The Effect of Expanding a Neonatal Intensive Care System on Infant Mortality and Long-Term Health Impairments

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Question

What's the effect of the expansion of a NICU/NETS system?

- NICU: Neonatal Intensive Care Unit (level 3)
- NETS: Newborn Emergency Transportation System (to level 3 hospitals)
- on neonatal mortality (< 7 days)
- on infant mortality (< 365 days) – likely long-run survival
- on long-run impairment

Why interesting?

- Very costly


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Data, method, results

Data from Hungary, where system expanded gradually

- National vital statistics
- National census
- Own survey on establishment of new NICUs and coverage of NETS

Method

- Identification from longitudinal geographic variation in access
  - longitudinal variation in the distance of the mothers' residence to nearest city with NICU/NETS hospital as instrument for city of birth with NICU hospital or hospital in the NETS

Results

- Substantial effects on reducing mortality
  - both for children $< 1500g$ and children $1500g$ *to* $2500g$
  - effects persist in long run
- No (net) effects on long-term impairment

What do we know so far?

- No existing study asks our question: the effect of geographic expansion of the system
- Many studies asking related questions
- Effect of neonatal intensive care on mortality: most (not all) find strong effects
  - Sosnaud (2019) USA, effect of NICUs, xsec
  - Grytten et al. (2017), effect of specific interventions on mortality, Norway, hospital FE
  - Laswell et al (2010), review, effect of NICU on mortality, xsec studies
  - Cutler (2007) and Bhardwaj et al. (2013), effect on mortality and school outcomes, USA, RD at $1500g$
- Effect of in-utero versus ex-utero transfers (NICU versus NETS) on mortality; xsec comparisons
- Studies on the health risks of pre-term births; xsec comparisons

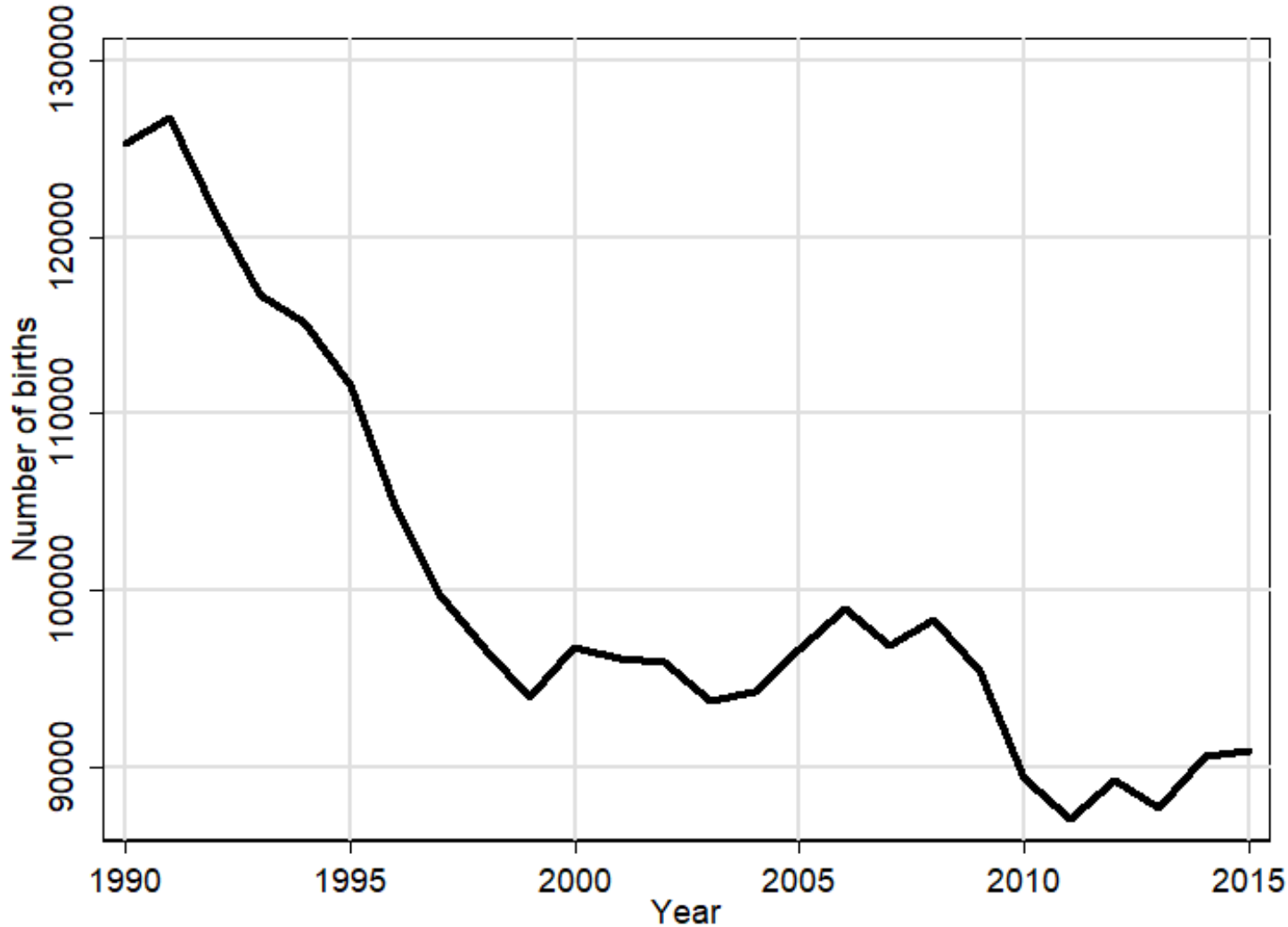
Our contribution

- We directly measure the effect of expanding a NICU system.
- We jointly estimate the effect of NETS and NICUs.
- We consider important outcomes in the same framework:
  - 0-7 day mortality
  - 0-364 day mortality
  - long-run impairment.
- We use a novel identification strategy:
  - longitudinal variation of distance
  - due to new establishments in previously under-served areas;
  - an improvement on existing strategies
    using either longitudinal variation in the place of delivery
    or xsec variation in distance.

