089 (0.211)	0.087 (0.212)
Comm. skills and general knowledge	-0.025 (0.057)	0.232 (0.213)	0.241 (0.213)
Observations	2,307	2,307	2,307
First stage F-statistic	.	48.75	48.75
Baseline Controls	Y	Y	Y
Extended Controls	N	N	Y
Average Test Score Outcomes (NAPLAN)			
Average across all tests	-0.002 (0.016)	0.112 (0.072)	0.109 (0.070)
Numerical	0.003 (0.018)	0.118 (0.099)	0.117 (0.096)
Reading	-0.016 (0.020)	0.091 (0.086)	0.091 (0.085)
Writing	-0.012 (0.018)	0.208*** (0.073)	0.205*** (0.072)
Spelling	0.010 (0.022)	0.071 (0.090)	0.061 (0.090)
Grammar	0.003 (0.020)	0.073 (0.075)	0.069 (0.074)
Observations	7,784	7,784	7,784
First stage F-statistic	.	188.72	188.72
Baseline Controls	Y	Y	Y
Extended Controls	N	N	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

Column 1 provides OLS regression estimates of the relationship between SCN assignment and the outcomes indicated in the row titles in a model which includes only the SCN indicator, the natural log of birth weight, and our baseline set of controls which could affect SCN assignment (gestation, apgar scores, labour complications, birth year, hospital of birth, child gender, indigenous status). Column 2 provides 2SLS regression estimates using indicators for the two SCN treatment regions (borderline and below 2300g) and interaction of these indicators with the natural log of birth weight as instruments for SCN assignment with the baseline set of controls. Column 3 adds an extended set of controls additional control variables: a quadratic in mother age, number of total prior pregnancies for the mother (gravidity), number of antenatal visits, indicators for maternal smoking or drinking during pregnancy, and indicators for hospital of birth.

Table 3: Heterogeneous Impact of SCN assignment on AEDI and NAPLAN by Gender and Indigenous Status

	MALE	FEMALE	INDIG	NONINDIG
Early Childhood Development Outcomes (AEDI)				
Developmentally Vulnerable (any domain)	-0.451*** (0.125)	-0.204 (0.137)	-0.295* (0.151)	-0.234 (0.173)
Physical health and wellbeing	0.589 (0.369)	0.444* (0.236)	0.716** (0.330)	0.069 (0.238)
Social competence	0.499 (0.369)	0.205 (0.277)	0.729*** (0.279)	-0.097 (0.299)
Emotional maturity	0.806** (0.363)	0.186 (0.246)	0.848*** (0.247)	0.069 (0.301)
Language and cognitive skills	0.430 (0.351)	-0.119 (0.248)	0.335 (0.257)	-0.344 (0.322)
Comm. skills and general knowledge	0.269 (0.310)	0.075 (0.274)	0.392 (0.299)	0.008 (0.273)
Observations	1,071	1,236	1,109	1,198
First stage F-statistic	20.35	25.11	31.02	20.91
Baseline Controls	Y	Y	Y	Y
Extended Controls	Y	Y	Y	Y
Average Test Score Outcomes (NAPLAN)				
Average across all tests	0.154 (0.124)	0.060 (0.082)	0.167** (0.072)	0.059 (0.127)
Numerical	0.107 (0.168)	0.084 (0.094)	0.121 (0.090)	0.106 (0.182)
Reading	0.168 (0.140)	0.040 (0.098)	0.083 (0.103)	0.136 (0.157)
Writing	0.178 (0.149)	0.204** (0.095)	0.337*** (0.095)	0.070 (0.103)
Spelling	0.201 (0.155)	-0.050 (0.106)	0.160* (0.083)	-0.047 (0.167)
Grammer	0.117 (0.125)	0.023 (0.100)	0.131* (0.078)	0.028 (0.134)
Observations	3,652	4,132	3,716	4,068
First stage F-statistic	57.13	165.01	71.47	41.84
Baseline Controls	Y	Y	Y	Y
Extended Controls	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This table displays estimates of the 2SLS regression with extended controls for the following subpopulations: male (column 1), female (column 2), indigenous (column 3), and non-indigenous (column 4).

