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Is High-Tech Care in a Middle Income Country Worth It? Evidence from Perinatal Centers in Russia

By Dzhamilya Nigmatulina[†], Charles Becker[‡]

How much does a dramatic increase in technology improve healthcare quality in an upper-middle income country? Using rich vital statistics on infant health outcomes, this study evaluates the effect of introducing technologically advanced perinatal hospitals in 24 regions of Russia on infant mortality during the period 2009-2013. A 7-year aggregate panel dataset reveals that opening a perinatal center corresponds to infant mortality reduction by 3.8 percent from the baseline rate, neonatal (0-28 day) mortality by 7 percent and early neonatal (0-6 day) mortality by 7.3 percent. We find that the perinatal centers help to save 263 additional infant lives annually, ranging from 3 to 25 lives in regions with different birth rates. However, we further find that an average cost per life saved is 52 mln rb (or 2.6 m 2014 PPP USD), which is much higher than the cost of similar interventions in the US.
JEL: I120, I180
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At the beginning of *perestroika*, the Soviet government revealed that infant mortality in the USSR was 3 to 5 times higher than in most countries in Western Europe. Today the gap has narrowed, yet Russian infant mortality (8.7 per 1000 births in 2012) remains higher than in Hungary, Czech Republic and Latvia. A stricter definition of a live birth than the EU countries prior to 2012 aggravates this situation and results in many fewer infant deaths recorded in Russian official statistics.[1]

Poor international rankings together with shrinking population have motivated the Russian government to increase its investment in improving demographic indicators. In December 2007 some 19 billion rb (or 471 million 2014 USD) (Ministry of Healthcare of the Russian Federation, 2008) were invested from federal funds into building one perinatal

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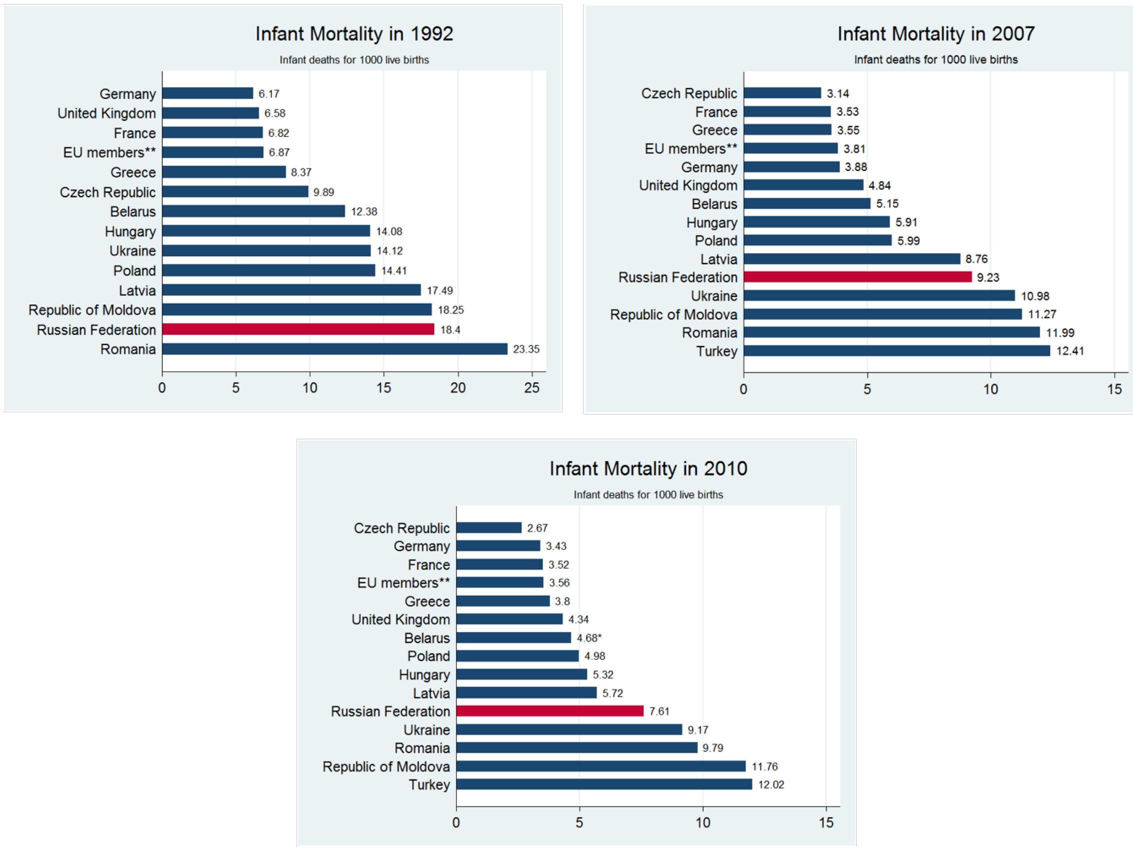
[1] Russia and previously the USSR imposed a restriction on weight and gestational period for regarding a birth as live-born, which meant eliminating the most risky cases from the statistics; many other countries have never imposed restrictions and consequently have had higher reported infant mortality rates.

Figure 1. European Rankings of Infant Mortality



Note: Infant mortality in Russia is one of the highest in Europe, even in comparison to the other transition economies. Its rank has not improved significantly over the years.
∗ Belarus value is from 2009. ∗∗ The member states that were part of the European Union by 2004.
Source: World Health Organization Europe.

center in each of 23 (out of 83) Russian regions as part of the National Health Project; one more center was built in Omsk region (oblast) in the same period solely funded by the local budget.[2] Each centrally-funded hospital required a contribution of 10-50 percent from the local government (Minister of Healthcare Veronika Skvortsova, quoted in *Rossiiskaya Gazeta* on May 5th, 2013). Most centers opened in late 2010 and late 2011. They were placed in oblast capitals and the citizens of the region were entitled to free services if a mother had sufficient risk of a complicated delivery.

These state-of-the-art hospitals were intended to provide intensive care for births with

[2]The centers co-financed by the federal funds were Blagoveshchensk, Volgograd, Voronezh, Irkutsk, Kemerovo, Kaliningrad, Kirov, Krasnodar, Krasnoyarsk, Kurgan, Kursk, Perm, Rostov-on-Don, Ryazan, Saratov, Saransk, Tver, Tomsk, Chita, Yaroslavl, Murmansk, Sverdlovsk and Saint-Petersburg.

complications, premature births, and other conditions for which a standard hospital or maternity unit did not have the requisite facilities. Most importantly, each of the perinatal centers was equipped with a Neonatal Intensive Care Unit (NICU) with high-tech machinery for resuscitating prematurely born infants. The mechanism of mortality reduction works via re-routing of potentially risky deliveries from regional maternity hospitals to these centers (Sukhanova, 2012), thereby increasing the probability that an infant under risk gains access to advanced infrastructure, and specifically to NICU.

The investment was carried out without rigorous economic evaluation of its potential returns. How much did health improve from the perinatal centers alone and was it worth it? We attempt to answer this question in our study. Since the survival of at-risk infants in the very early ages is most dependent on availability of equipment (Cutler and Meara (2000)), we expect to find a reduction in infant mortality overall and especially in neonatal mortality (age 0-28 days) and early neonatal mortality (age 0-6 days). Indeed, we find that the highest proportional reduction in mortality was for the 0-6 day category (7.3 percent from the baseline), less for 0-28 day category (7 percent from the baseline rate) and that there was almost no effect on deaths at 28-365 days.