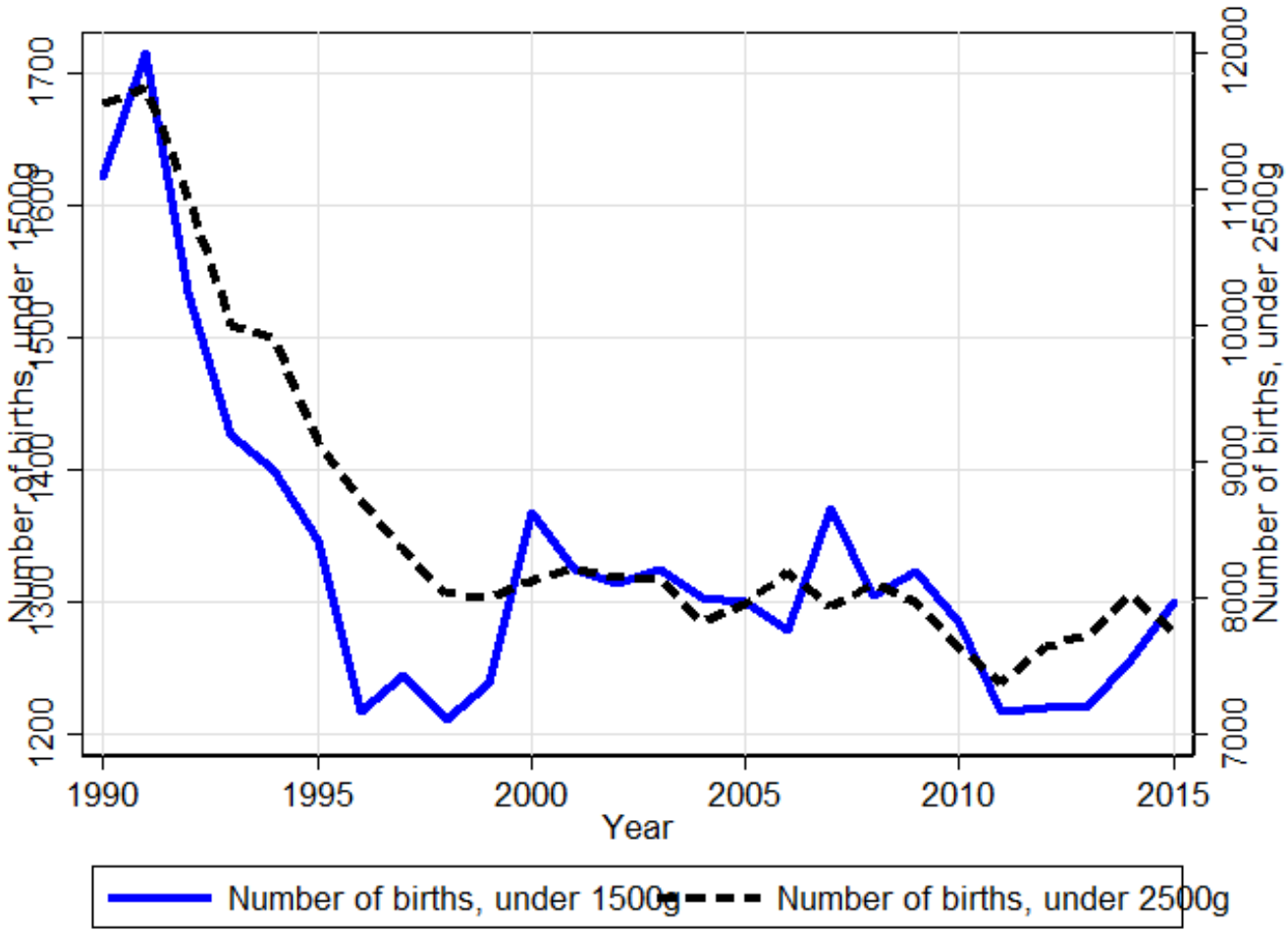
Data

- National vital statistics
  - administrative data with full national coverage for years 1990-2015
    - ★ 2,610,468 live birth events linked with 22,136 neonatal and infant mortality events
    - ★ around 3000 municipalities of residence
  - Information: birth weight, gestational age, municipality of delivery and a rich set of covariates
- Census, 2011
  - linked to vital statistics data
  - various types of self-reported long-term impairment (response rate: 80%)
- Own survey on the expansion of NICUs and NETS:
  - openings of level-3 NICU facilities: 6 events
  - establishment of regional NETS and their coverage of hospitals in three points in time
- Two work samples
  - Mortality: birth year 1990 to 2015, $n = 223,119$ for $< 2500g$
  - Impairment: birth year 1990 to 2007, $n = 104,758$ for $< 2500g$

