INSTITUTE OF ECONOMICS
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KÖZGAZDASÁG-TUDOMÁNYI INTÉZET

CERS-IE WORKING PAPERS | KRTK-KTI MŰHELYTANULMÁNYOK

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

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CERS-IE WP – 2020/20
May 2020

https://www.mtakti.hu/wp-content/uploads/2020/05/CERSIEWP202020.pdf

INSTITUTE OF ECONOMICS, CENTRE FOR ECONOMIC AND REGIONAL STUDIES,
BUDAPEST, 2020

ABSTRACT

We study the effects of the geographic expansion of a Neonatal Intensive Care Unit (NICU) system and a Newborn Emergency Transportation System (NETS) on neonatal and infant mortality and long-term impairments. We utilize gradual expansion in Hungary, we use administrative and census data, and we identify the effects from longitudinal variation in access, using changing distance as an instrument. Improving access to delivering in a city with a NICU decreases 0-6-day mortality by 153/1000 (<1500g) and 24/1000 (<2500g). NETS effects are positive but smaller. Improved access saves lives in the long run, with zero overall effects on long-term impairments.

JEL codes: I1, H51

Keywords: Neonatal Intensive Care, Newborn Transportation, fixed effects, mortality

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Egy országos lefedettségű intenzív koraszülött-ellátó rendszer kiépítésének hatása a csecsemőhalálozásra és a maradandó egészségkárosodások előfordulására: Magyarország 1990-2015

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ÖSSZEFOGLALÓ

A tanulmányban a magyarországi intenzív koraszülött-ellátó rendszer és a koraszülöttek sürgősségi szállítását végző alapítványi hálózatok földrajzi expanziójának hatását elemezzük az érintett újszülöttek halálozási és maradandó egészségkárosodási valószínűségére. A nagyon kis súlyú koraszülöttek (<1500 g) legnagyobb része és a kis súlyú koraszülöttek (1500-2500 g) jelentős hányada számára a születést követően magas a halálozás és az egészségkárosodás kockázata, ezért speciális ellátást igényelnek. Ezt a speciális ellátást az intenzív koraszülött-ellátó központok (Perinatális Intenzív Centrumok, a továbbiakban: PIC-ek) biztosítják. A PIC-ekben steril körülmények, ideális hőmérsékleti és fényviszonyok között, inkubátorokban látják el – szükség esetén, lélegeztetik – a veszélyeztetett újszülötteket, vagy életmentő sebészeti beavatkozásokat hajtanak rajtuk végre. Tanulmányunkban a legmagasabb, 3-as szintű PIC-ek hatását elemezzük.

Magyarországon először az 1970-es évek második felében létesítettek PIC-eket a legnagyobb kórházak szülészeti osztályai mellett, majd fokozatosan az egész országban kiépült a PIC-ek hálózata (új PIC létesítésére legutóbb 2014-ben került sor). A PIC-ek hálózatát a koraszülöttmentő alapítványok hálózata egészíti ki, amelyek gondoskodnak a PIC nélküli kórházban született, de PIC-ellátásra szoruló újszülöttek biztonságos átszállításáról a PIC-cel rendelkező kórházakba.

A PIC-ek és a koraszülöttmentő hálózatok felszerelése, működtetése, fenntartása és bővítése rendkívül költséges feladat. Ezért fontos, hogy megbízható mérések álljanak rendelkezésre arról, hogy ezek a létesítmények milyen hatékonysággal képesek ellátni fő céljukat: az életek megmentését rövid, illetve hosszabb távon. Az is rendkívül fontos, hogy megértsük, hogy az intenzív ellátás

milyen hatással van a maradandó egészségkárosodások előfordulási valószínűségére. Az intenzív ellátás egyrészt megfelelő körülményeket biztosít a PIC-be bekerült újszülötteknek, ami csökkenti számukra az egészségkárosodások valószínűségét vagy súlyosságát, másrészt viszont mivel a nagy mortalitási (és egészségkárosodási) kockázatú újszülöttek körében növeli az életben maradási esélyeket, növelheti a későbbi egészségkárosodások valószínűségét. Tanulmányunkban a két ellentétes előjelű hatás eredőjét tudjuk megmérni.

A tanulmányban három eredményváltozót használunk: a születést követő 0-6. napon belüli, ún. korai neonatális halálozást, a születést követő 0-364. napon belüli csecsemőhalálozást, valamint a hosszú távon megmaradó komolyabb egészségkárosodásokat. A célunk olyan hatásbecslések előállítása, amelyekre szakpolitikai döntések alapozhatóak. A PIC és a koraszülöttmentés hatásait egyazon modellben becsüljük meg. A hatásbecslés identifikációjának az adja az alapját, hogy az új PIC-ek létesítésének (vagy a koraszülöttmentő szállítási kapacitás területi bővítéseinek) következtében a potenciálisan veszélyeztetett várandós anyák számára e 25 éves időszak valamelyik évében a korábbi helyzethez képest könnyebben elérhetővé váltak a PIC-ek által nyújtott ellátások: a lakóhelyükhöz közeli kórházak szülészeti osztályai mellé PIC-et telepítettek, vagy a szülészetet bekapcsolták a koraszülöttmentő hálózatok egyikébe, amely megoldja a veszélyeztetett újszülöttek PIC-be szállítását.

A mortalitási következmények elemzését a KSH élveszületési és csecsemőhalandósági regisztereinek egyéni szinten kapcsolt adatain, az 1990 és 2015 közötti évek több mint két- és félmillió egyéni születési rekordján végeztük el. A tartós egészségkárosodási következmények elemzését pedig a KSH élveszületési regiszter 1990 és 2008 közti születési évjáratainak és a 2011. évi népszámlálás egyéni rekordjainak összekapcsolásával oldottuk meg. A népszámlálás önbevalláson nyugvó tartós betegség, illetve fogyatékosság kérdéseit (melyre a népesség / szülők 80 százaléka válaszolt) alapul véve, a 2011-ben 3-20. éves gyerekek, illetve fiatalok esetében fennálló egészségkárosodásokat mértük. A mortalitási, illetve egészségkárosodási következmények mérését azonos mérési design keretében végeztük el. Az adatkapcsolásokra és a számítások elvégzésére anonimizált adatokon, az MTA KRTK kutatószobájában, a KSH adatvédelmi szempontból biztonságos szerverén került sor.

A cikkben panel módszereket alkalmazunk a hatások becslésére. A különbségek különbsége módszert instrumentális becslési technikával ötvözzük, hogy kezeljük a mintaszelekcióból eredő torzításokat. Ehhez az anya lakóhelyéhez legközelebb eső PIC-nek, valamint a koraszülöttmentő hálózat legközelebb eső begyűjtési kórházának az anya lakóhelyétől mért mindenkori távolságát – e távolság időbeli változását – használjuk instrumentális változóként.

Az eredményeink azt mutatják, hogy ha egy anya PIC-es kórházzal rendelkező városban szül, akkor ez a körülmény 15,3%-kal csökkenti a 1500 g alatti újszülöttek 0-6 napos halálozási esélyét. Ez a hatás 1500-2500 g közötti újszülöttek esetében 1,0%. A 0-364 napos mortalitásra kapott becsléseink ugyanezekre a súlykategóriákra 14,4%, illetve 2,1%. Valamennyi eredmény statisztikailag szignifikáns. A két időtávú eredmény összhangja azt jelenti, hogy akinek az életet a PIC-es kezelés pár hete alatt megmentik, azt tartósan is megmentik. A koraszülött-szállítás révén PIC-be került újszülöttek esetében ezek a hatások kisebbek, de ugyanígy javítják a túlélési esélyeket. A 0-6 napos mortalitás az 1500 g-nál kisebb születési súlyú újszülöttek esetében 5,7%-kal (nem szignifikáns), az 1500-2500 g-os csecsemőknél pedig 0,9%-kal (szignifikáns) kisebb. Lényeges eredmény, hogy sem a PIC-es ellátáshoz való hozzáférésnek, sem a koraszülött-szállításnak nincs kimutatható hatása a maradandó egészség-károsodásokra.

JEL: I1, H51

Kulcsszavak: Koraszülött gyermekmentő központ, Koraszülött szállítás, fixhatás modellek, mortalitás

A kutatást a Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal OTKA pályázata (NKFI-116354) finanszírozta. Hajdu Tamást, Kertesi Gábort és Szabó-Morvai Ágnest a Magyar Tudományos Akadémia Lendület Programja (LP2018-2/2018) támogatta. Hajdu Tamást a Magyar Tudományos Akadémia Bolyai János Kutatási Ösztöndíj Programja is segítette a kutatás elkészítésében.

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

By Tamás Hajdu, Gábor Kertesi, Gábor Kézdi, and Ágnes Szabó-Morvai*

We study the effects of the geographic expansion of a Neonatal Intensive Care Unit (NICU) system and a Newborn Emergency Transportation System (NETS) on neonatal and infant mortality and long-term impairments. We utilize gradual expansion in Hungary, we use administrative and census data, and we identify the effects from longitudinal variation in access, using changing distance as an instrument. Improving access to delivering in a city with a NICU decreases 0-6-day mortality by 153/1000 (<1500g) and 24/1000 (<2500g). NETS effects are positive but smaller. Improved access saves lives in the long run, with zero overall effects on long-term impairments.

(JEL I1, H51)

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Data availability statement. In this research, we used individual-level de-identified registry data of the Hungarian Central Statistical Office (HCSO) on live births, infant deaths, and the population census. The de-identified microdata sets are available only for research purposes in a secure data environment. Because of its restricted nature, we are not in the position to share the data. We can share all code for inspection. The specifics of the secure data environment and access are described here: http://www.ksh.hu/safe_centre_access

Disclosure Statement. All the authors of this paper declare that they have no relevant or material financial interests that relate to the research described in this paper. IRB approval was not obtained for this research, as all data analysis was carried out in Hungary, in a secure data environment. In this research, we used individual-level de-identified registry data of the Hungarian Central Statistical Office (HCSO) on live births, infant deaths, and the population census. The de-identified microdata sets are available only for research purposes in a secure data environment. In the research room of the HCSO researchers access to datasets prepared for research in a safe environment with a CCTV surveillance system in place. To access to the datasets all researchers were required to sign a contract and a confidentiality commitment. (see http://www.ksh.hu/safe_centre_access)

Acknowledgments

We thank dr. Miklós Szabó (Hungarian Society of Perinatology and Obstetric Anesthesiology) for his support in conducting our survey on the history of the Hungarian neonatal intensive care system, as well as for his thoughtful comments and advices. Tamás Börcsök provided excellent research assistantship. Our research was supported by the Hungarian National Research, Development and Innovation Office (grant no. NKFI-116354). Tamás Hajdu, Gábor Kertesi and Ágnes Szabó-Morvai were supported by the Momentum ("Lendület") Program of the Hungarian Academy of Sciences (grant no. LP2018-2/2018). Tamás Hajdu was also supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences. The funding sources had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication. We owe thanks for the staff of the Databank and the Central Statistical Office for their support.

The present study has been produced using the birth and infant mortality records and 2011 census the data files of the Hungarian Central Statistical Office. The calculations and the conclusions within the document are the intellectual product of the authors.