In December 2013, Russian Ministry of Health initiated a program to build 32 additional perinatal centers in 30 Russian regions at the cost of 53 billion rb (1.277 billion 2014 USD) to the federal budget (Ministry of Healthcare of the Russian Federation, 2013).[3] As before, no sufficient comparative analysis was conducted as to the effectiveness of this vast expenditure on health outcomes. Moreover, it is overwhelmingly likely that other large health infrastructure projects are also under contemplation, in Russia and elsewhere, with little reliance on serious effectiveness assessments. Our study provides both a template of how to analyze these investments and an estimate of what to expect from them.

The relevance of our study is not limited to the economic evaluation of this single policy. While technology-intensive investments such as NICU's have been shown to be life-saving, the cost of each life saved is a matter of hot debate (Cutler and Meara, 2000; Almond et al., 2010; Almond and Doyle Jr, 2011; Cutler et al., 1998). Moreover, although there is a large body of literature estimating the returns to technology-intensive spending in first-world countries, like the US, and returns to basic investments in developing countries, like Tanzania, the evidence regarding any health interventions in middle-income countries is quite scarce. Further, by focusing on a middle income country, we benefit from evaluating the setting where the entire population has access to basic elements of care, but often limited access to advanced care: in high income countries near universally good health outcomes make it difficult to identify the effect of technology investments, whereas in low income countries it is hard to separate the effects of healthcare access expansion and technology itself.

[3] The selected cities (all regional capitals) are Arkhangelsk, Belgorod, Bryansk, Kaluga, Lipetsk, Nizhny Novgorod, Orenburg, Penza, Pskov, Samara, Sakhalin, Smolensk, Tambov, Ulyanovsk, Chelyabinsk, Stavropol, Krasnodar, Barnaul (Altaiskiy kray), Ulan-Ude (Republic of Buryatia), Ufa (Bashkortostan), Makhachkala (Dagestan), Magas (Ingushetia), Nalchik (Kabardino-Balkaria), Petrozavodsk (Republic of Karelia), Yakutsk (Republic of Sakha-Yakutia), Abakan (Republic of Khakassia), Moscow, 2 centers in Krasnoyarsk, 1 center in Leningradskaya oblast' and 2 centers in Moscovskaya oblast'.

On the one hand, we may expect to find higher returns than in the US, as there is less medical infrastructure at baseline. On the other hand, bottlenecks, such as a low supply of doctors, or poor healthcare organization and infrastructure may impede the realization of the technology in full.

We believe that our choice of data and sample can give an important and informative estimate of the returns to costly medical advances in a middle-income country. First, low birth weight infant care is expensive. Cutler and Meara (2000) quote a cost as high as $3,500 per infant per day in a NICU in the US; ultimately, this can sum to as much as $1 million for a prolonged stay. Second, in middle-income countries newborns' outcomes reflect both the state of and changes to the healthcare system and span all income and education groups of the population, as births outside of hospitals comprise only 0.16 percent in Russia today (2013). Third, for extremely low and low birth weight outcomes the probability of survival almost fully depends on the availability of technology (Paneth, 1995; Williams and Chen, 1982; Muraskas and Parsi, 2008), whereas for other outcome variables such as tuberculosis rates or occurrence and mortality from cardiovascular diseases, it difficult to distinguish the relative roles of income, lifestyle, and doctor's qualifications.

Finally, the introduction of perinatal centers with NICU's across so many locations and in such a short time is unprecedented. The perinatal centers opened within a sufficiently short period (1-4 years) that many other aspects such as the composition of the population, organization of care, and number of at-risk infants born annually could not have changed much. Thus, our data allow us to estimate the marginal returns to the change in medical technology (rather than the average return over a long period of time). The remaining, more sensitive, factors include a possible increase in the number of doctors, and a 'substitution effect' whereby the new centers could have detracted resources from other facilities in the region. We explore these concerns by measuring the impact of closures of basic obstetrics hospitals and maternity units. We further account for potential increases in the number of neonatologists in the treated regions and attempt to estimate the heterogeneity of outcomes from different supply thereof. We also face and address a second methodological challenge, when some treatment coincided with a change in birth accounting in 2012. Although as the change was country-wide, the response to the change could have been different depending on whether the region was treated or not. By using data birth by birthweights and the proportion of 'late abortions', we check whether the response to the accounting policy was significantly different in the treated regions vs. untreated and confirm that this was not the case.

The paper is organized as follows. Section I provides background on the policy and the relevance of the study, Section II reviews prior literature on returns to healthcare investment, Section III briefly outlines the mechanism of reducing mortality, Section IV describes the variables, Section V outlines the empirical model and validity checks, Section VI presents the lifesaving effect of the perinatal centers and evaluates it against their costs of construction and maintenance, and Section VII concludes.

I. Background

A. Perinatal Care in Russia

Every Russian woman in childbirth is entitled to free care during delivery regardless of the type of hospital, be it high or basic, at which she presents herself. She will be referred for delivery in a perinatal center if she is designated as at risk for a complicated delivery. Perinatal centers on average hosted 22.9 percent of all births in the country in 2012 (Starodubov and Sukhanova, 2013). A perinatal center mainly differs from other obstetrics facilities by being equipped with an NICU and providing the latest available technologically intensive care for infants. Even before the expansionary policy was enacted, perinatal centers targeting complicated deliveries existed in 54 regions, but they generally were not as technologically advanced as the new ones (we later test whether the presence of a perinatal center in the region yields a different result than if the high-tech facility is introduced for the first time).

B. Mortality Statistics in Russia

Until 2012, Russia had higher gestation time and birth weight thresholds for reporting live and stillbirths than in most European countries. Such rules not only meant reporting lower infant deaths than under conventional WHO definitions, but it also made it fairly easy to recategorize some marginal delivery cases into groups that were less significant for national statistics (stillbirths) or not accounted at all by official statistics ('late abortion' or 'miscarriage').

In 2012 the official threshold for registering a birth as a 'live birth' was moved from the 1000g minimum weight and 28 weeks minimum gestation down to 500g and 22 weeks, respectively. Naturally, these changes caused the reported mortality to rise (as shown in Appendix Figure A1). As for misreporting (due to category transfers), it is likely to have shrunk, but potentially remained an important concern just around the new threshold: marginal births at 22-23 weeks of pregnancy (or births of live infants weighing 500-700g). Details of definitional changes and likely impacts on recorded values are provided in the Online Appendix. Another type of undercounting may have become widespread in the meantime: at any weight or gestational age fragile infants who die very soon after birth often may be characterized as stillbirths, since stillbirths is a statistic less scrutinized by domestic and international public health officials.

Undercounting is only a threat to validity in our difference in difference design if the degree of undercounting changes after treatment. We thus focus on dynamics of undercounting in each region to ensure it does not affect the validity of our results. The concern may arise if, for example, obstetricians in the treated region are directed to misreport infant deaths in order to show improvements attributed to the perinatal center. By using the internal Ministry of Healthcare records of countrywide births by weight, in the Online Appendix we investigate whether bunching of birth records at the unaccounted categories, or categories just above the relevant threshold (1000g prior to 2012 and 500g post 2012) have shrunk. We rule this concern out by showing that there is no relative change in bunching (or shrinking) after treatment.