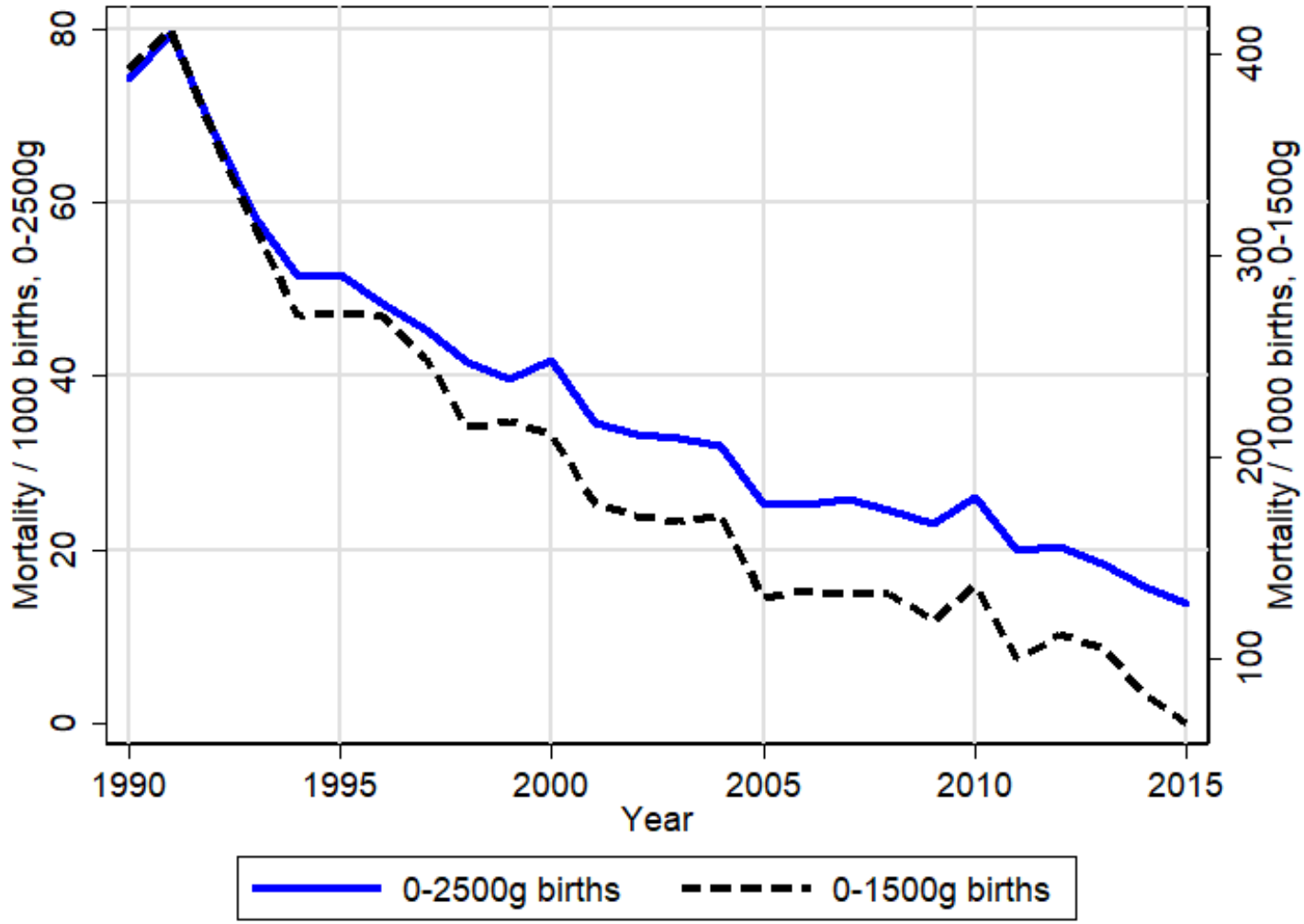
Background: Number of births in Hungary



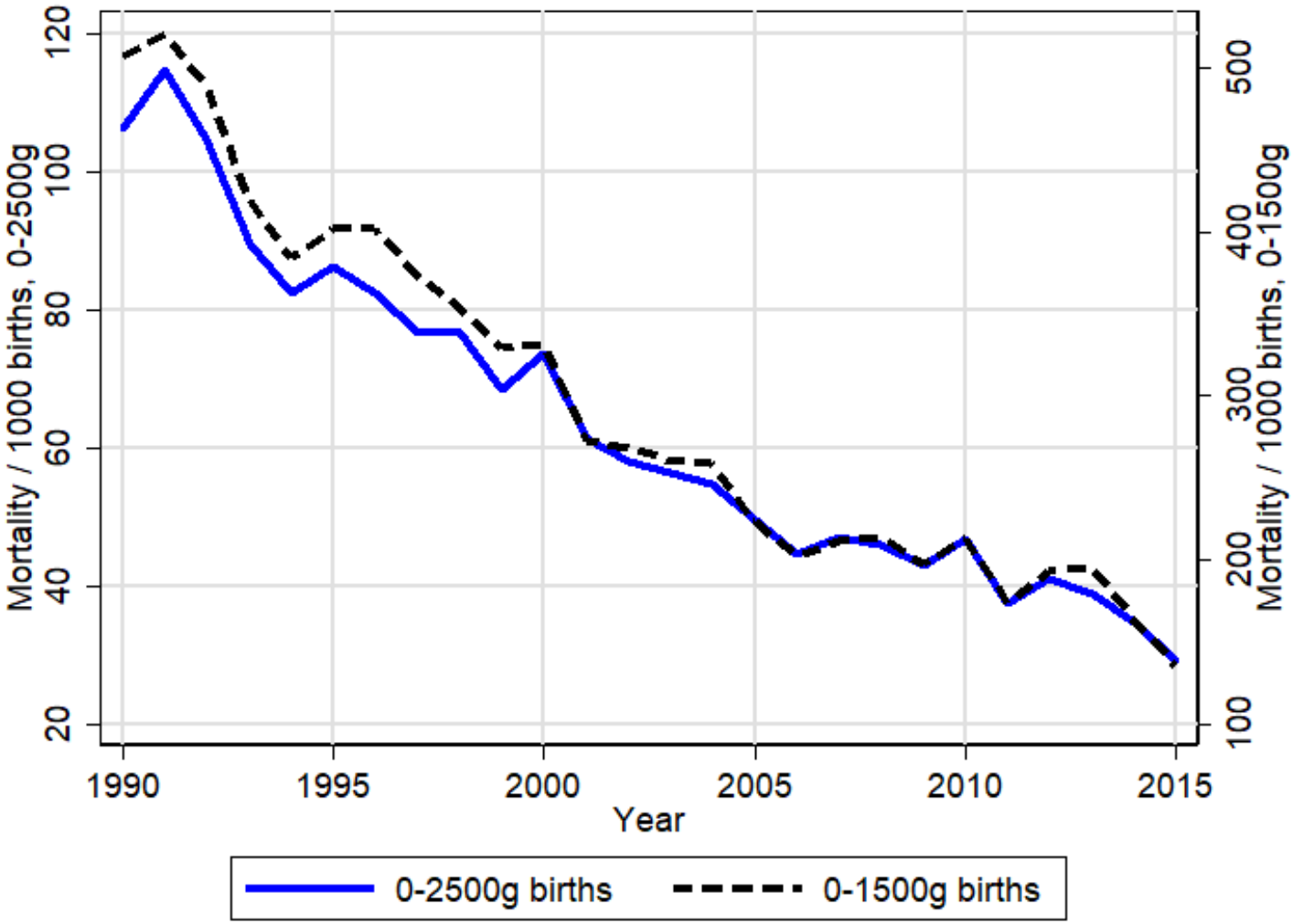
Background: Number of births ($< 1500g$ and $< 2500g$)



Background: 0-6 day mortality ($< 1500g$ and $< 2500g$)



Background: 0-366 day mortality ($< 1500g$ and $< 2500g$)



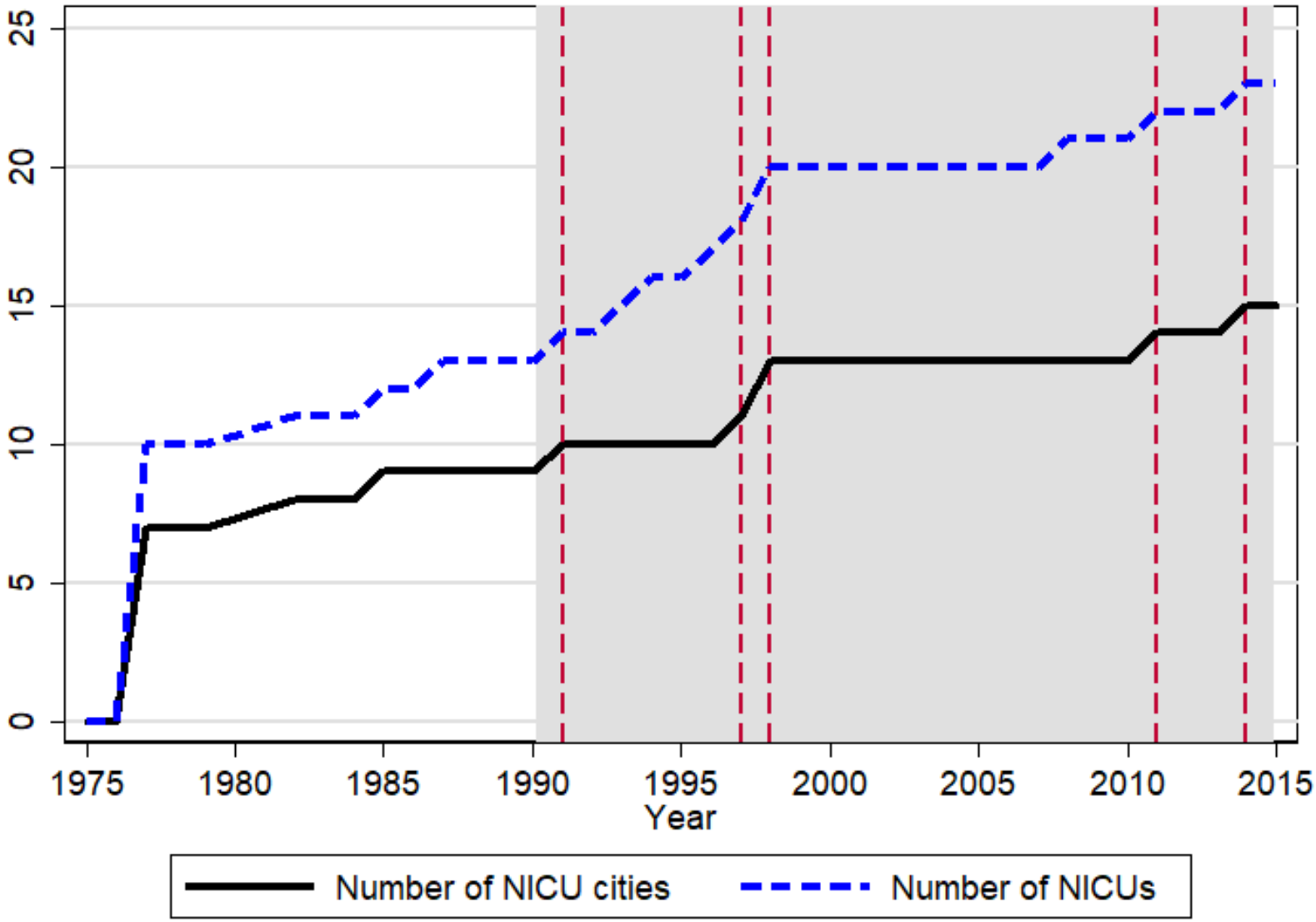
Background: Health care in Hungary

- Universal coverage, mandatory single-payer health insurance
- 7.4% of GDP spent on health care in 2013 (70% public)
- services free of charge (nominally; informal gratuity is wide-spread)
- territorial supply obligation
- patients should receive health care at the assigned lowest level
- choice in where to seek specialized care