The death of a child is a tragedy that should be prevented if resources allow for it. Thus, reducing the infant mortality rate is an important policy goal, even if its level is already low. Large reductions in high-level infant mortality are possible by promoting relatively inexpensive practices, such as free antenatal care or the use of antibiotics or aseptic techniques (Martines et al. 2005). However, some infant mortality remains difficult to prevent after such measures are exhausted. In particular, reducing early neonatal mortality (death within 6 days of birth) may require highly specialized intensive care for very risky births. Such care is provided by Neonatal Intensive Care Units (NICUs) (AAP 2012; Valek and Szabó 2018).

NICUs are specialized units located next to obstetrics units in the same hospitals that care for newborn babies with high risk of mortality right after they are born. Newborns at high risk include the majority of very low birth weight (VLBW) children (<1500 g), and many of the substantially larger pool of children with birth weights between 1500 g and 2499 g (the two groups together are called low birth weight, or LBW, children). In this study, as in most of the literature, we focus on level-3 neonatal intensive care units and call them simply NICUs (excluding level-2 units).

NICUs were first established in the 1960s in the U.S.A. and other wealthy countries. Virtually all other high- and medium-income countries followed later (e.g., India in the 2000s and Hungary in the 1970s). Typically, such systems are built up gradually, starting with lower capacity and limited geographic coverage. NICU systems are often complemented with a Newborn Emergency

Transportation System (NETS), which provides specialized transport for newborn babies from obstetrics units at other hospitals to NICUs.

Both NICUs and NETS are expensive to establish, operate, maintain, and expand (Russell et al. 2007; Hallsworth et al. 2008; Phibbs et al. 2019; Behrman 2007, 403–15; Watson, Arulampalam, and Petrou 2017). It is therefore important to learn how effective they are in saving lives, not only in the short run but also in the long run. In addition, it is important to know whether they have additional effects on the prevalence of chronic illnesses or significant impairment in the longer run, either by reducing such risks for infants who would survive anyway or increasing such risks by saving infants at the margin of survival who would later develop such conditions.

In this paper, we estimate the effect of expanding a NICU system and the corresponding NETS system on three outcomes: early neonatal mortality (within 0-6 days of delivery), infant mortality (within 0-364 days), and significant impairment that is diagnosed any time during childhood. Our goal is to obtain quantitative estimates for the effects that may guide policy decisions of expanding a NICU system in a middle- or high-income country in the 21st century.

We jointly estimate the effect of improved access to NICU hospitals and the NETS that connects non-NICU hospitals to NICU hospitals. We estimate the effects on long-term impairment on a smaller subsample using the same empirical strategy. To be more precise, instead of the effects of giving birth in such hospitals, due to data restrictions, we estimate the impact of giving birth in a city with a NICU hospital or a NETS-connected hospital. We show that the effects of being born in a hospital with NICU or connected to NETS are likely close to, or somewhat stronger than, our estimates of being born in a city with such a hospital or hospitals. Our empirical strategy identifies these effects from improved access due to decreasing distances in a country where geographic distance tends to be an important determinant of access to public services (Elek, Váradi, and Varga

2015). We argue that these effects are relevant from a policy point of view. They include the choice of the hospital of delivery if there are more hospitals in a city, a choice that is part of how the system works. Additionally, they measure the effect of improved access due to better geographic coverage.

To our knowledge, all papers on the effects being born in a hospital with a NICU on early neonatal mortality rely on cross-sectional comparisons (e.g., the meta-analysis of Lasswell et al. 2010; and J. H. Chung et al. 2010; Lorch et al. 2012; Jensen and Lorch 2015; Mújica-Moca et al. 2019). However, identifying the effect of NICUs is difficult due to various selection mechanisms, which make cross-sectional studies vulnerable to bias even if they condition on many covariates or use an instrumental variable such as distance to hospitals. Specific care practices of neonatal intensive care have been examined in a longitudinal framework (e.g., Grytten et al. 2017), but those results are not about expanding the entire system. We do not know of any study that has estimated the effects of expanding the NICU system or the effects of the neonatal transportation system from non-NICU hospitals to NICU hospitals.

The available evidence is also incomplete in terms of the outcome variables. Typical analyses focus on early neonatal mortality within 0-6 days of delivery. However, when evaluating the social benefits of a NICU/NETS system, it is necessary to uncover the longer-run effects on mortality or the likelihood of developing significant impairments during childhood. Our paper estimates such effects together with neonatal mortality in a unified empirical framework.

To gain credible estimates of the effect of expanding a NICU system, including NETS, to full coverage, this paper uses an empirical strategy that allows for identification from longitudinal variation in geographic coverage. We combine a difference-in-differences analysis with an instrumental variables strategy to handle selection, using the distance of residence of the mother to the nearest city with a NICU hospital and the nearest city with a NETS-connected hospital as instruments. While the residential distribution of mothers is not random, hindering cross-sectional comparisons, our strategy relies on longitudinal variation in distance due to opening new NICUs in hospitals in new cities and due to connecting existing non-NICU hospitals to the NETS in new cities. This longitudinal variation in distance is more likely to be random than its cross-sectional variation would be, which is supported by additional evidence that we will present. It is also a strong instrument because distance is an important determinant of access in the context of our analysis. In cross-sectional settings, distance to health facilities has been used in the literature as an instrument (Cutler 2007; Mújica-Moca et al. 2019; McClellan, McNeil, and Newhouse 1994). To our knowledge, ours is the first paper to utilize longitudinal variation in distance to analyze the effect of access to health care services.

We make use of the experience of Hungary. Hungary started to establish its NICU system in the 1970s in a few cities, and it gradually expanded it through 2015 by establishing new NICUs, often in new cities. Starting in 1990, it introduced and then expanded a newborn emergency transportation system from hospitals without a NICU to hospitals with a NICU. We collected information on the expansion of the NICU and NETS systems by a survey with the management of relevant organizations. To estimate the effects on early neonatal and infant mortality, we use individual-level administrative data on all births and all infant mortality events in Hungary from 1990 through 2015. To estimate the effects on long-run impairment, we use data from the national census of 2011, which includes questions on impairments, linked to birth registry data. While we have data for earlier time periods, we focus on the effects after 1990, as that is when NICUs started to use highly improved medical technology, making earlier estimates less relevant for today's policy decisions.

To summarize our results, we estimate substantial effects of improved access to NICUs on early neonatal mortality (0-6 days), and we find very similar estimates on total infant mortality (0-364 days). The magnitudes are larger for newborns with very low birth weight (<1500 g), but they are also significant for the much larger group of newborns with 1500 g to 2499 g birth weight. When comparing to baseline mortality rates, the effect estimates are similar in magnitude in these two groups. We estimate smaller, but non-negligible, effects of the NETS. Finally, our estimates of the effects on impairments are all very close to zero and statistically not significant. Taken together, these results provide strong evidence that the NICU/NETS system leads to a substantial decrease in early neonatal mortality, most of the lives it saves are lives saved for the long run, and the NICU/NETS system does not increase long-term impairment on average. The reason is either that the children on the margin of mortality do not develop such impairment or, if they do, it is compensated by a reduced impairment rate of the infra-marginal newborns by the NICU/NETS system.

In more detail, we estimate that giving birth in a city with a NICU decreases the 0- to 6-day mortality by 153 per 1000 live births for infants with birth weight 1500 g or less, by 10 per 1000 live births for infants with birth weight 1500 g to 2499 g, and by 24 per 1000 live births for infants with birth weight less than 2500 g; the corresponding 95% confidence intervals are [77, 229], [4, 16], and [10, 38]. These figures correspond to a 35% to 50% reduction relative to baseline rates in the first five years at the beginning of the time period (350/1000, 20/1000, and 65/1000). The point estimates for 0- to 364-day mortality are 144/1000, 21/1000, and 31/1000 (baseline rates 460/1000, 40/1000, 100/000). Giving birth outside a city with a NICU but connected in a NETS is estimated to decrease 0- to 6-day mortality by 57/1000 for <1500 g births (not significant), 9/1000 for 1500 g-2499 g births and 9/1000 for <2500 g births; effects on one-year mortality are 20/1000 (not significant), 11/1000, and 8/1000 (not significant). Our point estimates on the effect of NICUs on the incidence of impairment are 23/1000 for <1500 g births, 0/1000 for 1500 g-2499 g births, and 4/1000 for <2500 g births; neither these estimates, nor the estimated NETS effects, are significantly different from zero at any conventional level.

Our analysis contributes to the existing literature in at least four ways. First, to our knowledge, this is the first study to directly measure the effect of expanding a county-wide NICU system as opposed to the effect of delivery in individual hospitals or the effect of specific interventions. Second, it estimates the effect of establishing and expanding neonatal transportation systems (NETS) jointly with the expansion of NICUs. Third, it estimates longer-run mortality and long-run impairment effects to quantify the effects on saving at-risk newborns past the first few days of delivery and its potential trade-offs. Fourth, our study uses an identification strategy based on changing distance, which improves upon existing identification strategies and circumvents selection bias.

We believe that the Hungarian experience is especially relevant for middle- and high-income countries that consider establishing or expanding their NICU and NETS systems to improve access to previously underserved regions. Our estimates quantify the potential benefits, which we find to be substantial. Perhaps as importantly, we find that a NICU system can save lives in the long run without substantial effects on developing significant impairment later in life or compensating such effects by helping other infants.

The remainder of this paper is organized as follows. The next section summarizes the results from the previous literature. We then introduce the sources of our data and the data linkages we carried out. We continue with showing trends in births and infant mortality and discuss the details of the health system of Hungary, with a focus on the establishment and expansion of NICUs and

NETS. We then outline our empirical strategy and present evidence in support of it. The subsequent two sections show our main results and summarize the results of the robustness checks. The last part concludes.

I. Literature

Our paper estimates the effect of the geographic expansion of a NICU/NETS system, and we use longitudinal variation in the distance of residence to facility as a source of identifying variation. We are not aware of papers in the literature that attempt to answer the same question or use the same identification strategy. At the same time, there is a rich literature on the effects of various aspects of neonatal intensive care from a wide range of countries.

A meta-analysis of earlier studies finds strong associations of giving birth in NICUs and mortality, but all papers rely on observational cross-sectional data (Lasswell et al. 2010). Similarly, strong effects are found by later articles based on observational cross-sectional data, such as J. H. Chung et al. (2010), Lorch et al. (2012), Jensen and Lorch (2015) and Mújica-Moca et al. (2019). Sosnaud (2019) uses cross-sectional estimates and finds a significant negative relationship between the number of NICUs and infant mortality. The results are based on a large set of data, using almost 23 million infant birth records across 50 states of the U.S. from 1997 to 2002, controlling for a rich set of individual characteristics. Shah et al. (2020) find that neonatal mortality is significantly lower for infants born in a level-3 hospital compared to those born in non-level-3 hospitals. They do not find a significant negative effect for antenatal transfer to level-3 hospitals (see also Whitham and Dudley 2020). Grytten et al. (2017) provide an analysis of the effects of various medical interventions, many of which are offered in NICUs. It uses data for more than 40 years in Norway and establishes a negative causal relationship between the introduction of some new medical interventions and mortality among newborns. As the overlap is incomplete between medical services studied by Grytten et al. (2017) and those offered by the NICUs, their results cannot be interpreted as the effect of NICUs on infant mortality. Lorch et al. (2012) and Mújica-Moca et al. (2019) use distance to facility as an instrument in cross-sectional analyses of various levels of neonatal care on mortality. Mújica-Moca et al. (2019) examine the U.K. and find small effects; Lorch et al. (2012) examine several U.S. states and find effects that vary substantially across states. Watson, Arulampalam, and Petrou (2017) use short panel data of NICUs and longitudinal variation in the cost of care at the nearest NICU hospital as an instrument to estimate the effect of higher costs of intensive care on mortality; their source of variation is not changes in distance but changes in costs. They find that increased spending decreases mortality significantly. Almond et al. (2010) apply a regression-discontinuity framework on U.S. data to estimate the effect of access to more specialized care on infant mortality; Bharadwaj et al. (2013) use a similar approach to assess the effects on school outcomes in Chile and Norway. The regression-discontinuity approach makes use of discontinuity in access to additional treatment at 1,500 g of birth weight. This additional treatment includes, among other things, more likely referral to a NICU in Chile and Norway but not in the U.S., and it includes additional treatments in non-NICU hospitals in all three countries. Both of these studies find strong effects on all outcomes, but these effect estimates include the effects of many other treatments besides the effect of treatment in NICUs.