II. Prior Literature

Interventions that save infant lives can vary greatly in their costs and their effectiveness, depending on the baseline level of health and the intensity of the investments. The literature to date concentrates primarily on costly high-tech interventions in the US and low-cost interventions in developing and middle-income countries (or historical data for developed countries).[4]

The low-cost interventions included training traditional birth attendants to refer riskier patients to hospitals and performing basic tasks in Tanzania (Gill et al., 2011), training male nurses in India (Bang et al., 1999), improved sanitation of water facilities for Native American populations (Watson, 2006), and a Danish home-visiting program in the late 1930's (Wüst, 2012), all of which were shown to reduce infant mortality on the order of 40-65 percent. Some low-cost interventions also have been implemented in middle-income countries; analyses find moderate to high reductions in mortality, and high cost effectiveness of these reductions. Nizalova and Vyshnya (2010) estimate how the 'Mother and Infant' program in Ukraine, which involved training the obstetrics personnel and changes in practices, has reduced infant mortality rate by 3.13 deaths per 1000 births (23 percent from the baseline rate). Galiani, Gertler and Schargrodsky (2005) argue that cleaner water from privatization of water facilities saved infant lives in Argentina. New investments and expansion of services led to improved sanitation and reduced first-month mortality by 8 percent compared to the baseline mortality rate in 1990. All these interventions are likely to save lives of healthy infants who have normal birth weights and are not born pre-term (for example, water sanitation only eliminates deaths from parasitic diseases caught by otherwise healthy infants). These interventions would likely be unimportant for the prematurely born, because low birth weight infants are likely to die in the first day or week without the availability of an NICU. Thus, the target group examined here is not covered, to our knowledge, in any of the previous literature on middle-income and developing countries.

High-tech intervention studies are concentrated in the US and are related to the analysis of the returns to healthcare spending. The US literature shows two common findings. Cross-sectional studies of American regions tend to indicate small or no effects of the incremental spending in technology (Baicker and Chandra, 2004; Grumbach, 2002; Almond and Doyle Jr, 2011; Goodman et al., 2002; Finkelstein and McKnight, 2008), or at most moderate evidence from (Fisher et al., 2003; Almond et al., 2010; Doyle, 2011), whereas studies concentrating over large time periods demonstrate large benefits to technologically intensive and costly interventions (Cutler and Meara, 2000; Cutler and McClellan, 2001; Schwarcz et al., 2000; Luce et al., 2006).

[4] Mangham-Jefferies et al. (2014) provides a comprehensive review of studies on delivery care interventions in developing countries.

Cutler and McClellan (2001) consider both treatment expansion and treatment substitution when they evaluate returns to new technologies used to treat heart attacks, low birth weight infants, depression, cataracts and breast cancer diagnosis. They demonstrate a very large positive return to catheterization and to technologies introduced in the 1990's to treat LBW infants, while breast cancer screening had an indeterminate effect. Cutler, Rosen and Vijan (2006) show that the cost of year of life saved has increased from $7,400 to $36,600 during the period 1960-2000, which still yields a positive return, as the commonly cited social value for a statistical year of life gained is $100,000 (Viscusi, 1993). The authors emphasize that the return to healthcare spending remains positive for all age groups, except for the elderly, for whom the costs for a year of life gained is $145,000, indicating possible 'overspending' in US healthcare in this area. Cutler and Meara (2000) demonstrate considerable cost effectiveness of the investment in LBW infant health by considering both the length and the quality of life.

In our study we compare the cost effectiveness of an expensive intervention to both low-cost interventions in middle-income countries and expensive interventions in the US. We add to the literature by analyzing a setting in which on the one hand high-tech care is likely to be underutilized, unlike in the US, but on the other hand there are institutional barriers and bottlenecks in other healthcare inputs, resulting on uncertain marginal returns compared to the US. Moreover, while most studies on middle-income and developing countries focus on low-cost care and its returns, and we try to verify whether an advanced, high-cost intervention will demonstrate superior or inferior health outcomes and at what price.

III. Economic Mechanism

The opening of the perinatal center primarily changes 'technology', which is an input into each region's health production function. Other inputs such as regular obstetricians and number and condition of patients are likely to be stable in the several years' time before and after the opening (we are able to confirm this assertion for obstetricians, neonatologists and midwives later on). On the one hand, we anticipate that Russia had been on the steep portion of its production function curve, and to some extent technology was underutilized and outdated; thus, adding complex technology could improve health outcomes positively and to a larger extent than in richer countries. At the same time, this positive effect may be counteracted by institutional barriers and insufficient numbers of qualified doctors able to work at the center, so that the cost of a year of life saved actually could be higher than in the US.

The mechanism on a micro level will work through a higher probability of admission to a NICU of infants who can benefit most from such treatment. For example, a prematurely born infant who has a collapsed lung will only be able to survive if given an artificial ventilation in a NICU. We regard a NICU treatment as a summary measure for procedures, such as artificial ventilation, diagnostic ultrasound audiological screening, and operations on the heart. Thus, once a perinatal center is open, the probability of an at-risk infant (early term birth and/or low birth weight) of accessing a NICU increases. We expect early mortality level (0-6 days, 0-28 days and perinatal losses) to decrease more than mortality in the other categories, as the group of infants who usually die in the first week survives only through admission into a NICU.

Conversely, the occurrence of deaths in older ages (one month and more) is not expected to change with the presence of NICU, since older infants usually are not admitted there. Thus, such a variable can be used as a placebo test. We expect that infant mortality will decrease overall in a treatment region because the highest risk group will be selected into the NICU and will survive. However, only a decrease in overall (total) infant mortality will show the true effectiveness of the technology, as the survival of the at-risk group on average would exceed one year (as opposed to improved neonatal survival at the expense of increased post-neonatal mortality).

IV. Variables

We run regressions with six categories of mortality rates as outcome variables for our first specification: infant, neonatal, early neonatal and post neonatal mortality, perinatal losses, and stillbirths. Our data are region-level and constitute a 7-year panel (2007-2013) of all (83) Russian oblasts. Births are coded by the address of parents in most cases, whereas deaths are more likely to be reported at the hospital address, so if any mothers choose to go to perinatal centers outside their regions of residence, this may lead to a downward bias through also improving the recorded outcomes in the control groups. However, traveling to the regional capitals with perinatal centers is costly (most regional capitals are located at the center of the region), and there are institutional barriers to giving birth outside one's home city or region.[5] According to the expert opinion of the Chief Neonatologist of Russia, D. N. Degtyarev, although legal, it is administrationally costly for a doctor in one region to direct a patient to a hospital in another, which is why doctors are unwilling to identify sufficient medical conditions for redirecting.[6] So, even if it were true that some mothers give birth outside the region they reside, the number of such mothers is likely to be small. In order be sure, we test whether the birth counts change in the region itself and the neighboring regions after the opening of the perinatal center and add an interaction term for centers close to borders.

We also use additional variables, such as infants born extremely prematurely (22-27 weeks) for 2010 and 2011 and shares of births by weight for years 2010-2012 (published in the Ministry of Health Statistics *Rodovspomozhenie*). As is discussed earlier, these detailed characteristics prove useful in eliminating suspicions as to the possibility of greater undercounting in treated regions.