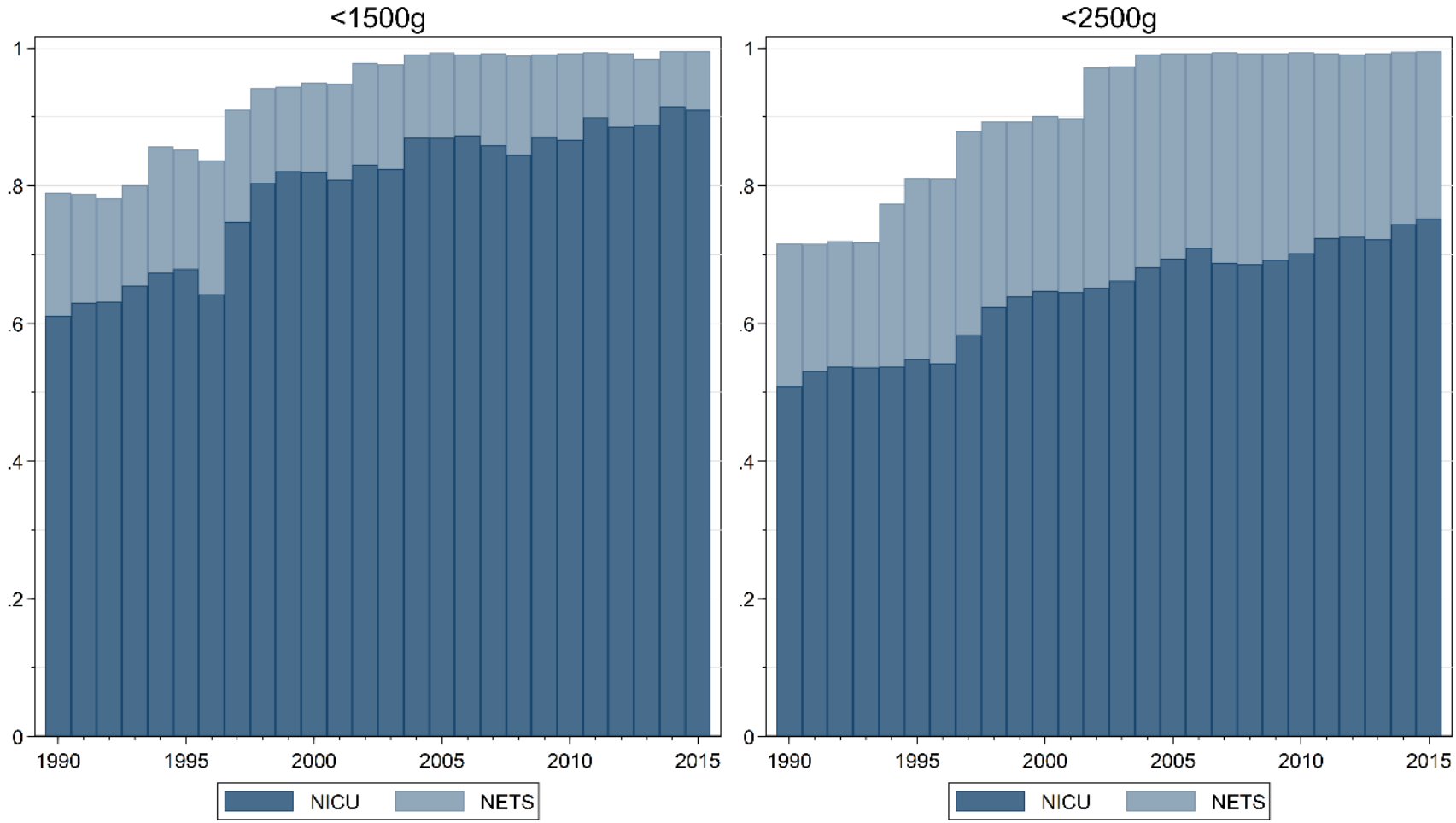
Background: the NICU/NETS system in Hungary

- First NICUs in the 1970s (10 in 7 cities)
- Some expansion until 1990 (2 new cities)
- Expansion of NICUs continues after 1990 (6 new cities)
  - $< 1500g$ births: from 60% to 85%
  - $< 2500g$ births: from 50% to 70%
- First NETS with regional coverage in 1990
- More regional NETS and expansion of coverage of existing NETS
- By 2005, all $< 1500g$ and all $< 2500g$ births in NICUs or NETS hospital

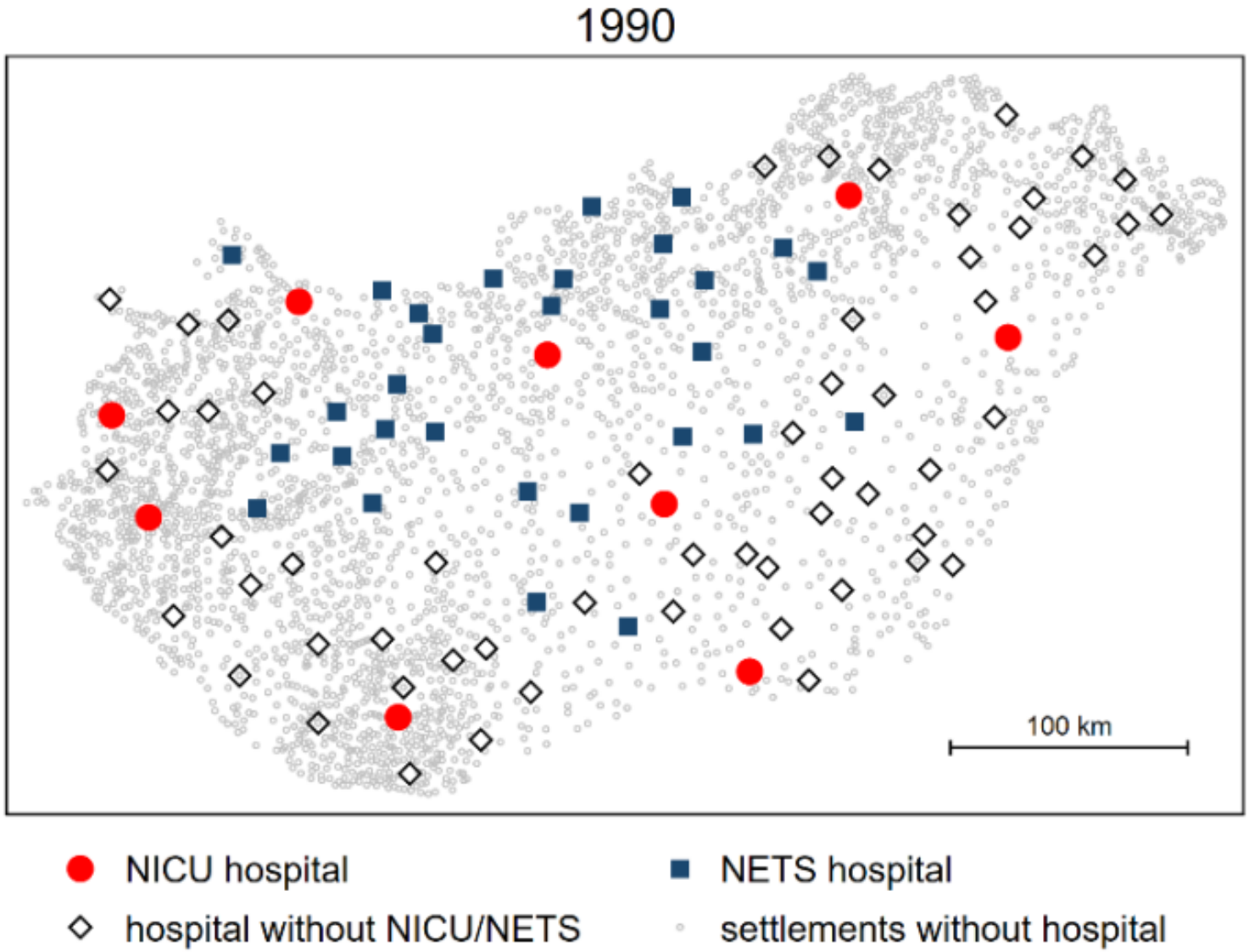
Number of NICUs and number of cities with a NICU hospital