Several papers address the risks of the transportation of newborns to intensive care units. Most of this part of the literature finds that transportation comes with undoubted benefits as well as higher risks. Most related studies find significant health gains in terms of child outcomes for in utero versus ex utero transfer to NICUs (Bowman et al. 1988; M.-Y. Chung et al. 2009; Hohlagschwandtner et al. 2001; Kaneko et al. 2015; Kollée et al. 1992; Lamont et al. 1983; Marlow et al. 2014; Mori et al. 2007; Shlossman et al. 1997). These papers mostly use relatively small samples and cross-sectional data, and none of these studies focus on the gains of newborn transportation as opposed to no access to a NICU at all.

The literature on the long-run health of infants treated in NICUs focuses on the health risks related to preterm births, including visual impairments, hearing problems, learning disabilities and many more (Behrman 2007; Wilson-Costello 2007; Lindström et al. 2007; Lindström, Lindblad, and Hjern 2011; M. C. McCormick 1989; Marie C. McCormick and Litt 2017; Blencowe et al. 2013). To our knowledge, there has not yet been a documented attempt in the literature to estimate the causal effect of having access to a NICU on these long-term outcomes.

Our identification strategy uses longitudinal variation in the distance of residence to cities with NICU/NETS hospitals. We are not aware of studies that use the longitudinal variation in distance. In contrast, cross-sectional variation of distance to health services is used by many papers to identify various effects (McClellan, McNeil, and Newhouse 1994; Cutler 2007; Ambardekar et al. 2010; Abrams et al. 2011; Khan et al. 2011; Lorch et al. 2012; Mújica-Moca et al. 2019). However, as emphasized by Garabedian et al. (2014), the cross-sectional spatial distribution of patients is likely correlated with health outcomes independently of the potential effects of access to health services. In contrast, our strategy of using longitudinal variation in distance is likely free from that endogeneity.

II. Data

We combine data from three sources for the analysis in this study: vital statistics, the national census, and our own survey on the expansion of NICUs and NETS. Birth and mortality data are from the national vital statistics of all births and any subsequent deaths up to 364 days. Birth and mortality data are linked at the individual level. The birth data include information on birth weight, gestational age, other birth-related variables, municipality of delivery, municipality of residence of the mother, whether the father is known, and education and labor market status of mother and father (if known). For future reference, each city, town and village is a separate municipality in Hungary. In line with the literature, we classified live births of very low birth weight (VLBW) if weight was <1500 g and low birth weight (LBW) for <2500 g. We present results for the two birth weight groups as well as the non-overlapping group of 1500 g to 2499 g. The administrative database covers cohorts born in 1990-2015 and includes 2,610,468 live birth events and 22,136 infant mortality events.

We focus on results by birth weight. An alternative indicator of risk, also contained in our data, is whether the birth is pre-term (<37 weeks) or very pre-term (<32 weeks). Our main results are for birth weight categories, as those are more precisely measured; we show among the robustness checks that the results are similar for pre-term categories. These indicators are ex-post to delivery; our data have no ex-ante risk indicators. For reasons similar to ours, much of the related literature has focused on low birth weight infants (Lasswell et al. 2010; Grytten et al. 2017; Koller-Smith et al. 2017).

Long-term impairment data come from the 2011 census, which covered the entire population of Hungary. Among other things, the census contains self-reported information on long-term impairment and its various types. Information on legal minors was provided by their parents. Participating in the census was mandatory, but answering these specific questions was voluntary; the response rate to them was approximately 80%. Some long-term impairments take time to discover (see Figures A1 and A2 on the prevalence rates by birth year in the Appendix); thus, we restricted our analysis to people who were born between 1990 and 2008 (they were 3 to 20 years old in the census).

To analyze the incidence of impairment by birth weight, we linked the census records to the records in the national vital statistics using exact date of birth, gender, municipality of residence of the mother when the person was born, and the exact date of birth of the parents if they lived together with the person in 2011. We successfully linked approximately 75% of LBW and VLBW births from the vital statistics (see Table A.1 in the Appendix). The rate of successful linkages is slightly increasing in the year of birth because the information on parents helps with linking the records, and older children (of the 3- to 20-year-old target population) are less likely to reside with their parents. We focus on two indicators of long-term impairment: any impairment and impairment present at birth (congenital disorder). The prevalence of the first (any impairment) is only slightly higher than the prevalence of the second: a little over 15% for individuals over age 3 born with birth weight <1500 g, and approximately 5% if birth weight <2500 g (Figures A1 and A2 in the Appendix). Birth and infant mortality records and census data are administered by the Hungarian Central Statistical Office (HCSO). We accessed and linked the datasets in the secure data environment of the HCSO.

Our third data source is a simple survey that we designed and implemented to uncover the history of opening of NICUs and connecting non-NICU hospitals to NETS across the country. The data were collected by the Institute of Economics, CERS of the Hungarian Academy of Sciences. The directors of each Level 3 NICU operating in 2015 were asked to complete a questionnaire, which asked for the date when their unit was established and a few questions on circumstances. To be more precise, they indicated the first calendar year in which their unit was operating year-long at its planned capacity. A similar data collection was carried out among NETS organizations. This survey collected data on the starting year of their service and their territorial coverage in their start year and in two other points in time.

III. Trends and institutional background

Fertility decreased substantially in Hungary between 1990 and 1995 and remained relatively stable afterwards. In parallel with this trend, the number of LBW and VLBW births dropped substantially in the first half of the 1990s, followed by relative stability and a small further decrease in the 2010s. Figure A3 in the Appendix shows the time series.

During the same time, mortality both among LBW and VLBW births declined steadily, at comparable rates. The 0- to 6-day mortality among VLBW births decreased from approximately 350/1000 in the first five years of the 1990s to below 100/1000 after 2010; the corresponding figures for 0- to 364-day mortality decreased from 460/1000 to below 200/1000. For LBW births the 0- to 6-day mortality decreased from 65/1000 to below 20/1000, while the 0- to 364-day mortality decreased from 100/1000 to below 40/1000. Figure A4 shows the time series.

The Hungarian health-care system has been characterized by single-payer health insurance and universal coverage since the 1960s. In Hungary, the majority of the individuals are insured, inpatient and outpatient services are financed through compulsory health insurance, and opting out from the system is forbidden. In 2013, Hungary spent 7.4% of its GDP on healthcare, of which nearly 70% was public expenditure (OECD 2015). The public expenditure part is financed through payroll taxes and transfers from the government budget.

There are no out-of-pocket payments at the points of service, except for drugs. At the same time, informal gratuity payments are widespread. Approximately 50% of respondents who used hospital care reported to have paid informal gratuity, with a prevalence of 85% for deliveries, according to a nationally representative survey (Baji et al. 2012). There is territorial supply obligation, where primary care is the responsibility of the municipalities, and county governments are responsible for specialist health care provision. According to the main rule, patients must receive health care at the lowest adequate level (Gaál et al. 2011; Bíró and Elek 2018). At the same time, patients have a choice of where to seek more advanced care, including where to give birth.

Cutting the infant mortality rate (IMR) became a leading goal in health policy in the 1970s in Hungary, with focused attention on very low birth weight and preterm births (Gecser, Ifkó, and Kiszel 1977). As a response, Hungary established the first 10 NICUs in 1977 in some of the largest cities, with a gradual expansion of the system, opening new NICUs and increasing the capacity of existing NICUs in the following decades. Since the introduction of the NICU system, Hungary underwent major political and economic changes, including the transition from a socialist regime to democracy and capitalism starting in 1989 and joining the European Union in 2004.

In parallel with the major social and economic changes, the available therapies of high-risk pregnancies and newborn infants improved considerably as well (e.g., antenatal steroids, surfactant and ventilators). Meanwhile, the first newborn emergency transportation system (NETS) organizations were established in 1990 to ensure safe transportation of infants to NICUs from hospitals without a NICU. By 2015, 21 NICUs were functioning in 15 cities. The NETS gradually expanded to reach full geographic coverage by 2005. Since 2005, nearly all infants at risk in the country have been born either in a city where a NICU operated or in a municipality that was covered by NETS.

By 2015, the Hungarian NICU system became similar in its coverage to most rich countries. Conditional on the size of the country and the number of live births, including the number of LBW births and VLBW births, the number of units in the U.S. and Hungary are very similar (see Table A2 in the Appendix), relative not only to all live births but also to VLBW births at highest risk.

Thus, analyzing the effects of expanding a NICU system to its current level in Hungary is informative for the expected effects of expanding coverage in a range of countries that include both Hungary and the U.S.

To inform current policy decisions, our analysis starts with data from 1990. It ends with data from 2015 for analyzing mortality and 2008 for analyzing long-term impairments due to data availability. By focusing on this time period, we can estimate the effects for neonatal care with medical technology that is closer to what is available now; we can estimate the effects for a health system that is similar to many middle- and high-income countries; and we can jointly estimate the effects for NICUs and NETS.

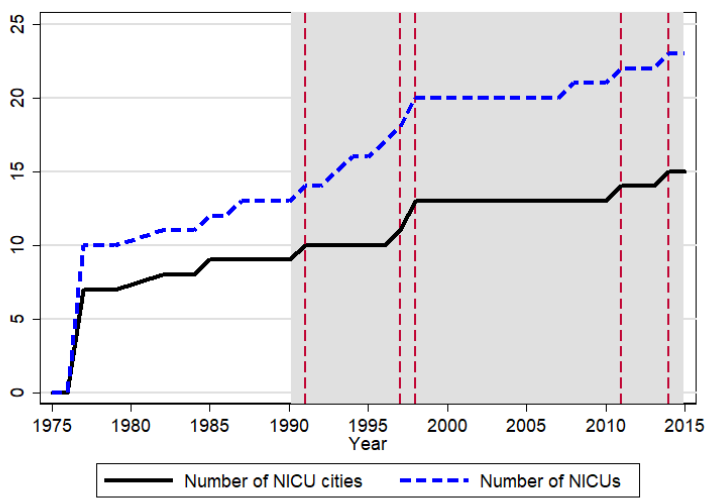

FIGURE 1. NUMBER OF HOSPITALS WITH A NICU AND NUMBER OF CITIES WITH A NICU HOSPITAL

Source: Author calculations, based on the authors' survey on NICU establishments.