We collect the first set of outcome variables for 2007-2013 for each oblast from the Central Research Institute for Organization and Informatization of Healthcare, by reaching out to the institute and requesting the access to restricted data. Control variables related to healthcare directly, such as obstetrics beds provision, the number of Ob Gyn doctors

[5] Exceptions are Tomsk, Tyumen, Cheboksary, Ryazan and Gorno-Altaisk

[6] Dmitry Nikolaevich Degtyarev, e-mail message to the author (Nigmatulina), June 19, 2014

per woman, and the percent of normal births, are collected from *Rodovspomozhenie*. Local economic and transportation variables, such as income per capita (2007-2014), urban and rural population are collected from Rosstat's publication *Regioni Rossii*[7]. To our knowledge, few if any other upper middle income countries have comparable publicly available data.

All variables are summarized by treatment group in Appendix Tables A2-A3 and for the overall sample across all years in Appendix Table A1. There are no significant differences in most variables across two groups of interest: treated and to-be-treated. A few exceptions include treated group being more urbanised, and its income per capita being slightly lower, both of which we control for.

V. Methodology

A. Baseline Model

We use a difference in difference (DD) model to estimate the effect of introducing the perinatal centers. The 7-year panel of 83 regions allows us to measure the Average Treatment Effect (ATE); that is by how much mortality changes on average if the perinatal center is introduced in any of the regions. Accounting for fixed differences between the treatment and control groups (with oblast dummies) and capturing the unobserved factors that cause changes in the health outcome even in the absence of a policy change (with time variant controls and year dummies), we thus measure ATE with a DD approach. The coefficient of interest multiplies the binary variable that is equal to one whenever a center is open in that year and that region.

We account for each oblast's time invariant (at least for 7 years) characteristics, such as baseline wealth, population, geography, ecology and transportation network and the level of healthcare quality, which can affect the underlying level of mortality in each region. By adding a full set of region dummies we remove the above characteristics, including all fixed selection criteria for treatment, such as presence of the medical university and minimum population requirement for the regional capital.[8] We account for possible serial correlation in the error term by clustering at the oblast level(Bertrand, Duflo and Mullainathan, 2004). This reduces the significance of our coefficients in a preferred specification from 0.05 percent to 0.1 percent, indicating that errors are indeed likely to be positively correlated within

[7]Chechen Republic reported missing income per capita in 2007-2009, the three values were replaced by the value in 2010. All regression results are robust to exclusion of the region from the sample

[8]According to the unpublished presentation by E. N. Baybarina (currently a department head in the Russian Ministry of Health) an oblast is to be selected based on following criteria. If the center is to be built from scratch: 1) shortage of neonatal emergency beds (less than 2 in a 200-300 km radius); 2) existence of a higher medical institution with a Pediatric Department, and 3) readiness of the region to co-finance. If the center is being renovated, selection was awarded to hospitals in which 1) the neonatal emergency room was designed to contain no less than 9 -12 beds 2) the center was planned for being built in cities with no less than 300 000 people 3) there exists a shortage of a neonatal emergency beds, and specifically less than 2 per 1000 births in the radius 200-300 km, and 4) existence of a university-level medical school (Dmitry Nikolayevich Degtyarev, Chief Neonatologist of Russia, email message to author, April 16, 2014). Moreover, D. M. Degtyarev, who also is a member of the selection committee for the regions with the perinatal center, has pointed out in the email that political factors also played a role in the selection.

oblasts.

We should also be aware of that by using a DD estimator with aggregate data we ignore the true sampling variability of mortality in the control oblasts, so the estimated variance could still be too small (Besley and Case, 2000). This problem can only be solved with more detailed data, which we lack at this point. Our primary regression is as follows:

$$M_{r,t} = \beta_0 + \beta_1 P_{r,t} + \beta_2 Z_{rt} + \lambda_t + \gamma_r + \varepsilon_{r,t} \tag{1}$$

Infant mortality $M_{r,t}$ at time t in region r is affected by the presence of one of the 24 perinatal centers, P_{rt}. If the center opens in the beginning of the year, the binary variable takes the value 1 starting from that year; if the center opens in the end of the year, which is usually the case, the value of 1 is only assigned starting the following year, so the treatment is correctly aligned with mortality calculated at the end of each year. In this way, one center opened in 2009 (in Omsk), three centers became effective in 2010, 11 centers started in 2011 and another nine opened in early 2012. λ_t and γ_r are time and oblast dummy variables. Z_{rt} includes the set of additional region-year factors, such as non-infrastructure healthcare spending in a region, a measure of regional prosperity (income per capita) and a measure of social distress (recorded cases of alcoholism per capita). Our original list of controls was longer and included other measures of social distress such as proportion of the population below the poverty line and alcohol purchases per capita. We instead chose income per capita as it is more informative about the overall wealth in the region, and used alcoholism occurrence, as alcohol purchases positively correlated with wealth and thus made a poor control for social distress.[9]

Importantly, we should be wary of using variables that are affected by treatment (Wooldridge, 2010, p.910). These include the number of hospital beds and number of neonatologists, because we are unable to condition on these variables being constant and have an unbiased estimator of the effect of treatment. We explore an alternative way of isolating these possible co-moving inputs into healthcare production function in Section VI.B.

Appendix Table A5 demonstrates how our coefficient of interest changes when we sequentially add various fixed effects and controls. We further find that the coefficient β_1 on the key outcome variable, 0-6 day mortality, is robust to the inclusion of the oblast-specific linear time trend. However, our preferred specification excludes a time trend, since otherwise we are left with too few degrees of freedom to have power to estimate the effect on other outcome variables. Finally, the intercept measure, β_0, signifies the mean of the fixed effects.

The policy variable is restricted to have the same effect every year (Wooldridge, 2010, p. 151). We also run a sequential model (Equation 2), in which we use a set of indicators,

[9]The regression with the alternative controls of social distress is included in the Table A4 of the appendix, in which the coefficients and significance remain almost the same.

d_i, of one, two and up to five years after opening.

$$M_{r,t} = \beta_0 + \sum_{i=1}^{5} \beta_{1,i} * d_i * Treated_{r,t} + \beta_2 Z_{rt} + \lambda_t + \gamma_r + \psi_t + \varepsilon_{r,t} \tag{2}$$

The DD estimator in Equations (1) and (2) is valid and we can estimate the ATE, if the mean changes in the no-program outcome measures are the same for participants and nonparticipants (Heckman, LaLonde and Smith, 1999):

$$E(Y_{0t} - Y_{0t'}|D = 1) = E(Y_{0t} - Y_{0t'}|D = 0) \tag{3}$$

If present, bias could be caused by a non-random selection of the treatment and control groups leading to the differential trends in the absence of treatment. We address this issue with the methods discussed below.

B. Test for Pre-Existing Trends and for Other Policies

If the regions receiving hospitals are developing more rapidly at the time of treatment, they would have a steeper mortality reduction trend and the policy impact may be overestimated. As the financing of a center is done via a matching grant with both federal and local funds, the average of 20 percent from local funds requirement to co-finance the investment increases the chances of a grant to be awarded to richer areas. Therefore, a wealthier oblast with a larger local budget might have more to spend on other infrastructure and amenities around the center, such as roads and doctor's salaries and benefits, improving mortality more even in the absence of treatment. In short, the treated oblasts might get the center because they can make it work. This would make condition in equation (3) fail and bias the estimate of the policy effect, but the direction is unclear. Better administration could lead to more lives saved, but location in wealthier regions that already have relatively good facilities could have the reverse effect.

Another source of potential selection bias is the possibility that federal government gave preference to locations in the greatest *need* of a center, namely places with high congestion in obstetrics units, long queues, or old facilities. Thus, the marginal returns to a center would be higher on average than in the control oblasts, working in addition via expansion of basic facilities and not just improving the technology input.