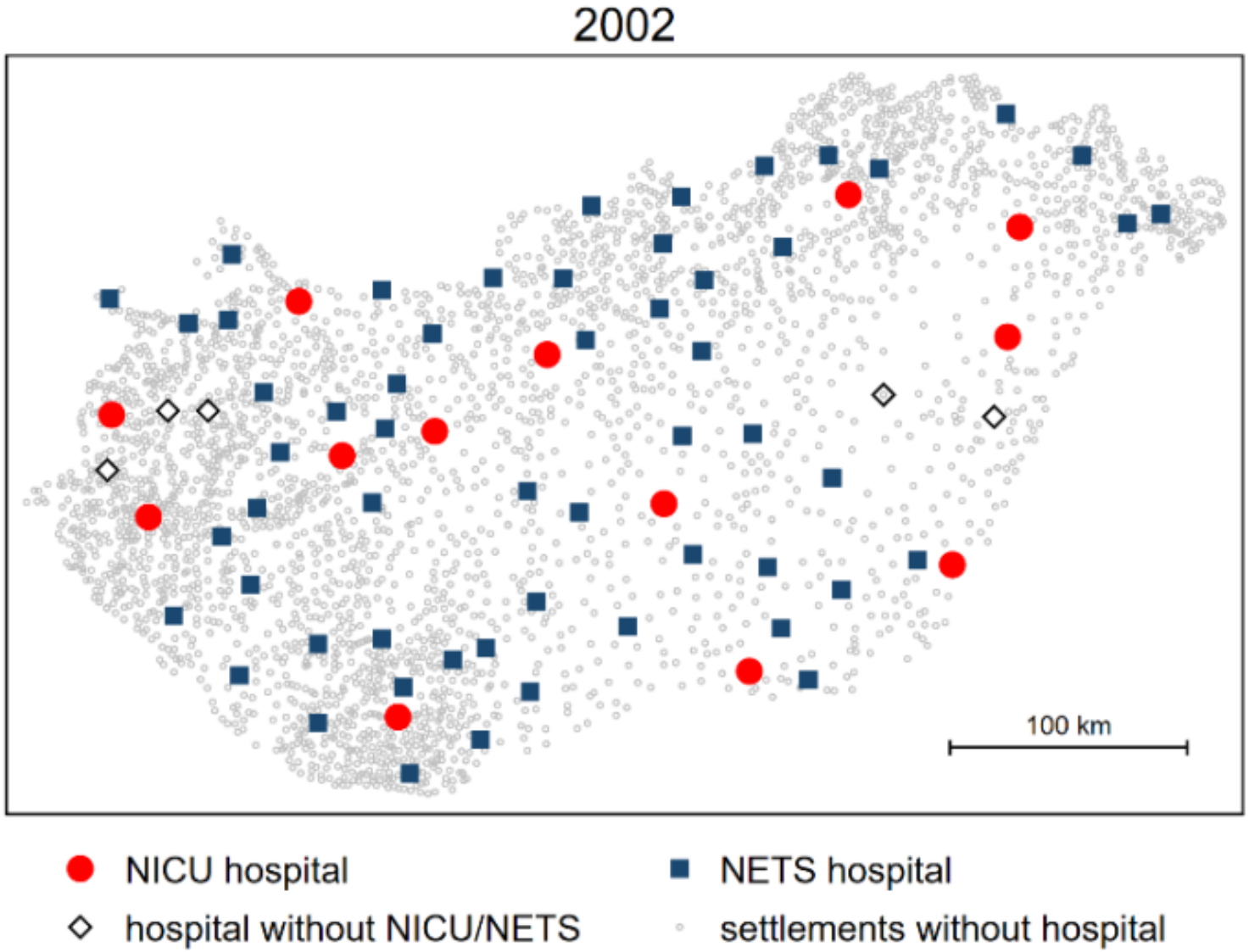
Proportion of births in cities with a NICU and in a hospital connected to NETS



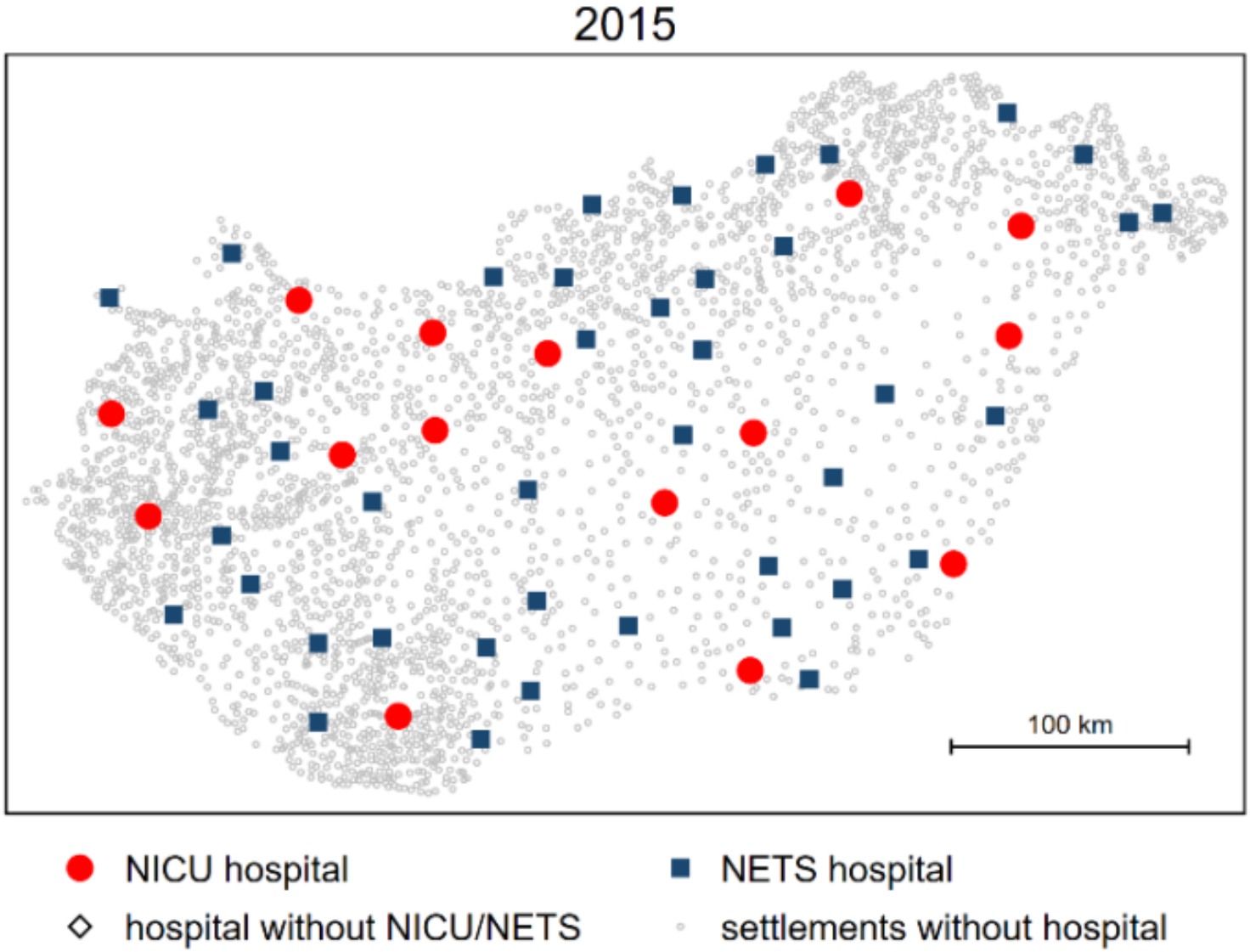
Geographic distribution if NICU and NETS hospitals