Figure 1 shows the expansion of the NICU system from its beginnings in 1977 to 2015. The shaded gray area shows the time period of our analysis, 1990 through 2015. The solid line shows the number of cities with a NICU; the dashed line shows the number of NICUs themselves. The dashed vertical lines show the years when NICUs were established in new cities after 1990. Those changes are the source of identification for the effects of the NICUs.

Another way of describing the expansion of NICUs and NETS is considering the proportion of births in cities they cover. Figure 2 shows the gradual buildup of complete geographic coverage of low birth weight (<2500 g) births and very low birth weight (<1500 g) births by NICUs and NETS. The rate of VLBW births in cities with NICUs was 60% in 1990 and increased to over 90% by 2015. The corresponding figures for LBW births are 50% to 70%. The first emergency transport services started in 1990 by adding another 20 percentage points of coverage to both VLBW births and LBW births. Together, NICU and NETS reached full coverage by 2005 so that all births take place in cities with either a NICU hospital or a hospital connected to NETS.

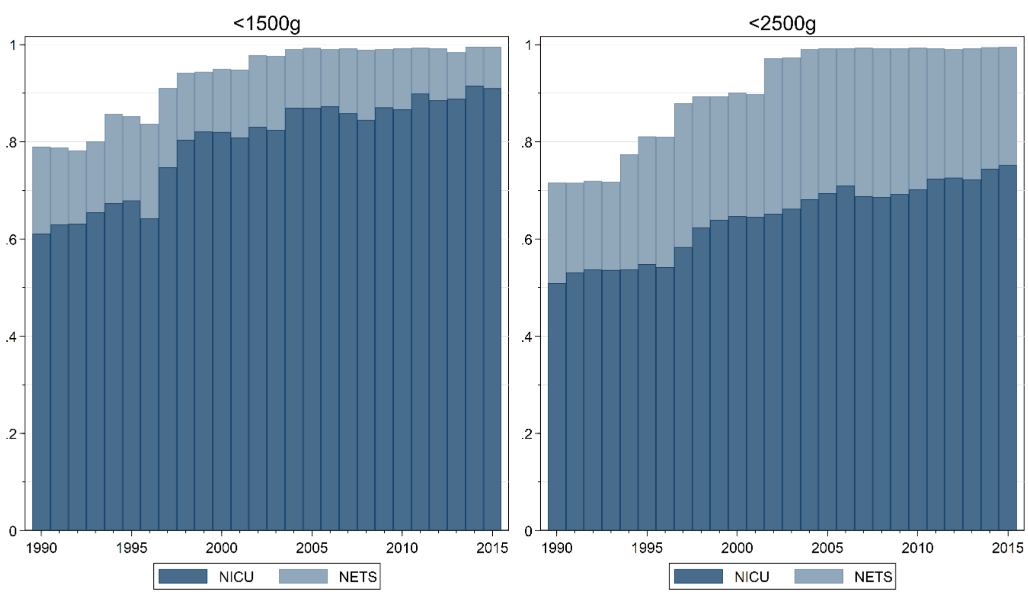

FIGURE 2. PROPORTIONS OF BIRTHS IN CITIES WITH A NICU AND MUNICIPALITIES WITHOUT NICU BUT COVERED BY NETS

Source: Author calculations. National vital statistics from Hungary, 1990-2015, linked to the authors' survey on NICU and NETS establishments

IV. Empirical strategy

Our study seeks to evaluate the effects of the geographic expansion of the NICU and NETS systems on early neonatal and infant mortality and long-term impairments. We operationalize this question by examining the effects of giving birth in a city with a NICU hospital and giving birth in a city without a NICU hospital but connected to such a hospital by NETS.

Some cities with a NICU hospital have other hospitals that process deliveries. One way to understand the effect we estimate is as an average intent-to-treat effect, where the treatment itself would be giving birth in a NICU hospital. However, we argue that the effect of giving birth in a city with a NICU is the more policy-relevant question when investigating the consequences of the geographic expansion of the system. This effect includes the effect of choice of hospital of delivery if there are more hospitals in a city, which is part of how the system works. In any case, this is the quantity we can estimate with our data and our empirical strategy that makes use of the distance between municipalities (more on that later).

Almost all cities with a hospital but without a NICU have a single hospital that performs deliveries. Thus, infants born in a city with a hospital connected to the NETS but without a NICU hospital are born in that connected hospital. At the same time, in cities with multiple hospitals, NETS connects non-NICU hospitals to NICUs. By focusing on the effect of being born in a city connected by NETS but without a NICU, we can estimate the effect of NETS for transfers between cities but not within cities. As mortality risk is larger at longer distances, our NETS estimates are likely weaker than the effect that includes saving lives by transferring infants within a city.

In the remainder of this section, we outline our identification strategy in detail. We use the same strategy for estimating the effect of giving birth in a city with a NICU and the effect of giving birth in a city with NETS. For simplicity, we discuss our strategy with respect to cities with NICUs here. Everything is analogous to our strategy of estimating the effects of NETS.

Our question is the effect of the geographic expansion of the system. A controlled experiment would choose the location of new NICUs randomly in previously underserved areas and would compare subsequent mortality to the unselected locations. Random assignment would ensure that the location of new NICUs would not depend on the level, or trends, of infant mortality. However, endogenous selection of births into NICU hospitals may occur even in this experiment. On the one hand, after the opening of a new NICU, riskier pregnancies could be transferred to them. On the other hand, from among pregnancies with similar risk, more informed mothers may be more likely to give birth in hospitals with NICUs. Finally, mothers might move into towns with newly established NICU hospitals. In principle, randomly assigning births to hospitals could circumvent these selection mechanisms.

Our empirical strategy simulates these two experiments at once. First, we address selection of the location of new NICU openings by a difference-in-differences strategy that exploits the variation in the timing of the establishment of new NICUs. Second, we use the distance of the mother's residence to the nearest NICU city as an instrumental variable to address selection of births into NICU hospitals. Within the difference-in-differences framework, this instrumental variable is based on the longitudinal variation in that distance. This instrumental variable strategy circumvents the effect of NICU availability on the selection of births into hospitals, as well as cities with such hospitals, as long as mothers at higher risk do not move closer to NICUs. We find no evidence for this: Figure A8 in the Appendix shows the time series of the proportion of potential mothers moving into each of the cities that had a NICU established during our time period. The figures show no evidence of more potential mothers moving into those cities after establishing a NICU.

Using individual birth-level data, we specify the following regression for the effect of giving birth in a city with a NICU/NETS hospital:

$$Y_{ijt} = \beta \cdot BNICU_{ijt} + \gamma \cdot BNETS_{ijt} + \delta' \cdot X_{ijt} + \eta_j + \theta_t + u_{ijt} \qquad (1)$$

Index i denotes the newborn child, j is municipality of residence of the mother, and t is the year of birth. Y is the outcome variable: whether the newborn died within 6 days, whether the infant died within 364 days, and whether the child developed an impairment by the time we observed them in the census (age 3 to 20). All outcomes are binary; our regressions are linear probability models.

BNICU is a binary variable denoting whether the infant was born in a city with a NICU hospital, and BNETS is a binary variable denoting whether the infant was born in a city with a non-NICU hospital that is connected to the NETS. Note that BNICU and BNEST are disjoint alternatives by definition. The η and θ are municipality of residence and birth year fixed effects. There are approximately 3000 municipalities of residence in the data; each village, town and city is a municipality. Vector X includes individual covariates, such as gender, parity, month of birth, mother's marital status, twin birth, highest level of education of the mother and father, labor market status of the mother and father, age of mother and father in 5-year categories, and indicators for previous abortions and miscarriages of the mother.

The coefficients of interest are β and γ. β aims at measuring the effect of giving birth in a city with a NICU hospital. γ aims at measuring the effect of giving birth in a municipality that has no NICU hospital but is connected to a NICU hospital via NETS.

To address selection into NICU hospitals or hospitals connected to NETS, and thus into cities with such hospitals, we instrument BNICU and BNETS with the distance of the mothers' residence to each. The first-stage regressions are the following:

$$BNICU_{ijt} = \pi_1 \cdot DNICU_{ijt} + \phi_1 \cdot DNETS_{ijt} + \delta_1 \cdot X_{ijt} + \eta_{1j} + \theta_{1t} + u_{1ijt} \quad (2)$$

$$BNETS_{ijt} = \pi_2 \cdot DNICU_{ijt} + \phi_2 \cdot DNETS_{ijt} + \delta_2 \cdot X_{ijt} + \eta_{2j} + \theta_{2t} + u_{2ijt} \quad (3)$$

We use subscripts to denote parameters in the two first-stage equations. As in the main regression, η and θ are municipality of residence and birth year fixed effects, and vector X includes individual covariates. The instruments are DNICU and DNETS; these variables indicate the distances between the mother's municipality of residence to the nearest municipality with a NICU and a NETS hospital, respectively. The π parameters show the effect of the distance of mothers' residence to a NICU hospital on giving birth in a municipality with a NICU or NETS hospital. Similarly, the φ parameters show the effect of the distance of the mothers' residence to the nearest municipality with a NETS-connected hospital on giving birth in a municipality with a NICU or NETS hospital. As we shall see, our instruments are quite strong.

To assess the identifying assumptions behind our strategy, let us consider the reduced form where we use the subscript R, for reduced form, to distinguish parameters from the previous equations:

$$Y_{ijt} = \pi_R \cdot DNICU_{ijt} + \phi_R \cdot DNETS_{ijt} + \delta_R' \cdot X_{ijt} + \eta_{Rj} + \psi_{Rt} + \omega_{Rijt} \quad (4)$$

In this reduced form regression, π_R shows the effect of the distance of mothers' residence from the nearest NICU city on the outcome variable, while parameter ϕ_R shows the effect of the distance from the nearest non-NICU NETS city.

Due to the presence of residence fixed effects, this is a generalized difference-in-differences setup. The source of identification is changes in the distance to NICU and NETS cities due to the opening of new NICUs and expanding the coverage of NETS. Recall Figures A5, A6, and A7 in the Appendix that show aggregate trends in the number of municipalities in discrete bins of distance to illustrate the source of variation in our distance variable.

The reduced form effects, and thus the instrumental variable estimates of the effects, are identified if the parallel trends assumption holds. This assumption stipulates that, without the expansion of NICU or NETS, the trends in the outcomes would have been the same in municipalities that saw their distance change because of a new NICU or NETS hospital as they were in municipalities that did not experience such a change. This assumption is untestable, as it compares actual trends to counterfactual trends, but examining pretreatment trends can be informative. However, defining and examining pretreatment trends in a direct way is not straightforward in our setup with a gradual expansion of NICUs and NETS. Thus, we will examine them among the robustness checks of our estimates by including lead terms of the treatment variables.

Finally, recall that our strategy estimates the effect of giving birth in a city with a NICU and the effect of giving birth in a city without a NICU but connected to NETS. While we argue that these effects are more interesting from a policy point of view, they are, at the same time, likely to be close to the corresponding effects of giving birth in a NICU hospital. The overwhelming majority of risky births in cities with a NICU hospital took place in the NICU hospitals themselves (over 90% of 0-1500 g births and over 60% of 1500-2499 g births were treated in NICUs in 2012 (Valek and Szabó 2014); the corresponding figure for 0-1500 g births a few years earlier was 85% (Páll, Valek, and Szabó 2011). Similarly, the overwhelming majority of newborn emergency transportations took place between cities as opposed to within cities (approximately 80% of transportations of infants with birth weight less than 2500 g in 2012 (Valek and Szabó 2014). In line with these considerations, when we restrict our analysis to cities with single hospitals, we get estimates that are similar to our main results (see the robustness checks later).