A formal method to test whether the mortality trends in the absence of policy would have been the same in the treatment and control group is to allow the to-be-treated regions to evolve along a different time trend before the policy. In other words, this test is to regress the mortality variables on overall time trend plus a time trend to be interacted with the 'to-be-treated' dummy in the pre-treatment period 2007-2009. The results in the Appendix Table A6 demonstrate that the treatment group does not reveal any statistically significant difference in the trend from the control in the years prior to treatment for our variables of interest.[10] Stillbirths and 28-365 days mortality decline more slowly on average in treated than in untreated regions, pointing out at that the to-be-treated regions are actually doing worse in some dimensions, but importantly, not in the dimensions we are interested in measuring.[11]

The risk of endogenous treatment might still not be showing up in the pre-trends: *good oblast effect* may not be internalized in observed mortality *unless* the oblast is treated. Selected oblasts could be responding better to treatment and that could be the very reason they were selected. In this case it is impossible to estimate an ATE, since the selection variable is not independent or conditionally independent of the unobserved random variable that causes the heterogeneity in the response to treatment (Wooldridge, 2010, p.910).

However, we address the possible selection biases outlined above, when we run our baseline model on a subsample of the regions (54) that are treated plus the regions that are selected for treatment in 2013-2017. In this case, our control group is more likely to both satisfy the DD identification condition by being more similar to the treatment group in terms of all observed criteria for selection and the unobserved 'need' and 'ability' of the region to maintain a high-tech centre. Both groups are likely to respond to treatment more similarly. We acknowledge, however, that the issue of which oblasts get treated first and which get treated last still stands, but concerns of unobserved differences and possible bias that may be caused by them are much milder.[12] We thus use this specification as our preferred model, as it is the most conservative one possible given the capacity of our data. We also apply all diagnostic tests above to this subsample of 54 regions and they all still hold.

We additionally test for the possibility that mothers are crossing regional borders to be treated in the center, which can cause contamination of control group, and find no evidence of such occurrence at a noticeable scale.[13]

[10] In this estimation we exclude Omsk, as it was treated in 2009, and we need at least 3 periods to test for differential trends.

[11] We also try a specification with one and two period policy *lead* variables included into our set of controls. *lead1* and *lead2* indicate the policy status one and two periods before the opening of the perinatal center in the treated regions, as in Frakes (2013) and Acemoglu and Finkelstein (2008). We use them to demonstrate that the opening of the center is not associated with some other socio-economic programs in the area that could have been improving health outcomes before the center was introduced. However, the coefficients on these variables are not significant (Online Appendix Tables 3 and 4), so we are less worried about the true impact of a perinatal center.

[12] Another way to 'purge' the potential endogeneity is to use an instrument orthogonal to the error components and that affects mortality only through the increased probability of selection. Ties of the local governor to Kremlin increase the probability of selection, but arguably do not affect infant mortality directly, hence a proxy of *connection to the federal government* can be a candidate for the instrument. We hypothesized that a good proxy could be years of the governor in power as a measure of connection, but failed to get significant first stage.

[13] In Table 5 of the Online Appendix the births count neither changes significantly in the treated regions after treatment, nor does it change in the neighboring regions after treatment. This shows that there is no evidence of mothers giving births in the neighboring treated regions and improving the control regions' statistics, thus biasing our effect downwards. We also do not find an effect if we interact a perinatal dummy with an indicator of being close to the border.

VI. Results

A. Main Findings

Table 1—Effect of Perinatal Center Opening on Infant Mortality, OLS

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Perinatal Center	-0.582***	-0.451**	-0.293**	-0.533**	-0.241	-0.130
	(0.211)	(0.177)	(0.141)	(0.238)	(0.197)	(0.109)
Income per Capita, in 1000 rub	-0.0186	-0.0176	-0.00792	0.0613	0.0694	-0.00103
	(0.122)	(0.0692)	(0.0511)	(0.0756)	(0.0485)	(0.0587)
Alcoholism (per 1000 population)	0.113	0.173	0.0960	0.322	0.233	-0.0600
	(0.528)	(0.378)	(0.303)	(0.518)	(0.292)	(0.212)
Healthcare Financing, in 1000 rub	0.0419	0.0350	0.00993	0.0554	0.0452	0.00692
	(0.0259)	(0.0220)	(0.0162)	(0.0380)	(0.0338)	(0.0281)
Percent of Urban Population	-0.0418	-0.0675	-0.104	-0.0952	0.00895	0.0257
	(0.1000)	(0.0887)	(0.0691)	(0.0745)	(0.0672)	(0.0607)
Observations	581	581	581	581	581	581
R^2	0.276	0.286	0.249	0.417	0.407	0.127
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Results suggest that the introduction of perinatal centers reduced infant mortality via saving lives soon after birth. Tables 1 and 2 show results of Model (1) on full sample and sample with to-be-treated controls respectively. We prefer the latter sample, Table 2, because we are wary of the fact that there may be a selection on unobservables that could lead to biased estimates. Infant mortality drops by 0.391 deaths per 1000 live births, or by 3.8 percent relative to the baseline mortality rate in 2007 (9.11 deaths per 1000 infants). Neonatal mortality (0-28 days) is reduced by 0.401 deaths per 1000 live births, which constitutes a 6.9 percent average reduction from the baseline rate of 5.5 deaths per 1000 births; mortality in 0-6 days after birth declines by 0.287 deaths per 1000 live births (or 7.3 percent on average from 3.750 deaths per 1000 births) due to a perinatal center introduction. These numbers suggest that 8-9 fewer infants die in the mean oblast with 23,300 births each year. As expected, the proportional effect on earlier mortality is larger.

Table 2—Specification with To-Be-Treated Control Group

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Perinatal Center	-0.391*	-0.401**	-0.287*	-0.429	-0.140	0.0103
	(0.198)	(0.185)	(0.157)	(0.281)	(0.209)	(0.0929)
Income per Capita, in 1000 rub	-0.000581	-0.00891	0.0205	0.0421	0.0249	0.00833
	(0.0615)	(0.0545)	(0.0562)	(0.0839)	(0.0543)	(0.0279)
Alcoholism (per 1000 population)	-0.260	0.0140	-0.000911	-0.182	-0.181	-0.274
	(0.518)	(0.409)	(0.380)	(0.558)	(0.296)	(0.202)
Healthcare Financing, in 1000 rub	-0.0185	-0.000792	-0.000367	0.0116	0.0108	-0.0177
	(0.0379)	(0.0219)	(0.0165)	(0.0287)	(0.0218)	(0.0209)
Percent of Urban Population	-0.00353	0.0410	-0.0237	-0.117	-0.0903	-0.0445
	(0.100)	(0.115)	(0.0826)	(0.113)	(0.102)	(0.0501)
Observations	378	378	378	378	378	378
R^2	0.443	0.373	0.318	0.449	0.434	0.303
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

We see the smallest, but still significant effect of a perinatal center's presence on total infant mortality. As for Table 1, we find that the magnitude of the coefficient on the two early mortality rates is almost the same as in a more conservative model, but the coefficient on infant mortality doubles. This shows that the declining trend for infant mortality in treated regions compared to any other region is likely steeper than that compared to regions that will receive treatment in the next stage of the project.