Table 4: Impact of SCN assignment NAPLAN by Grade Year

	Year 3	Year 5	Year 7	Year 9
Average Test Score Outcomes (NAPLAN)				
Average across all tests	0.063 (0.105)	0.105 (0.084)	0.039 (0.102)	0.219 (0.141)
Numerical	0.019 (0.130)	0.137 (0.114)	0.097 (0.154)	0.234 (0.231)
Reading	0.116 (0.137)	0.014 (0.104)	0.077 (0.121)	0.161 (0.178)
Writing	0.154 (0.113)	0.193* (0.104)	0.101 (0.121)	0.399** (0.190)
Spelling	0.075 (0.121)	0.038 (0.121)	-0.055 (0.158)	0.230 (0.170)
Grammer	0.007 (0.122)	0.088 (0.105)	-0.030 (0.113)	0.344** (0.164)
Observations	4,934	4,539	3,386	1,897
First stage F-statistic	112.50	242.17	68.88	36.25
Baseline Controls	Y	Y	Y	Y
Extended Controls	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This table displays estimates of the 2SLS regression with extended controls for the NAPLAN test scores by grade year.

Table 5: Robustness Check - Birth weight Specification

	(1) log	(2) linear	(3) quad	(4) cubic
AEDI: Developmentally vulnerable on any domain	-0.268** (0.110)	-0.243** (0.100)	-0.233 (0.154)	-0.211 (0.167)
Observations	2,307	2,307	2,307	2,307
First stage F-statistic	47.55	49.54	40.77	24.62
NAPLAN: Average across all tests	0.109 (0.070)	0.094 (0.068)	0.101 (0.067)	0.100 (0.097)
Observations	7,784	7,784	7,784	7,784
First stage F-statistic	192.96	181.01	193.64	100.89
Baseline Controls	Y	Y	Y	Y
Extended Controls	Y	Y	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This table displays estimates of the 2SLS regression with extended controls various specifications of the birth weight running variable. For each, the indicated function or polynomial is included on its own as well as interacted with the below 2300 and 2300-2500 indicator variables. The column headings indicate the specification of the birth weight function and the row titles indicate the dependent variable.

Table 6: Robustness Check - Discontinuities in Observables?

	AEDI-matched sample	NAPLAN-matched sample
Mother's age at time of birth	0.742 (1.274)	-0.822 (0.760)
Mother smoking at wk 36	-0.012 (0.086)	-0.123* (0.065)
Mother drinking alcohol at wk 36	0.065 (0.054)	0.030 (0.037)
Number of antenatal visits	-0.046 (0.833)	0.175 (0.779)
Observations	2,307	7,784
Baseline Controls	Y	Y
Extended Controls	N	N

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This table displays estimates of the 2SLS regression with baseline controls using observable maternal characteristics as outcomes. The table represents four separate models with the dependent variable indicated by the row titles (age of mother and number of antenatal visits) and the sample indicated by the column titles.

Table 7: Robustness Check - Effect of SCN assignment on probability of data match

	AEDI match	NAPLAN match
Probability of match to outcome dataset	0.059 (0.078)	-0.042 (0.037)
Observations	7,204	19,608
First stage F-statistic	180.63	212.22
Baseline Controls	Y	Y
Extended Controls	Y	Y

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary within 30g birth weight bin correlation in parentheses. Estimates based on our final sample of children matched between the perinatal and outcome database (see Section 1).

This table displays estimates of the 2SLS regression with the baseline and extended perinatal controls using an indicator for a match from the perinatal dataset to the outcome dataset as the outcome variable. Column 1 represents the relationship between SCN and match with the AEDI outcome database; Column 2 reports the relationship with NAPLAN outcome database. In each model, the sample is restricted to those born in cohorts captured in the AEDI data (2003,2004,2006,2007) the NAPLAN data (1996-2006).

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