V. Main results

Our main results are estimates of regressions (1) to (3) on three subsamples: births with very low birth weight (<1500 g), births with low but not very low birth weight (1500 g ≤ weight < 2500 g), and births with low weight (<2500 g). We consider two outcomes in this section: mortality within 0 to 6 days after birth (early neonatal mortality) and mortality within 0 to 364 days after birth (infant mortality). The descriptive statistics of the variables are summarized in Table A3 in the Appendix.

Table 2 shows the second stage (IV) results. The tables show the point estimates of the most important variables, with clustered standard errors. They also include the F-statistics on the excluded instruments from the first-stage regressions. The corresponding first-stage and reduced-form results are included in the Appendix, Tables A4 and A5.

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

	Mortality 0-6 days			Mortality 0-364 days		
	<1500 g	1500-2499 g	<2500 g	<1500 g	1500-2499 g	<2500 g
Born in a NICU city	-0.153 (0.038)	-0.010 (0.003)	-0.024 (0.007)	-0.144 (0.042)	-0.021 (0.005)	-0.031 (0.009)
Born in a NETS city	-0.057 (0.040)	-0.009 (0.002)	-0.009 (0.005)	-0.020 (0.043)	-0.011 (0.004)	-0.008 (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

Notes: Robust standard errors with municipality clustering are in parentheses. The individual covariates include the infant's gender, parity, twin birth, indicators for previous abortions and miscarriages of the mother, indicators for whether the mother is married, and the highest level of education, labor market status, and age of the mother and father (in 5-year categories).

Source: Author calculations. National vital statistics from Hungary, 1990-2015, linked to the authors' survey on NICU and NETS establishments.

According to the point estimates, giving birth in a city with a NICU decreased the 0- to 6-day mortality by 153/1000 live births among infants with birth weight <1500 g (95% CI [77,229]), by 10/1000 live births among infants with a birth weight between 1500 g and 2499 g (95% CI [4,16]), and by 24/1000 live births among infants with <2500 g (95% CI [10,38]). These are large effects. We can compare them to the corresponding mortality rates at the beginning of the time period, 350/1000, 20/1000, and 65/1000, respectively.

The estimated effects on 0- to 6-day mortality of being born in a city without a NICU but connected to a NICU hospital by NETS are 57/1000 live births for infants with birth weight <1500 g (not statistically significant), 9/1000 between 1500 g and 2499 g, and 9/1000 for <2500 g. These effects are substantially weaker than giving birth in a city with a NICU itself. This result is consistent with the high risks of transporting newborn babies and the more time that it takes to rescue newborn infants from distant hospitals.

The effect estimates on 0- to 364-day mortality are very similar to the estimates on 0- to 6-day mortality. These results are important. They imply that the large majority of lives saved in NICUs and by NETS are saved for the long term.

The first-stage results (Table A4 in the Appendix) are strong, and they are consistent with the causal interpretation of the instrument. Recall that we have two first-stage regressions, one for being born in a city with a NICU hospital and one for being born in a city without a NICU hospital but connected to NETS, and both regressions include both of our instruments. The results show that decreasing distance to a NICU city makes giving birth in a NICU city substantially more likely, and it makes giving birth in a non-NICU but NETS city somewhat less likely. At the same time, decreasing distance to a non-NICU but NETS city does not change the likelihood of giving birth in a NICU city, or it makes it marginally less likely, while it makes giving birth in a non-NICU but NETS city more likely. The reduced-form estimates (Table A5 in the Appendix) are in line with the two stages of the 2SLS, and they have similar t-statistics (coefficient estimates over standard errors). These results strengthen the credibility of our main estimates.

After estimating the effects of NICU/NETS on mortality, we turn to its potential effects on long-term impairment. Recall that most impairments manifest by age 3 but not earlier; therefore, we focus on impairments reported for children age 3 or above (Figures A1 and A2 show the age-impairment profiles). The impairment data are from the census of 2011; the response rate in the census was 80%, and its records were linked to birth records with a 75% success rate on average.

The age restriction leads to focusing on a shorter time period, 1990 through 2008. These factors result in substantially smaller numbers of observations than what we could use for the mortality estimates.

There are two reasons to expect an effect with opposing signs. First, lives saved by NICU/NETS are from very risky pregnancies and births that may be more likely to result in severe impairments of the children. Thus, the system may save lives but increase the number of individuals with long-term impairments. Second, the high-quality medical interventions in NICUs may directly reduce the risk of developing such impairments, even for those that were not at the margin of infant mortality. Our estimates show the net effects of the two. Table 2 shows the results, in the same structure as Table 1 above. The corresponding summary statistics, first-stage and reduced-form results are in Tables A6-A8 in the Appendix.

The point estimates are all very close to zero, and none of them are significant at conventional levels. Being born in a NICU city is estimated to increase the incidence of long-term impairment by 20/1000 for birth weight less than 1500 g, by 0/1000 for birth weight between 1500 g and 2499 g, and by 4/1000 for birth weight less than 2500 g. These should be compared to the point estimates of 144/1000, 21/1000, and 31/1000 lives saved by being born in a NICU (the 0- to 364-day mortality results in Table 1; note that child mortality is low after age 1, so most lives saved to age 1 are saved for a longer time). The estimated effects of NETS are of similar magnitude. While our confidence intervals are wide, it is remarkable that all point estimates are very close to zero. Thus, we think that the evidence here suggests that the effects are most likely close to zero indeed. Recall that these effects are the combination of negative selection (risky lives saved) and a direct effect of treatment on the likelihood of developing impairments. These two effects appear to add up to zero.

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

	Any impairment			Impairment present at birth		
	<1500 g	1500-2499 g	<2500 g	<1500 g	1500-2499 g	<2500 g
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

Notes: Robust standard errors with municipality clustering are in parentheses. Individual covariates: see notes to Table 1.

Source: Author calculations. National vital statistics of Hungary, 1990-2015, linked to the 2011 Census of Hungary and the authors' survey on NICU and NETS establishments.

VI. Additional Results and Robustness Checks

For comparison, Tables A9 and A10 (Appendix) show the results of the non-instrumented ("OLS") estimates of Eq. 1. They do include the municipality and year fixed-effects and thus estimate the effects from longitudinal variation in giving birth in NICU or NETS cities, but they do not address the endogenous change of the composition of births due to the new NICU hospitals and NETS connections. Recall that we expect selection to be strong for new NICU hospitals but not necessarily new NETS connections, and the direction of that selection is ambiguous in principle: riskier births are likely directed to new NICU hospitals, but conditional on risk, better informed mothers choose the new NICU hospital. We expect the first effect to dominate. Comparing the OLS and 2SLS results is in line with that expectation, especially for non-VLBW births. The coefficient estimates for mortality are negative but closer to zero or even positive, and the coefficient estimates for impairment remain zero or become positive. These results support the need for our instrumental variables strategy, and they are also consistent with how our instrumental variables strategy should reduce the bias.

Our instruments are the distance of the mother's residence to the nearest city with NICU or NETS. In the baseline specification of Eqs. 2 and 3, we entered the distance measures linearly. Although this is the simplest functional form, nothing guaranties that it is the right one. Thus, we re-estimated our models using different functional forms, including a quartic specification and one with 10-km bins. Tables A11 and A12 show the results for mortality.

To address potential non-parallel trends, we re-estimated our models including municipality-specific time trends. Note that we estimated linear probability models, while the trends in mortality are convex (Figure A4 in the Appendix shows the national trends). Thus, including linear trends is an imperfect solution to capture pre-trends. In particular, linear trends tend to predict weaker decline in the earlier time periods than the actual decline, and they tend to predict a stronger decline in the later time periods than the actual decline. As a result, including linear trends leads to an upward bias in the effect estimates (making them less negative) because the estimated pre-intervention deviations of mortality relative to a linear trend are biased upwards, and the estimated post-intervention deviations of mortality relative to a linear trend are biased downward. Table A13 shows the results for mortality; they are qualitatively similar, although somewhat weaker. Given that we expect weaker results by construction, these results provide strong support for the causal interpretation of the main results.

To examine pre-trends more directly, we re-estimated our models with lead terms. These pre-trends are best examined in the reduced-form results, which include the leads of the distance of the mother's residence to NICU and NETS cities. Table A14 shows the results of a specification with the contemporaneous term, the first lead, the second and third leads combined, and the fourth and fifth leads combined. These are lead terms in an FE model showing average differences in mortality from before to after the time period indicated, in successively additive ways. The results should be compared to the positive reduced-form effects we presented in Table A5 that show after/before differences corresponding to the assigned start years of NICUs and increasing coverage of NETS. The NICU results show that the significant change in mortality occurs one year prior to the start year, but the coefficients on the further leads do not show pre-trends. Recall that the NICU start date denotes the first full year of the unit; the unit itself, or most elements of it, were likely already in place the year before. The NETS results show a more spread out change in the years before. Here, the effects are estimated from the timing of increased coverage, which is even less well captured by our data, which only captures snapshots in several years. Taken together, these results are consistent with noise in measuring the precise timing of the expansion. Most importantly, especially in the case of the expansion of NICUs, they do not indicate strong pre-trends.

We also addressed the fact that our estimates show the effect of giving birth in a city with a hospital with a NICU or in the NETS and not of giving birth in a NICU or NETS hospital. The two kinds of effects are not the same because some of the largest cities have multiple hospitals with only some of them having a NICU, and because in such cities, neonatal transportation may take place within the city. We argued that the effects we estimate are more policy-relevant, and they are analogous to an intent-to-treat effect. At the same time, we also argued earlier that the estimates are likely close to what the effects of giving birth in a NICU or NETS hospital would be, especially among VLBW infants. To provide further evidence for the latter, we re-estimated our main model for only cities with a single hospital by excluding from the data all births to mothers who lived in or within 50 km of cities with multiple hospitals. The samples are smaller by more than two-thirds, and they are a selected sample, excluding the larger cities, including Budapest, the capital. The results, in Table A15 in the Appendix, are very similar to the main results.

Finally, we estimated our models for preterm births, instead of birth weight groups, in three categories: 0-31 weeks of estimated gestation week, 32-36 weeks and 0-36 weeks (Tables A16 and A17). Again, these results are very similar to the main results.

VII. Conclusions

This study estimated the effect of improved access to neonatal intensive care due to the geographic expansion of the care system into previously underserved areas. In particular, it estimated the effect of giving birth in a city with a neonatal intensive care unit (NICU) and in a city connected to a NICU hospital by a neonatal transportation system (NETS) on early neonatal mortality (0-6 days) and infant mortality (0-364 days) as well as long-term impairment of the children that survived. We made use of the gradual geographic expansion of this system in Hungary, a middle-income country where geographic distance is an important determinant of access to public services, between 1990 and 2015. Our empirical strategy was difference-in-differences identified from longitudinal variation in geographic coverage. We used the distance of the mother's residence to the city of the hospital as an instrument in this diff-in-diffs setup, which helped overcome selection into giving births in hospitals. Our results showed that being born in a city with a NICU has a substantial effect on early neonatal mortality, and the effects are very similar for overall infant mortality. Being born in a city without a NICU hospital but connected to such a hospital by NETS also reduces mortality, but its effects are substantially weaker. Our estimates on the effects on long-term impairment are all very close to zero. These are the first results in the literature that estimate the effect of the geographic expansion of a NICU system on 0- to 6-day mortality, longer-term mortality and long-term impairments in the same framework, jointly with the effects of NETS. The effects are identified using a transparent and credible empirical strategy that assesses multiple kinds of selection, and our estimates are robust to a number of potential issues that may arise with our strategy and our data.