The stillbirths rate declines insignificantly. With vast shifts in live birth/late abortion criteria, stillbirths are likely to have increased in many regions to offset a decline in the possibility of using late abortions as means of undercounting, and this may have happened regardless of the presence of the perinatal center.

Interestingly, postneonatal mortality does not change at significant levels. We know that the risk of death for LBW and prematurely-born infants is highest in the first week and month of life and it varies highly with the availability of technology. For infants with average weight and gestation the risk of death is more uniformly distributed throughout the first year of life and more likely to vary due to a number of different inputs, such

Table 3—Sequential Effect of Perinatal Center Opening on Mortality, OLS

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Year 1 after opening	-0.240	-0.388**	-0.277**	-0.446**	-0.159	0.148
	(0.216)	(0.184)	(0.132)	(0.193)	(0.146)	(0.122)
Year 2 after opening	-0.540*	-0.464*	-0.391*	-0.457	-0.0713	-0.0753
	(0.273)	(0.241)	(0.202)	(0.375)	(0.281)	(0.132)
Year 3 after opening	-0.525*	-0.347	-0.151	-0.366	-0.218	-0.178
	(0.291)	(0.273)	(0.255)	(0.569)	(0.463)	(0.208)
Observations	378	378	378	378	378	378
R^2	0.447	0.378	0.330	0.453	0.437	0.313
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

as good care, clean environment and timely doctor's diagnoses.[14] We thus can consider postneonatal category of mortality effectively as a placebo group that less depends on available technology. We are more confident that it is the change in access to equipment in the healthcare production function that is having an effect, as we see that only the early mortality groups are affected. This further confirms that our results are not driven by more general changes that improve health outcomes, other than the improved access to technology.

Table 3 represents a sequential effect of the perinatal center. These results are shown only for the first three years, since no other treated region except Omsk opened a sufficient number of years ago for us to have outcomes four and five years after opening. Even for three years after opening we are considering just four treated regions, so some loss of power is expected. The effect on all three mortality groups of interest (0-6, 0-28 days and 0-1 year mortality) is larger in the second year after opening, as anticipated, since it takes time for the doctors in the center to work out the best practices and get used to the new building and equipment. We witness this result also possibly due to some centers opening later in spring, while the treatment dummy is assigned as one for that first year, underestimating the full effect during the year of a center's opening.

[14]Dmitry Nikolaevich Degtyarev, telephone conversation with the author, Dzhamilya Nigmatulina, May, 2015

The reduction in all groups of mortality is comparable to the reduction of neonatal mortality in Argentina from improved water facilities of 0.226 from the mean of 2.3 deaths per 1000 live births, which is 11 percent (Galiani, Gertler and Schargrodsky, 2005), but significantly smaller than those from randomized policies in India and Tanzania (which is easily explained by diminishing marginal returns of mortality being relatively lower in Russia than in Tanzania). Hovever, the US evidence from admission to NICU due to marginally smaller weight enabling an infant meet the admission criteria reduces 0-7 day mortality by 16 percent, 0-28 day mortality by 23 percent and one year mortality by 17 percent(Almond et al., 2010), which is higher than what we find in Russia. Finally, Nizalova and Vyshnya (2010) also demostrate a much higher savings of 2.1 lives per 1000 births, vs. 0.391 lives per 1000 births in our study. Of course, to a large extent this difference may reflect more dire initial conditions in Ukraine.

B. Additional Considerations

Opening of a center can cause other processes to take place that also indirectly affect mortality in some cases. One such process is diversion of resources from other facilities or their closure. Another change is new centers inviting doctors from other regions to fill in new places. Such processes playing out at the same time as treatment can reduce or increase the effect attributed to the center. Further, there could be differences in the influence of the new center on mortality depending on whether the hospital was built from scratch or the new facility was annexed to the existing hospital. Finally, the change in mortality could be smaller if other advanced maternity facilities already existed in a given region, so mothers have had some access to high-tech care.

First, we test whether the effect of perinatal centers differs when facilities for complicated deliveries already existed in the region before (even if not as advanced), as opposed to the effect from just introducing the complicated delivery care for the first time. We thus add an interaction term $\beta_2 P_{r,t} * NoExist$ to our main specification (4), where $NoExist_{rt}$ is an indicator for whether the new hospital was the first high-tech delivery facility in the region. In the resulting Appendix Table A7, we see no difference in responses to treatment for 0-6, 0-28 days and 0-1 year mortality. However, there is a significant reduction of stillbirths and of perinatal mortality. This is intuitive, as the difficulty to perform proper and timely diagnostics in simple maternity hospitals affects the likelihood of fetuses to have been stillborn, and there is a significant improvement once an advanced facility opens.

$$M_{r,t} = \beta_0 + \beta_1 P_{r,t} + \beta_1 + \beta_2 P_{r,t} * NoExist_{rt} + \phi Z_{rt} + \lambda_t + \gamma_r + \varepsilon_{r,t} \tag{4}$$

We run the same regression as (4) but now interact the treatment with an indicator of whether the hospital has been built from scratch or as part of the existing hospital (Appendix Table A8). Except perinatal losses dropping significantly more in regions where the new facility did not belong to a larger existing hospital, there is no significant difference in treatment effect along this dimension. The regions with a large existing hospital that annexed the center tend to be slightly better off than those where it is built as a stand-alone facility, so this additional reduction in perinatal losses in the latter group stems from the fact that it possibly had some more avertable perinatal losses before treatment.

Regional governments may optimize by redirecting resources from other facilities in the region, which, if true, on the one hand means that fewer lives are saved, but on the other hand, that these lives are saved at a lower overall cost. We measure the substitution effect with counts of simple maternity units and maternity hospitals, expecting some of these facilities to close after perinatal center opens.[15] We find that even though some maternity hospitals do close, there is no compelling evidence that the substitution effect accompanying the perinatal center openings has a significant impact on mortality.

If neonatologists, Ob Gyn doctors and midwives (both counts and provision) are attracted to the treated regions, mortality can be expected to drop further, which can blur the effect attributed to the high-tech equipment. However, reassuringly, none of the relevant types of doctors increased in the treated regions after Perinatal Center opening at statistically significant levels.[16]

Finally, there is one remaining concern: out-of-pocket medical payments are prevalent in Russia. It could be that richer (and thus maybe healthier) mothers are more likely to get themselves into the NICU hospital and get treated, so this can overestimate the treatment effect. If this effect is important, it should lead to improvements in urban (richer) birth outcomes, but not rural (poorer) birth outcomes. We only could find the disaggregated data of infant mortality by urban and rural areas and for a subset of regions; we analyze these data in Table A9. Surprisingly, in the rural populations' mortality decreases significantly more, so it is likely that re-routing of births from remote areas does, indeed, take place, and out-of-pocket payments are at least not so severe as to completely offset this re-routing effect.

C. Cost-benefit analysis

Considering large monetary investments into the perinatal centers without an a priori obvious return, a cost-benefit analysis is imperative for policy evaluation and comparison with other interventions (for instance, with the return on Mother and Infant Project in Ukraine (Nizalova and Vyshnya, 2010)). We do two types of evaluations: a rate of return over the lifetime of a hospital (taken to be 40 years), and an estimation of a cost per life

[15] Tests for a substitution effect are included in Online Appendix, Table 6. The number of maternity hospitals indeed decreased with treatment, so we presume that some of the investment was done 'at the expense' of old basic hospitals. As for mortality outcomes of the perinatal center interacted with the maternity hospital count, Online Appendix Table 7 shows that neonatal mortality does not fall significantly more with higher count of maternity hospitals after treatment.