Geographic distribution if NICU and NETS hospitals



Geographic distribution if NICU and NETS hospitals



Empirical strategy

$$Y_{ijt} = \beta BNICU_{ijt} + \gamma BNETS_{ijt} + \delta' X_{ijt} + \eta_j + \theta_t + u_{ijt}$$

- Subscripts
  - i: newborn child
  - j: municipality of residence of the mother
  - t: year of birth
- Y: outcome variable
  - died within 6 days
  - died within 364 days
  - developed an impairment (age 3-20)
- *BNICU* whether born in a city with a NICU hospital
- *BNETS* whether born in a city with a hospital connected to NETS

Empirical strategy

$$Y_{ijt} = \beta BNICU_{ijt} + \gamma BNETS_{ijt} + \delta' X_{ijt} + \eta_j + \theta_t + u_{ijt}$$

- Fixed-effects
  - η_j municipality of residence FE
  - θ_t year of birth FE
- X: covariates
  - infant's gender, parity, twin, month of birth, mother single/married, twin birth, previous miscarriages, abortions, mothers' age, education, labor market status, whether married, father's age, education, labor market status

Empirical strategy: IV

- Problem: *BNICU* and *BNETS* are endogenous
  - when new NICUs open more of the ex-ante risky deliveries are planned there
  - when new NICUs open, more knowledgeable or better-connected mothers with the same ex-ante risk are more likely to plan deliveries there
  - first effect likely dominates (positive bias on mortality)
- Solution: distance of residence as instrument
  - *DNICU*: distance to nearest city with NICU hospital
  - *DNETS*: distance to nearest city without a NICU hospital but with a NETS hospital

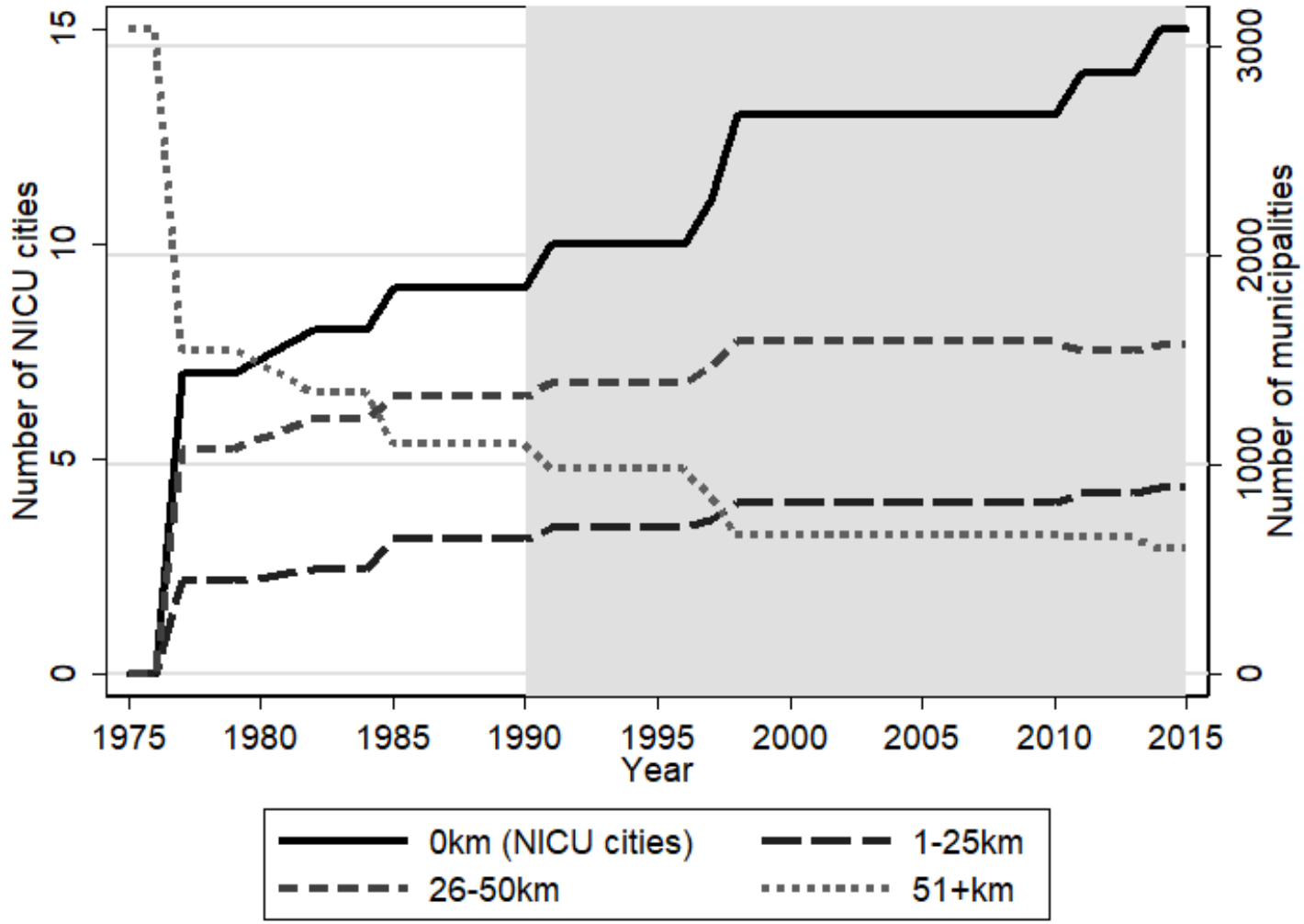
$$BNICU_{ijt} = \pi_1 DNICU_{ijt} + \phi_1 DNETS_{ijt} + \delta_1' X_{ijt} + \eta_{1j} + \theta_{1t} + u_{1ijt}$$
$$BNETS_{ijt} = \pi_2 DNICU_{ijt} + \phi_2 DNETS_{ijt} + \delta_2' X_{ijt} + \eta_{2j} + \theta_{21t} + u_{2ijt}$$