Several conclusions emerge from our results. First, our effect estimates suggest a substantial benefit to geographic expansion of access even though the newly established units may be of lower efficiency and quality due to less experience and, typically, lower number of cases treated. Second, the results suggest that the effects on early neonatal mortality are long-term effects: lives saved in the first week also tend to be saved for the remainder of the first year. This result is remarkable, as it suggests that most lives are saved for a very long time, as mortality after the first year is very low. Third, our results suggest that the system also helps to avoid long-term impairments. It either helps infants to survive without substantially increasing their risk of developing long-term impairments or, to the extent that some of them do develop such impairments, it balances the deficit by reducing the risk for other infants. Fourth, the estimated effects of the transport system (NETS) are also positive in reducing mortality, but they are substantially weaker than the effects of NICUs. Given the substantial risks of transporting newborns in critical condition, these results are not surprising. They highlight that giving birth in a hospital with a NICU offers substantially better chances for survival for newborns at risk. However, our results show that the NETS saves lives, too.

Our estimates can help to assess the benefits of expanding a NICU/NETS system to previously underserved regions using current medical technology in middle-income countries where geographic distance matters for access. Giving birth in a city with a NICU hospital is expected to save approximately 140 of 1000 very low birth weight infants and approximately 20 of 1000 infants between 1500 and 2500 g of birth weight in the long run. Giving birth in hospitals without a NICU but connected to a NICU by neonatal transportation is expected to save approximately 20 of 1000 very low birth weight infants and approximately 10 of 1000 infants between 1500 and 2500 g of birth weight. There appear to be no long-term impacts on impairment. The high costs of the expansion and subsequent maintenance of the NICU/NETS system should be weighed against these benefits.

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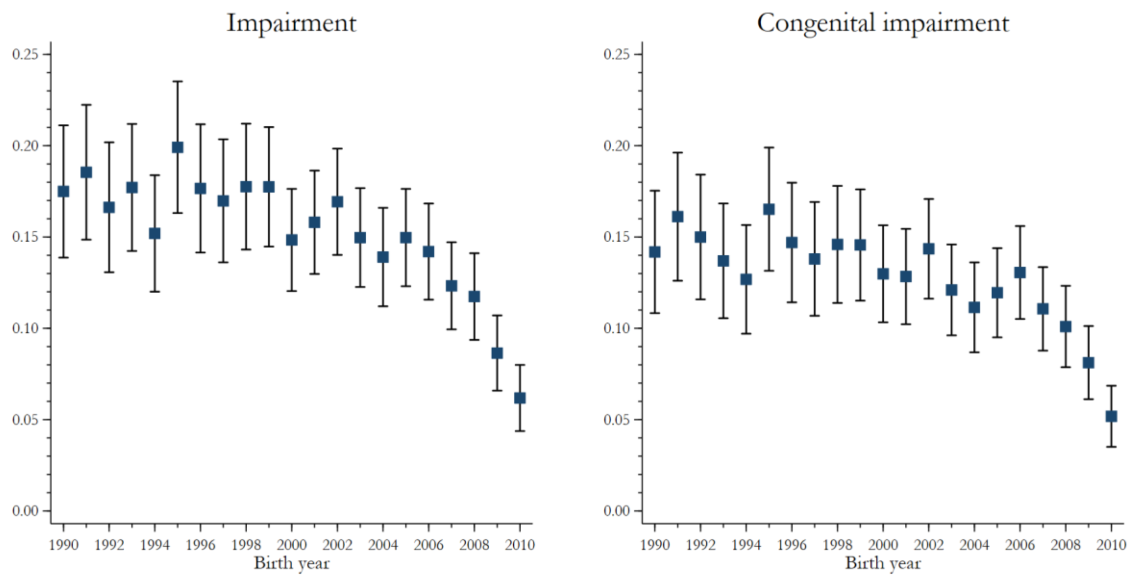
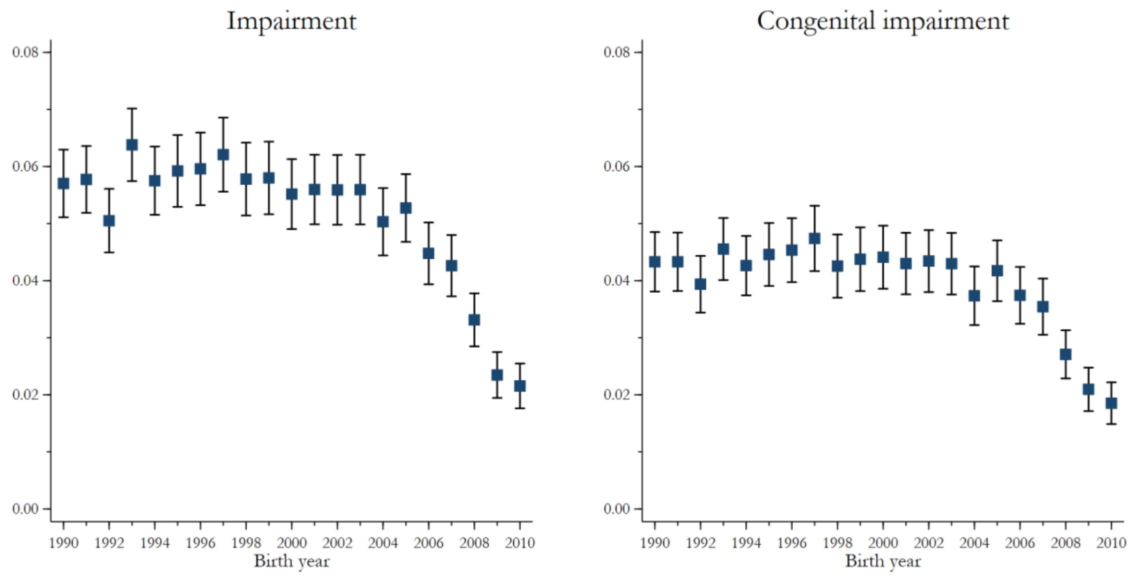
Appendix to “The Effect of Expanding a Neonatal Intensive Care System on Infant Mortality and Long-Term Health Impairments”

Figure A1 Impairment ratio by birth year in the Hungarian Census 2011, <1500g



Notes: Point estimates and their 95% CIs. Non-respondents (ca. 15-20%) are excluded.

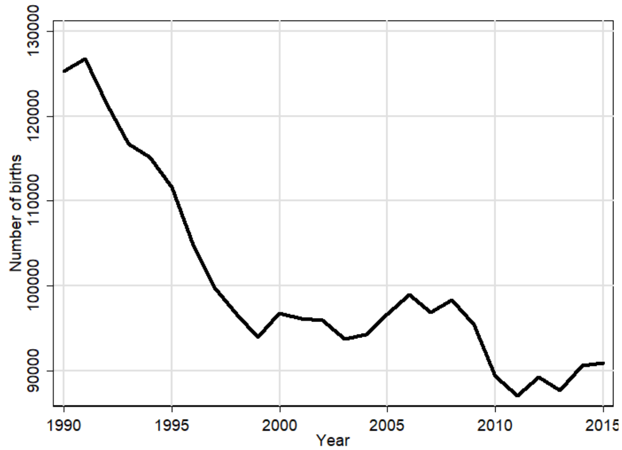
Figure A2 Impairment ratio by age in the Hungarian Census 2011, <2500g



Notes: Point estimates and their 95% CIs. Non-respondents (ca. 15-20%) are excluded.

Figure A3 Number of all births, LBW births (<2500g), and VLBW births (<1500g).

All births



Births <1500g and <2500g

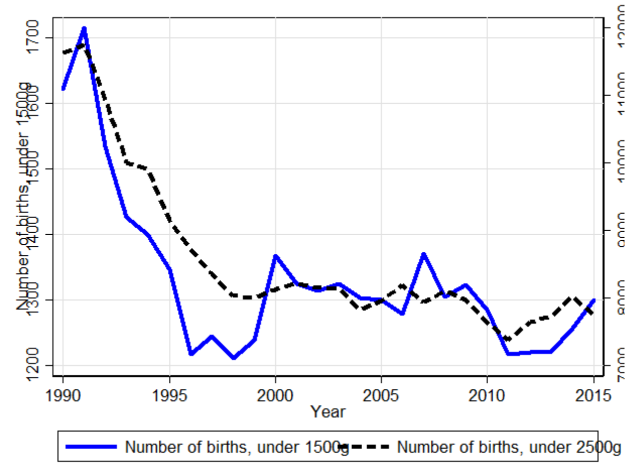
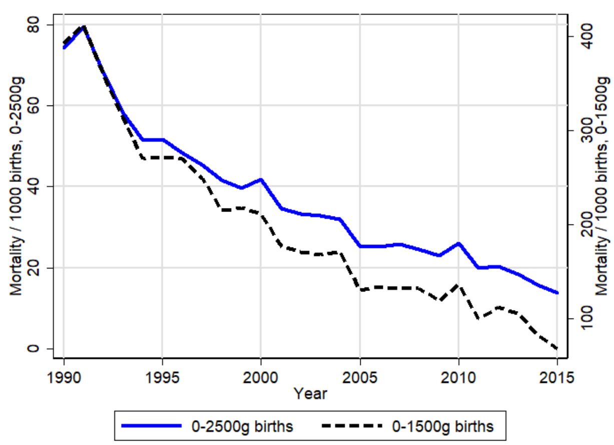


Figure A4 Mortality among LBW births (<2500g) and VLBW births (<1500g): within 0-6 days and within 0-364 days

0-6 day mortality



0-364 day mortality

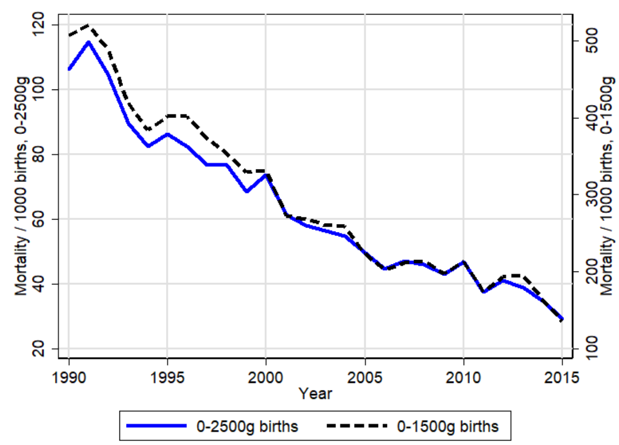


Figure A5 Snapshots of the geographic distribution of NICUs and hospitals connected to NICUs via NETS