[16] Results are included in Appendix Table 6 of the Online Appendix. The coefficients on midwives and neonatologists are positive, yet not significant. If we interact the change in neonatologists in the first year of treatment with the Perinatal Center dummy (Table 9 in the Online Appendix), we see that the larger is the increase in neonatologists in the first year of treatment, the smaller is the reduction in mortality. More variation is necessary to derive firmer conclusions, but it seems that the arriving neonatologists (and it is most plausible they go to work at the new center) need to acquire skills with the new equipment: the transition period thus may avert fewer deaths than the treatment in places where the specialists are locals.

Table 4—Cost Comparisons of Different Health Interventions

Incremental cost for QALY	As quoted	In 2014 dollars
Our estimate, high-tech neonatal care, 2014 PPP $	44,900	21,412
Cutler and Meara (2000), Neonatal care (US, 1990), $	3,726	6,065
Cutler and Meara (2000), Prenatal care (US, 1990), $	(4,214)(Cost Savings)	(6859) (Cost Savings)
Cutler and Meara (2000), Influenza vaccinations <3 years (US, 1990), $	1,745	2,840
Cutler and Meara (2000),Coronary arthery bypass (US, 1990), $	33,600-48,300	54,700-78,700
Cutler and Meara (2000), Severe hypertension treatment (US, 1990), $	17,000	27,700
Cutler and Meara (2000), Pap Smear every 3 years for ages 20-74, $	17,000	27,700
Mangham-Jefferies et al. (2014), Promoting hospital-based breast-feeding (Honduras, 1993), $	164 (per DALY averted)	249
Mangham-Jefferies et al. (2014), Outreach obstetrics units, referral assistance, tratining birth assistants (The Gambia, 1991), $	148-620 (per LY)	153-640
Cost per life saved		
Our estimate, high-tech neonatal care, 2014 PPP $	2,619,000	1,380,000
Mangham-Jefferies et al. (2014), Promoting hospital-based breast-feeding (Honduras, 1993), $	6,894	7,120
Mangham-Jefferies et al. (2014), Outreach obstetrics units, referral assistance, tratining birth assistants (The Gambia, 1991), $	1,380-6,414	1,400-6,625
Mangham-Jefferies et al. (2014), Teutanus Toxoid immunizaiton (Indonesia, 1985), $	1,564	1,615
Almond et al. (2010), Neonatal intensive care (US, 1983-2002), $	527,083-615,270	566,000-660,650

saved or per incremental year of life in order to compare our finding to other studies.[17] For either measure we use interest rate, an estimate of operational costs, and capital cost data. For capital costs we use an average capital investment of a perinatal center (2.064 bln rb or $103.2 mln in 2014 PPP USD). Operational cost is derived from the fact that most centers range between 130 -190 beds, and the number of people employed range between 600 (Kurgan) and 900 (Tomsk), but employee information was only available for a few hospitals. Taking 600 as a lower bound, and information on average wages of healthcare workers from Rosstat, we assume that doctors, nurses and junior nurses work in the center in equal proportions and find that a hospital on average needs to pay around 213 million rb in wages yearly. Adding a 5.4 percent required health insurance and 30 percent typically allocated maintenance cost on top of the wages, we assume operational cost to be 320 million rb, or (16 million 2014 USD in PPP).[18] We convert the yearly costs and benefits to present value terms utilizing the Central Bank of Russia's discount rate of 8.25 percent for 2012 (*stavka refinansirovaniya*) Adjusting the future cash flows by Russia's average inflation of 7 percent, the real interest rate becomes 1.25 percent.

In order to monetize the lives saved by a new perinatal center, we can turn to the expert estimates of Value of Statistical Life (VSL) in Russia. Guriev (2011) suggests the VSL to

[17]The lifetime of a hospital is chosen according to the expert opinion of Guzel Ernstovna Ulumbekova, email message to the author (Nigmatulina), 04 Oct, 2015

[18]The choice of 30 percent markup is fair according to the expert opinion of Guzel Ernstovna Ulumbekova, email message to the author (Nigmatulina), 04 Oct, 2015

be in the 60-135 mln rb ($2-4.5 mln) range. Bykov (2007) offers a slightly smaller, but comparable estimate, 50 mln rb, or $1.6 mln in 2014 dollars. We also calculate our own VSL to the government by dividing the GDP by working age population and multiplying by 43 years of expected working life to get 36 mln rb. We finally multiply the VSL with the newborn lives saved per year in a region and subtract the estimated average annual cost for a perinatal center.

We recognize that the resulting returns to investment are sensitive to the VSL and the interest rate chosen, which is why we provide sensitivity analyses, varying different VSLs and interest rates (Appendix Tables A11 and A12). In order to get a very small positive return of one percent, VSL needs to be 50 mln, or the region needs to have more than 30,000 births. Using our own VSL we find that an average perinatal center has a return to investment of negative 15 percent in a region with 23,292 yearly births (the average from 2013). Similarly, in Appendix Table A12 we see that keeping the VSL at 36 million rb, and for an average region with 30,000 births, the return to a perinatal center varies from one percent (for 3.5 percent discount rate) to nine percent (for 1.25 percent discount rate). We also assume that infants surviving past 1 year of life have an average life expectancy and quality.

However, it is important to note that estimating these benefits is done without considering any health benefits to the mother and better morbidity outcomes for infants who would not have died in the absence of treatment. Nevertheless, using just measurable lives saved is the standard procedure in the literature: for example, Nizalova and Vyshnya (2010) do not explicitly consider morbidity in their benefits estimation, so the comparison of our results to theirs is accurate.

Nizalova and Vyshnya (2010) find that the Mother and Infant Project in Ukraine generated 962 percent return accounting for the lives saved, which is in a much higher range than the returns in Russia, especially considering a much more conservative use of VSL for Ukraine: if Russian values were used, the return would be even higher. Such evidence points out that there could be other ways to avert deaths in Russia, with a much smaller investment, though the difference also reflects the dire state of healthcare funding in Ukraine.

Estimating the cost per life saved we first find that the perinatal centers altogether save 263 lives per year.[19] Then we use an average investment cost of a perinatal center in a region, annualized over 40 years using annualization formula (65,886,000 rb) plus the yearly perinatal center costs (320,000,000) and divide the total cost by the number of estimated lives saved in each region, as in Almond et al. (2010), and take the mean over all regions to get the national value.[20] The cost per life saved from our calculations is 52,153,000 rb (1,380,000 in 2014 USD or 2,619,000 in PPP 2014 USD). Regardless of which dollar equivalent we choose, the value per live saved is significantly larger than that for the US

[19]To get this value we multiply all the births in the treated regions in 2013 (when all 24 centers were open) by the reduction in mortality rate attributed to the centers (0.391 deaths per 1000 births from Table 2)

[20]Annualization formula used is $d = P * r/(1 - 1/(1 + r)^T)$, where $P = 2,064,000,000$ is the average cost of building a perinatal center, $r = 0.0125$ is the Bank of Russia interest rate net of inflation, $T = 40$ and is the upper bound of a lifetime of a hospital

quoted by Almond et al. (2010): $527,083-$615,270 in 2010.[21] According to the Ukrainian study, 5.63 lives are saved per maternity-year, costing the government 60,000 2005 USD per maternity-year. This translates into 12,592 2014 USD per life saved, which is around 100 times cheaper than the high-tech investment in Russia.