Empirical strategy: IV

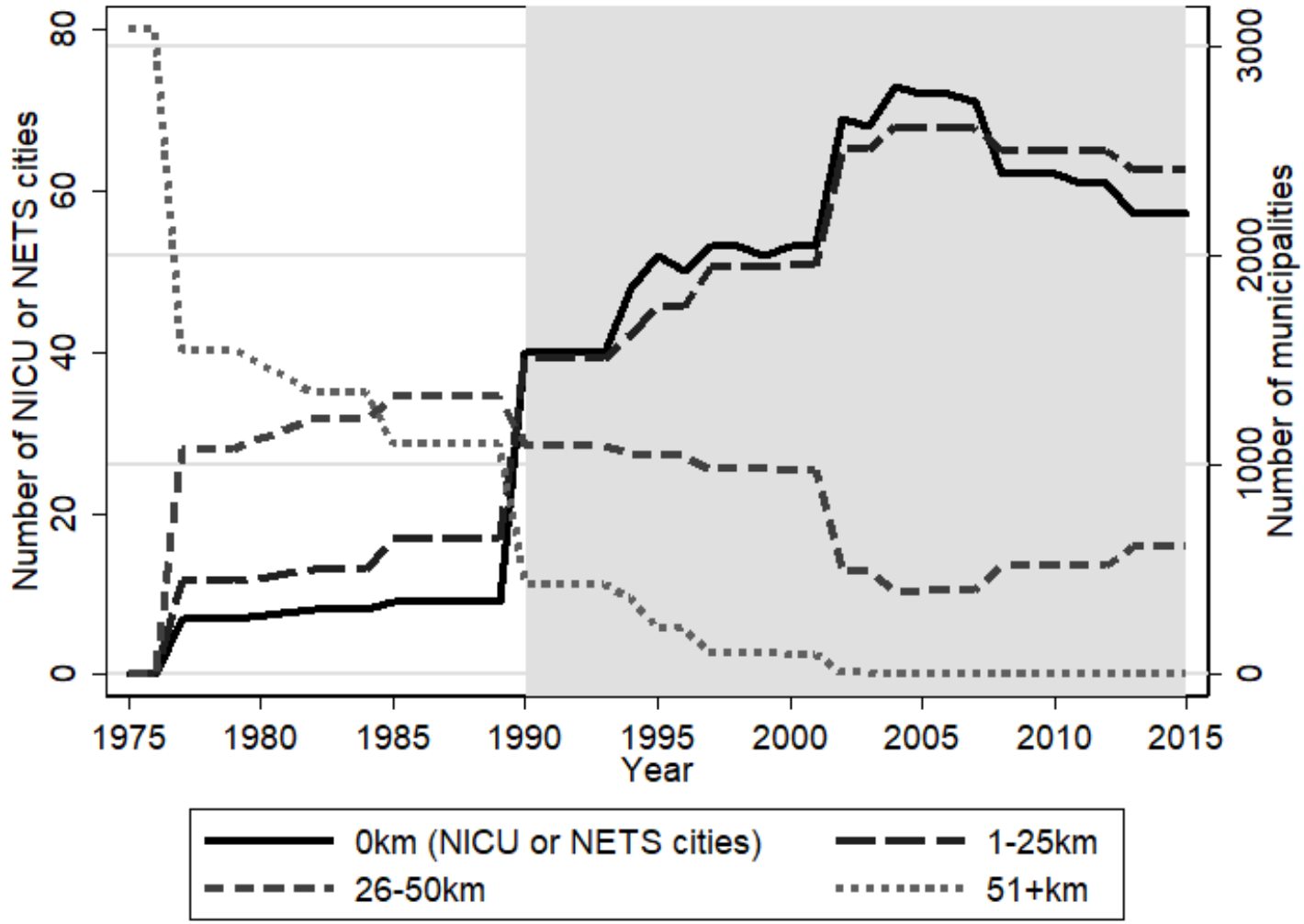
- Identification from changes in distance
  - *DNICU* changes when a new NICU hospital opens in new city
  - *DNETS* changes when a new regional NETS is established or when existing NETS connects a new hospital
- Reduced form:

$$Y_{ijt} = \pi_R DNICU_{ijt} + \phi_R DNETS_{ijt} + \delta_R' X_{ijt} + \eta_{Rj} + \theta_{Rt} + u_{Rijt}$$

Empirical strategy: Distance to NICU cities



Empirical strategy: Distance to NICU or NETS cities



Discussion of the empirical strategy

- Source of identification is changes in distance
  - no endogeneity from time-invariant geographic distribution of mothers and hospitals
  - potential endogeneity only from correlated changes in geographic distribution of mothers and hospitals
- Effect estimates likely lower bounds due to data imperfections
  - timing of change is captured with error (especially for NETS)
  - some cities have both NICU and non-NICU hospitals
  - NICU 2 hospitals in control group (very few)

Net migration to the 6 cities (women age 20-34)

Main results on mortality

TABLE 1—THE EFFECT OF BEING BORN IN A CITY WITH A NICU OR A NETS ON MORTALITY. 2SLS ESTIMATES

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a NICU city	-0.153	-0.010	-0.024	-0.144	-0.021	-0.031
	(0.038)	(0.003)	(0.007)	(0.042)	(0.005)	(0.009)
Born in a NETS city	-0.057	-0.009	-0.009	-0.020	-0.011	-0.008
	(0.040)	(0.002)	(0.005)	(0.043)	(0.004)	(0.006)
Municipality of residence FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
IV F-stat NICU	78.4	57.3	63.7	78.4	57.3	63.7
IV F-stat NETS	106.5	235.2	231.3	106.5	235.2	231.3
Number of municipalities	2029	2929	2964	2029	2929	2964
Number of observations	34,213	188,611	223,319	34,213	188,611	223,319

Main results on long-term impairment

TABLE 2—THE EFFECT OF BEING BORN IN A CITY WITH A NICU OR A NETS ON THE PROBABILITY OF LONG-TERM IMPAIRMENT. 2SLS ESTIMATES

	Any impairment			Impairment due to issues at birth		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a NICU city	0.023	0.000	0.004	-0.001	0.008	0.010
	(0.048)	(0.009)	(0.009)	(0.050)	(0.007)	(0.007)
Born in a NETS city	-0.023	-0.004	-0.007	-0.011	0.000	-0.003
	(0.066)	(0.006)	(0.007)	(0.067)	(0.005)	(0.006)
Municipality of residence FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
IV F-stat NICU	50.38	42.70	47.54	50.39	42.29	47.09
IV F-stat NETS	40.13	230.5	225.2	39.07	230.6	225.2
Number of municipalities	1173	2719	2763	1168	2719	2762
Number of observations	9,992	94,106	104,758	9,891	93,726	104,273

Discussion of main results

- Strong NICU effects on 0-6 day mortality
  - 153/1000 live births for $BW < 1500g$ (95% CI [77,229]); corresponding mortality rate 400/1000 in 1990
  - 10/1000 live births for $1500g \leq BW < 2500g$ (95% CI [4,16]); corresponding mortality rate 25/1000 in 1990
  - 24/1000 live births for $BW < 2500g$ (95% CI [10,38]); corresponding mortality rate 80/1000 in 1990
- Much weaker but often stat.sig. NETS effects on mortality
- Similar effects on 0-364 day mortality as on 0-6 day mortality
  - indicating that lives saved by NICU and NETS are lives saved for a long run
- Zero effects on long-term impairment
  - Either the infants saved by NICU/NETS don't develop impairments and NICUs don't decrease the likelihood of impairment for infra-marginal infants
  - Or the two effects cancel out approximately