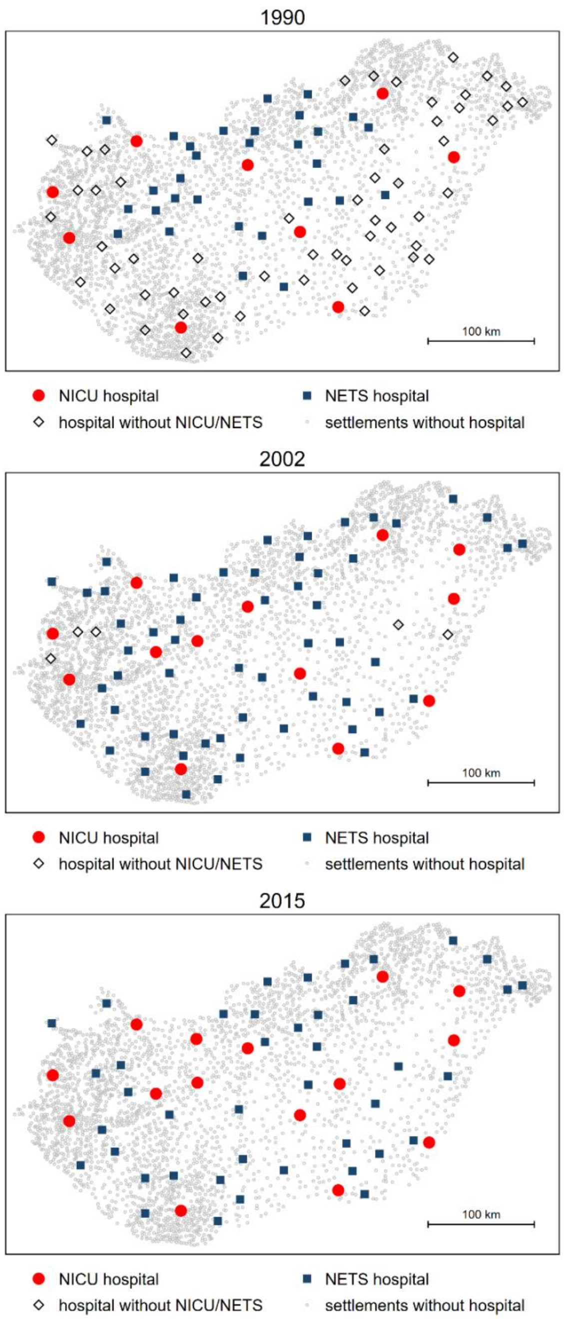


Figure A6 Time series of the number of municipalities by distance to the nearest NICU city.

(Number of NICU cities: left scale; Number of municipalities in distance categories: right scale)

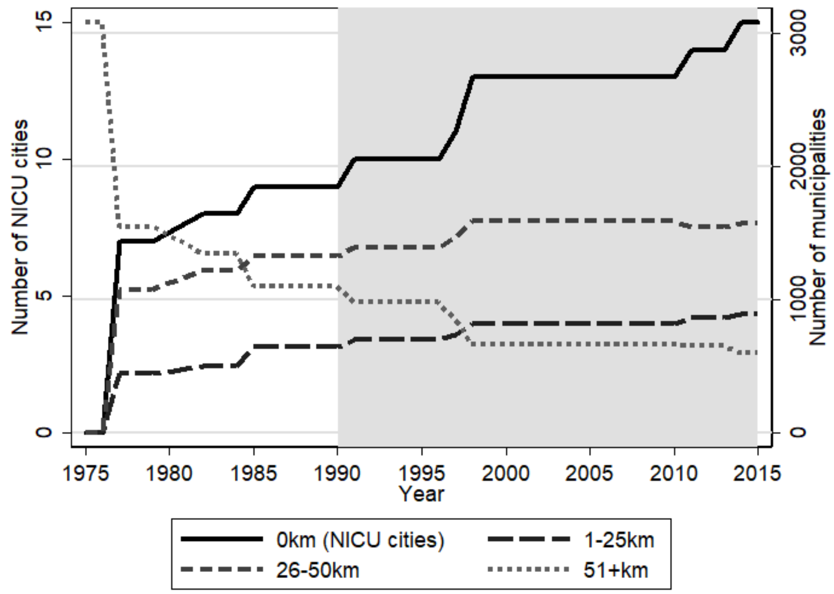


Figure A7 Time series of the number of municipalities by distance to the nearest NICU or NETS city.

(Number of NICU/NETS cities: left scale; Number of municipalities in distance categories: right scale)

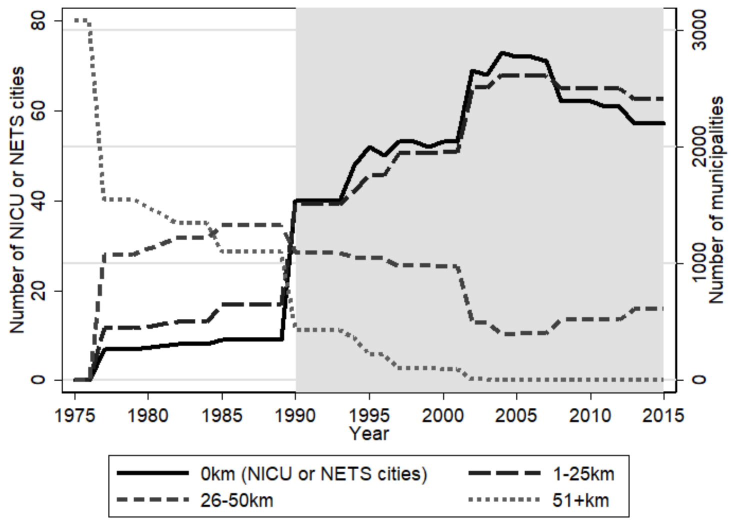
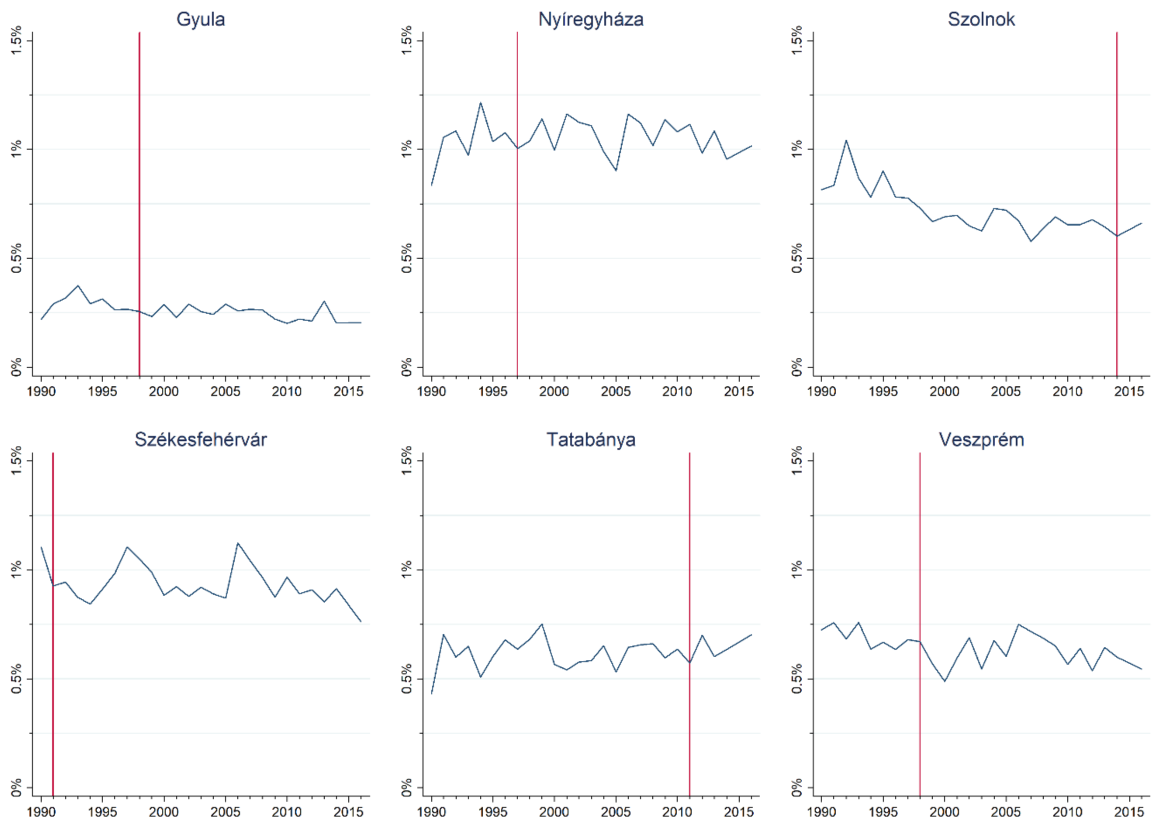


Figure A8. Proportion of women (age 20-34) moving into cities with a newly established NICU as the percentage of all change of residential location (women, age 20-34)



Notes: Vertical lines indicate the first full year of the newly established NICU. Source: Hungarian Central Statistical Office inter-municipality migration registry.

Table A.1 Rate of successful linkages

Linked data	Successful links, %	Notes
Live births to Infant mortality (cohorts of 1990-2015)		
<1500 g	99.8	as the % of infant deaths
1500g-2499 g	99.8	as the % of infant deaths
Live births to Census of 2011 (cohorts of 1990-2008)		
<1500 g	74.7	as the % of newborns are live at age 1
1500g-2499 g	79.9	as the % of newborns are live at age 1

Table A2. The coverage of NICUs in the United States (2008) and in Hungary (2015)

	Number of NICUs	Number of NICUs per 1000 live births		
		All births	LBW infants	VLBW infants
United States, 2008[(a)]	850	0.2	2.5	13.7
Hungary, 2015[(b)]	21	0.2	2.7	16.4

Source: (a) Holmstrom and Phibbs (2009), Martin et al. (2010) (b) Author calculations. National vital statistics from Hungary, 1990-2015, linked to the authors' survey on NICU and NETS establishments

Table A3. Descriptive statistics

	<1500 g			1500-2499 g			<2500 g		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Mortality: 0-6 days	34,213	0.203	0.402	188,611	0.009	0.097	223,319	0.040	0.195
Mortality: 0-364 days	34,213	0.303	0.459	188,611	0.023	0.150	223,319	0.066	0.249
Impairment	9,894	0.158	0.365	93,171	0.043	0.202	103,723	0.054	0.227
Impairment: present at birth	9,793	0.132	0.339	92,794	0.032	0.175	103,241	0.042	0.200
Born in NICU city (mortality sample)	34,213	0.792	0.406	188,611	0.605	0.489	223,319	0.634	0.482
Born in NETS city (mortality sample)	34,213	0.137	0.344	188,611	0.282	0.450	223,319	0.260	0.439
Distance from the closest NICU city (in 10km) (mortality sample)	34,213	2.776	2.358	188,611	2.935	2.373	223,319	2.913	2.371
Distance from the closest NETS city (in 10km) (mortality sample)	34,213	2.502	2.199	188,611	2.644	2.348	223,319	2.624	2.328
Born in NICU city (impairment sample)	9,894	0.809	0.393	93,171	0.576	0.494	103,723	0.599	0.490
Born in NETS city (impairment sample)	9,894	0.130	0.337	93,171	0.287	0.452	103,723	0.271	0.445
Distance from the closest NICU city (in 10km) (impairment sample)	9,894	2.758	2.325	93,171	3.067	2.397	103,723	3.042	2.390
Distance from the closest NETS city (in 10km) (impairment sample)	9,894	2.491	2.214	93,171	2.760	2.499	103,723	2.737	2.476
Twin birth	34,213	0.254	0.435	188,611	0.187	0.390	223,319	0.197	0.398
Boy	34,213	0.505	0.500	188,611	0.459	0.498	223,319	0.466	0.499
Married mother	34,213	0.593	0.491	188,611	0.592	0.491	223,319	0.593	0.491

Mother's education: less than primary	34,213	0.076	0.265	188,611	0.098	0.298	223,319	0.095	0.293
Mother's education: primary	34,213	0.325	0.468	188,611	0.349	0.477	223,319	0.346	0.476
Mother's education: vocational	34,213	0.187	0.390	188,611	0.185	0.388	223,319	0.185	0.389
Mother's education: secondary	34,213	0.252	0.434	188,611	0.228	0.419	223,319	0.231	0.422
Mother's education: college/university	34,213	0.145	0.352	188,611	0.133	0.340	223,319	0.135	0.342
Mother's education: missing	34,213	0.015	0.121	188,611	0.006	0.079	223,319	0.008	0.087
Father's education: less than primary	34,213	0.022	0.145	188,611	0.030	0.169	223,319	0.028	0.166
Father's education: primary	34,213	0.166	0.372	188,611	0.202	0.401	223,319	0.196	0.397
Father's education: vocational	34,213	0.240	0.427	188,611	0.264	0.441	223,319	0.260	0.439
Father's education: secondary	34,213	0.170	0.375	188,611	0.162	0.368	223,319	0.163	0.369
Father's education: college/university	34,213	0.111	0.314	188,611	0.107	0.309	223,319	0.108	0.310
Father's education: missing	34,213	0.292	0.455	188,611	0.236	0.425	223,319	0.245	0.430
Mother's labor force status: active	34,213	0.570	0.495	188,611	0.537	0.499	223,319	0.542	0.498
Mother's labor force status: maternity leave	34,213	0.120	0.325	188,611	0.134	0.340	223,319	0.131	0.338
Mother's labor force status: unemployed	34,213	0.077	0.267	188,611	0.075	0.263	223,319	0.075	0.264
Mother's labor force status: other	34,213	0.212	0.409	188,611	0.243	0.429	223,319	0.238	0.426
Mother's labor force status: missing	34,213	0.020	0.140	188,611	0.012	0.108	223,319	0.013	0.113
Father's labor force status: active	34,213	0.591	0.492	188,611	0.620	0.485	223,319	0.616	0.486
Father's labor force status: unemployed	34,213	0.063	0.242	188,611	0.078	0.268	223,319	0.075	0.264
Father's labor force status: other	34,213	0.049	0.215	188,611	0.060	0.238	223,319	0.058	0.234
Father's labor force status: missing	34,213	0.298	0.457	188,611	0.242	0.428	223,319	0.251	0.433

Mother's age: x-19	34,213	0.086	0.281	188,611	0.122	0.327	223,319	0.116	0.320
Mother's age: 20-24	34,213	0.195	0.396	188,611	0.242	0.428	223,319	0.234	0.424
Mother's age: 25-29	34,213	0.266	0.442	188,611	0.265	0.441	223,319	0.265	0.441
Mother's age: 30-34	34,213	0.255	0.436	188,611	0.223	0.416	223,319	0.228	0.420
Mother's age: 35-39	34,213	0.157	0.363	188,611	0.120	0.326	223,319	0.126	0.332
Mother's age: 40-x	34,213	0.041	0.197	188,611	0.028	0.166	223,319	0.030	0.172
Father's age: x-19	34,213	0.009	0.093	188,611	0.016	0.124	223,319	0.015	0.120
Father's age: 20-24	34,213	0.077	0.266	188,611	0.111	0.314	223,319	0.106	0.308
Father's age: 25-29	34,213	0.173	0.379	188,611	0.203	0.402	223,319	0.198	0.399
Father's age: 30-34	34,213	0.207	0.405	188,611	0.209	0.406	223,319	0.209	0.406
Father's age: 35-39	34,213	0.151	0.358	188,611	0.140	0.347	223,319	0.142	0.349
Father's age: 40-x	34,213	0.106	0.307	188,611	0.092	0.289	223,319	0.094	0.292
Father's age: missing	34,213	0.278	0.448	188,611	0.230	0.421	223,319	0.237	0.425
N of previous live births: 0	34,213	0.376	0.484	188,611	0.406	0.491	223,319	0.402	0.490
N of previous live births: 1	34,213	0.279	0.449	188,611	0.273	0.445	223,319	0.274	0.446
N of previous live births: 2	34,213	0.163	0.369	188,611	0.156	0.363	223,319	0.157	0.364
N of previous live births: 3	34,213	0.085	0.279	188,611	0.078	0.268	223,319	0.079	0.269
N of previous live births: 4+	34,213	0.098	0.297	188,611	0.087	0.282	223,319	0.089	0.284
N of abortions: 0	34,213	0.763	0.425	188,611	0.811	0.391	223,319	0.804	0.397
N of abortions: 1	34,213	0.142	0.349	188,611	0.127	0.333	223,319	0.129	0.335
N of abortions: 2	34,213	0.057	0.232	188,611	0.040	0.196	223,319	0.043	0.202
N of abortions: 3+	34,213	0.038	0.191	188,611	0.022	0.147	223,319	0.025	0.155
N of abortions: missing	34,213	0.000	0.000	188,611	0.000	0.000	223,319	0.000	0.000
N of miscarriages: 0	34,213	0.761	0.427	188,611	0.821	0.383	223,319	0.812	0.391
N of miscarriages: 1	34,213	0.150	0.357	188,611	0.122	0.327	223,319	0.126	0.332
N of miscarriages: 2	34,213	0.056	0.229	188,611	0.038	0.191	223,319	0.041	0.197
N of miscarriages: 3+	34,213	0.034	0.181	188,611	0.019	0.137	223,319	0.021	0.145
N of miscarriages: missing	34,213	0.000	0.005	188,611	0.000	0.000	223,319	0.000	0.002
Birth year	34,213	2002.075	7.621	188,611	2001.587	7.697	223,319	2001.662	7.687

Birth month	34,213	6.565	3.410	188,611	6.560	3.431	223,319	6.561	3.428

Table A4: First-stage results of the 2SLS regressions for the effect of being born in a city with a NICU or in a city connected to NETS on 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

Table A5: Reduced-form estimates of the 2SLS regressions for the effect of being born in a city with a NICU or in a city connected to NETS on mortality

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Distance to NICU (10km)	0.015	0.001	0.002	0.016	0.002	0.003
	(0.004)	(0.000)	(0.001)	(0.004)	(0.001)	(0.001)
Distance to NETS (10km)	0.003	0.001	0.001	0.002	0.001	0.000
	(0.002)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
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

Table A7: First-stage results for the 2SLS regressions for the effect of being born in a city with a NICU or in a city connected to NETS on 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

Table A8: Reduced-form results for the 2SLS regressions for the effect of being born in a city with a NICU or in a city connected to NETS on impairment

	Impairment: any			Impairment: present at birth		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Distance to NICU (10km)	-0.004	-0.000	-0.001	-0.000	-0.001	-0.001
	(0.006)	(0.001)	(0.001)	(0.006)	(0.001)	(0.001)
Distance to NETS (10km)	0.001	0.000	0.001	0.000	-0.000	0.000
	(0.003)	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)
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

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

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

	Impairment: any			Impairment: present 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

Table A11: 2SLS estimates for the effect of being born in a city with a NICU or in a city connected to 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

Table A13: 2SLS estimates for the effect of being born in a city with a NICU or in a city connected to NETS on mortality.

Municipality of residence linear trends included

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a city with NICU	-0.121	-0.003	-0.015	-0.158	-0.006	-0.021
	(0.054)	(0.004)	(0.008)	(0.063)	(0.006)	(0.010)
Born in a city with NETS	-0.015	-0.007	-0.010	0.011	-0.005	-0.007
	(0.066)	(0.003)	(0.007)	(0.075)	(0.005)	(0.009)
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	81.35
IV F-stat NETS	65.17	230.6	221	65.17	230.6	221
Number of municipalities	2029	2929	2964	2029	2929	2964
Number of observations	34,213	188,611	223,319	34,213	188,611	223,319

Table A14: Reduced-form estimates for the effect of the distance of the mother's residence to the closest city with a NICU or to the closest city connected to 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

Table A15: 2SLS estimates for the effect of being born in a city with a NICU or in a city connected to NETS on mortality.

Only cities with single hospitals (sample with mother's residence within 50km to such cities).

	Mortality 0-6 days			Mortality 0-364 days		
	<1500g	1500-2499g	<2500g	<1500g	1500-2499g	<2500g
Born in a city with NICU	-0.177	-0.010	-0.026	-0.150	-0.021	-0.031
	(0.041)	(0.003)	(0.007)	(0.049)	(0.005)	(0.009)
Born in a city with NETS	-0.074	-0.005	-0.011	-0.014	-0.009	-0.009
	(0.036)	(0.002)	(0.005)	(0.037)	(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	79.02	51.63	56.22	79.02	51.63	56.22
IV F-stat NETS	103.3	353.8	325.8	103.3	353.8	325.8
Number of municipalities	1327	2496	2530	1327	2496	2530
Number of observations	13,012	99,665	113,210	13,012	99,665	113,210

Table A16: 2SLS estimates for the effect of being born in a city with a NICU or in a city connected to NETS on mortality.

	Mortality 0-6 days			Mortality 0-364 days		
	0-31 weeks of gestation	32-36 weeks of gestation	0-36 weeks of gestation	0-31 weeks of gestation	32-36 weeks of gestation	0-36 weeks of gestation
Born in a city with NICU	-0.123	-0.007	-0.026	-0.121	-0.012	-0.032
	(0.035)	(0.004)	(0.008)	(0.043)	(0.005)	(0.009)
Born in a city with NETS	-0.034	-0.008	-0.007	0.003	-0.009	-0.003
	(0.037)	(0.003)	(0.006)	(0.039)	(0.004)	(0.007)
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	76.52	46.81	53.25	76.52	46.81	53.25
IV F-stat NETS	107.8	169	175.1	107.8	169	175.1
Number of municipalities	2080	2899	2942	2080	2899	2942
Number of observations	35,753	180,503	216,694	35,753	180,503	216,694

Table A17: 2SLS estimates for the effect of being born in a city with a NICU or in a city connected to NETS on impairment.

	Impairment: any			Impairment: present at birth		
	0-31 weeks of gestation	32-36 weeks of gestation	0-36 weeks of gestation	0-31 weeks of gestation	32-36 weeks of gestation	0-36 weeks of gestation
Born in a city with NICU	0.002	-0.004	-0.000	-0.004	0.005	0.006
	(0.045)	(0.010)	(0.008)	(0.045)	(0.008)	(0.006)
Born in a city with NETS	-0.047	-0.000	-0.005	-0.030	0.002	-0.002
	(0.054)	(0.006)	(0.007)	(0.055)	(0.005)	(0.006)
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	67.51	38.11	43.97	67.42	38.21	43.98
IV F-stat NETS	51.22	157.5	162	50.39	157.4	161.8
Number of municipalities	1255	2692	2744	1250	2691	2742
Number of observations	11,091	89,646	101,377	10,983	89,316	100,936