Additional results: First stage for mortality

	<1500g		1500-2499g		<2500g	
	BNICU	BNETS	BNICU	BNETS	BNICU	BNETS
Distance to NICU (10km)	-0.117	0.058	-0.119	0.068	-0.119	0.067
	(0.009)	(0.008)	(0.011)	(0.008)	(0.011)	(0.008)
Distance to NETS (10km)	-0.006	-0.045	0.007	-0.080	0.006	-0.075
	(0.004)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
Number of municipalities	2029	2029	2929	2929	2964	2964
Number of observations	34,213	34,213	188,611	188,611	223,319	223,319

Additional results: First stage for long-term impairment

	<1500g		1500-2499g		<2500g	
	BNICU	BNETS	BNICU	BNETS	BNICU	BNETS
Distance to NICU (10km)	-0.115	0.046	-0.111	0.058	-0.112	0.058
	(0.012)	(0.012)	(0.012)	(0.009)	(0.012)	(0.008)
Distance to NETS (10km)	-0.009	-0.037	0.003	-0.079	0.002	-0.075
	(0.005)	(0.004)	(0.002)	(0.004)	(0.003)	(0.004)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
Number of municipalities	1173	1173	2719	2719	2763	2763
Number of observations	9,992	9,992	94,106	94,106	104,758	104,758

Robustness checks

- OLS estimates are less negative on mortality, sometimes positive on impairment, esp. $< 1500g$
- Non-linear functional forms for the distance variables: similar results
- Including municipality-specific linear trends: results slightly weaker
- Including lead terms; significant effect estimate for year prior to NICU "establishment" but not before; estimates similar for a few years prior to NETS establishment/expansion (reduced form results)
- Excluding cities with multiple hospitals (and their 50-km-radius): similar results
- Estimating effects for pre-term births (< 32 *weeks* and < 36 *weeks* : similar results

Conclusions

- Estimated the effect of improved access to neonatal intensive care due to the geographic expansion of the system into previously under-served areas
  - NICUs and NETS
  - on 0-6 day mortality
  - on 0-364 day mortality
  - on long-term impairments
- Making use of the establishment of new NICUs, establishment of regional NETS and increasing their coverage
- Using data from Hungary, 1990-2018
- National vital statistics, National census, own survey on NICU and NETS establishments
- Making use of a novel identification strategy: longitudinal variation in the distance of the mothers' residence to the nearest NICU/NETS city

Conclusions

- We estimated strong effects on 0-6 day mortality
- We estimated similar effects on 0-364 day mortality
  - thus, lives are saved for long-term
- We estimated zero effects for long-term impairment
  - these are the net effect of saving riskier lives and treating infra-marginal infants

- Our estimates are likely lower bounds for the expected benefits of expanding the NICU/NETS system to under-served areas in medium-to-high-income countries

Robustness checks

Table A9: OLS (non-instrumented FE) regression results for the effect of being born in a city with a NICU or a NETS on mortality

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a city with NICU	-0.143	0.002	0.009	-0.117	0.005	0.026
	(0.012)	(0.001)	(0.003)	(0.013)	(0.002)	(0.003)
Born in a city with NETS	-0.030	-0.004	-0.010	-0.011	-0.006	-0.013
	(0.013)	(0.001)	(0.002)	(0.014)	(0.002)	(0.003)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
Number of municipalities	2029	2929	2964	2029	2929	2964
Number of observations	34,213	188,611	223,319	34,213	188,611	223,319

Robustness checks

Table A10: OLS (non-instrumented FE) regression results for the effect of being born in a city with a NICU or a NETS on impairment

	Impairment: any			Impairment: due to issues at birth		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a city with NICU	-0.005	0.008	0.020	-0.021	0.009	0.019
	(0.021)	(0.003)	(0.003)	(0.019)	(0.003)	(0.003)
Born in a city with NETS	0.014	-0.004	-0.007	0.002	-0.001	-0.005
	(0.024)	(0.003)	(0.003)	(0.022)	(0.002)	(0.003)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
Number of municipalities	1173	2719	2763	1168	2719	2762
Number of observations	9,992	94,106	104,758	9,891	93,726	104,273

Robustness checks

Table A11: 2SLS estimates for the effect of being born in a city with a NICU or a NETS on mortality. Distance quartic

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a city with NICU	-0.144	-0.010	-0.022	-0.136	-0.019	-0.027
	(0.036)	(0.003)	(0.006)	(0.041)	(0.004)	(0.007)
Born in a city with NETS	-0.060	-0.008	-0.010	-0.031	-0.009	-0.008
	(0.038)	(0.002)	(0.004)	(0.040)	(0.003)	(0.005)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
IV F-stat NICU	89.55	224.1	247.6	89.55	224.1	247.6
IV F-stat NETS	64.31	272.9	270.4	64.31	272.9	270.4
Number of municipalities	2029	2929	2964	2029	2929	2964
Number of observations	34,213	188,611	223,319	34,213	188,611	223,319

Robustness checks

Table A13: 2SLS estimates for the effect of being born in a city with a NICU or a NETS on mortality. Municipality of residence linear trends included

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<250
Born in a city with NICU	-0.121	-0.003	-0.015	-0.158	-0.006	-0.0
	(0.054)	(0.004)	(0.008)	(0.063)	(0.006)	(0.01
Born in a city with NETS	-0.015	-0.007	-0.010	0.011	-0.005	-0.0(
	(0.066)	(0.003)	(0.007)	(0.075)	(0.005)	(0.0(
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Municipality of resid. trend	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
IV F-stat NICU	76.42	74.53	81.35	76.42	74.53	81.3
IV F-stat NETS	65.17	230.6	221	65.17	230.6	22
Number of municipalities	2029	2929	2964	2029	2929	296
Number of observations	34,213	188,611	223,319	34,213	188,611	223,3

Robustness checks

Table A14: Reduced-form estimates for the effect of the distance of the mother's residence to the closest city with a NICU or a NETS on mortality. Lead terms included to test pre-trends

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Distance to NICU (10km)						
contemporaneous	0.004	-0.000	-0.000	0.008	-0.002	-0.001
	(0.006)	(0.000)	(0.001)	(0.006)	(0.001)	(0.001)
lead 1	0.018	0.001	0.003	0.015	0.005	0.006
	(0.008)	(0.001)	(0.001)	(0.009)	(0.001)	(0.002)
leads 2-3	0.001	0.000	0.002	0.000	-0.000	0.002
	(0.006)	(0.001)	(0.001)	(0.008)	(0.001)	(0.002)
leads 4-5	-0.005	0.001	-0.002	-0.005	0.000	-0.003
	(0.008)	(0.001)	(0.001)	(0.008)	(0.001)	(0.002)
Distance to NETS (10km)						
contemporaneous	0.003	0.000	0.000	-0.000	-0.001	-0.001
	(0.004)	(0.000)	(0.001)	(0.004)	(0.001)	(0.001)
lead 1	-0.005	0.000	-0.001	-0.004	0.001	-0.000
	(0.005)	(0.000)	(0.001)	(0.005)	(0.001)	(0.001)
leads 2-3	0.005	0.001	0.001	0.005	0.001	0.001
	(0.005)	(0.001)	(0.001)	(0.005)	(0.001)	(0.001)
leads 4-5	0.004	-0.000	0.001	0.007	0.000	0.001
	(0.005)	(0.000)	(0.001)	(0.005)	(0.001)	(0.001)
Municipality of resid. FE	Y	Y	Y	Y	Y	Y
Birth year FE	Y	Y	Y	Y	Y	Y
Birth month FE	Y	Y	Y	Y	Y	Y
Individual covariates	Y	Y	Y	Y	Y	Y
Number of municipalities	2029	2929	2964	2029	2929	2964
Number of observations	34,213	188,611	223,319	34,213	188,611	223,319