To be able to compare to a few other studies we calculate the cost per quality-adjusted life year (QALY). Since we do not have any information on quality of life conditional on the weight of the newborn, we use estimations from Cutler and Meara (2000) assuming that all lives saved are those of LBW newborns, and that in Russia in 2014 newborns of a certain weight on average can expect to live a life of comparable quality as in the US in 1990, and have the same longevity *relative* to the Russia's average life expectancy. Knowing the shares of different LBW categories in 2013 for Russia we estimate that on average a LBW infant who survived to 1 year will live 58.3 QALY's.[22] In Table 4 we compare our findings with costs for QALY or cost per life saved of various interventions from other studies. Our cost per QALY finding stands as one of the highest on this list only surpassed by coronary arthery bypass.

One possible explanation of the high-tech care being so unproductive given the cost is the inefficiency with which the hospitals are run. The main component of cost of life saved is operational expenses, rather than investment cost. This means that running these hospitals is so expensive that they are expected to be saving more lives than they currently are. Poor performance could arise from poorly qualified or unmotivated doctors and nurses, doctors unable to use high-tech equipment, or bad hospital management. Additionally, centralized high tech services in a vast country inherently will be inaccessible to many high risk moms.

VII. Conclusion

Investment in high-tech infrastructure reduces infant mortality in a middle-income country, but at a high cost. Building state-of-the-art hospitals in 24 out of 83 regions in Russia reduced infant mortality rate by 3.8 percent on average (the rate drops by 0.0391 percentage points), but each life saved costed the government around 52 million rb (2.6 million 2014 PPP USD), which is higher than similar investments in the US. This demonstrates that bottlenecks, such as institutional capacity to build hospitals at lower costs, or lack of other quality inputs into healthcare, remain and restrict the potential effect from the investment. The subject of the study is further relevant, as the federal government plans to build centers in additional 30 regions, and it is important to accurately predict expected mortality reductions from the investment. If the reduction of mortality is expected to be the same as in the current part of the treatment, only the large regions with more than 30,000 births a year should expect a positive return, and only if a life is valued at 30 mln rb or more.

At the same time, the regions that built a perinatal center in the last three years did achieve the government-set target rates of early neonatal mortality that declined from 3.66

[21] We believe that PPP 2014 USD is most accurate numeraire for comparison with the US result, because it represents the cost to the government in real terms.

[22] We are only considering cases of infants who survived their first year of life for this QALY calculation.

to 2.9, compared to 3.82 to 3.24 (when the control group is regions "to-be-treated"). The establishment of a perinatal center reduces infant mortality by saving babies in the first week and in the first month of their lives. The largest reduction in the rate compared to baseline rate in 2007 is for first week mortality (7.3 percent).

We address two major concerns with the validity of the results. First, the propensity of the selected regions (in 2007) to benefit from the center may be higher than that of a usual control region, so the DD estimate might exaggerate the treatment effect. We carefully select the control group and only include regions that are subject to treatment in the second stage of the policy. We further test for the pre-existing differences in the trends for the treatment and control groups. Second, the degree of mortality underreporting could be higher in the treated oblasts, since they have an incentive to demonstrate favorable effects of the federal investment. We rule this concern out with diagnostic regressions on variables that capture underreporting; namely terminations of pregnancy in 22-27 weeks of gestation and proportion of births by birth weight.

It bears mention that our estimates of benefits are restricted to lives saved directly. To a modest extent, then, the true returns of the perinatal center may be underestimated, since the treatment in the center have very likely improved morbidity of mothers and infants as well. In addition, the center should raise the overall obstetrics care quality in the region by interacting with other hospitals, encouraging the dissemination of best practices, and monitoring their performance in the long run. Unfortunately, we do not have any information on improved morbidity or how to quantify it. Nevertheless, the investment remains expensive when compared to similar studies in other countries, which also *only* consider lives saved as their outcome measure.

The commitment of roughly 75 billion rb (3.8 billion 2014 USD in PPP) to creating NICUs, along with still larger operation costs, is a major commitment by the Russian Ministry of Health and has accounted for about 1/3 of the 2013 capital budget of 222.5 billion rb. As noted in Evans and Garthwaite (2012), $1.1 billion was spent in the US for a comparative effectiveness research in the frame of the American Recovery and Reinvestment Act that became law in 2009. Such a detailed research investment may be costly in a country that may lack basic accessibility of care. However, when resources allocated to healthcare are limited, comparing relative returns of major investment, such as Neonatal Intensive Care Units, high-tech cardiac centers, or, increasing the number of beds in a large number of hospitals, is absolutely necessary. Although the evidence is that the money spent on Perinatal Centers' project has yielded some returns, there may exist much higher returns from addressing basic needs of current Russian healthcare system, such as increasing the number and quality of maternity units accessible to those who live far from big centers. Upper middle income countries will be making vast health infrastructure investments in the near future and one should not underestimate the importance of informed choices to achieve higher returns to healthcare.

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Appendix

A1. Tables

Table A1—Summary Statistics Full Sample

	count	mean	sd	min	max
0-1 yr Mortality	581	8.447761	3.03274	0	23.9
0-28 days Mortality	581	4.883685	2.115317	0	18.1
0-6 days Mortality	581	3.266017	1.712627	0	14
Perinatal Losses	581	8.610403	2.512963	0	19.9
Stillbirths	581	5.351271	1.505431	0	11.1
28-365 days Mortality	581	3.564076	1.599954	0	17.9
Perinatal Center	581	.1153184	.3196811	0	1
Births, count	581	21871.61	19736.67	641	135853
Life Expectancy at Birth (yrs)	579	68.33382	2.870074	57.5	78.84
Income per Capita, in 1000 rub	581	17.40301	8.996022	4.0059	66.276
Healthcare Financing, in 1000 rub	581	8.047805	5.973791	1.7235	43.73544
Ob Gyn per 10000 wmn in fert age	581	5.135663	1.204077	2.8	10.02
Percent of Urban Population	581	69.26351	13.2023	26.7	100
Percent below Poverty Line	576	15.30972	5.333456	5.6	45.3
Maternity Hospital, count	581	2.156627	2.67902	0	19
Vodka Consumption per Capita (litres per cap)	581	11.18373	4.261653	0	24.3
Neonatologists per 1000 infants	581	32.20998	9.206235	0	61.4
Observations	581				

Table A2—Summary Statistics in 2007 (Before Treatment)

	Never Treated	To-Be-Treated	Treated	Total
0-1 yr Mortality	10.42	9.307	9.599	9.773
	(3.805)	(2.909)	(2.459)	(3.132)
0-28 days Mortality	5.750	5.503	5.497	5.586
	(1.871)	(2.424)	(1.679)	(2.021)
0-6 days Mortality	3.933	3.823	3.658	3.812
	(1.409)	(1.942)	(1.193)	(1.558)
Perinatal Losses	9.450	9.130	9.148	9.244
	(2.262)	(2.419)	(1.539)	(2.120)
Stillbirths	5.506	5.333	5.486	5.437
	(1.606)	(1.033)	(0.952)	(1.227)
28-365 days Mortality	4.670	3.803	4.102	4.187
	(2.639)	(1.213)	(1.223)	(1.847)
Births, count	11208	24027.2	23886.4	19608.7
	(9930.0)	(20881.4)	(14561.4)	(16918.4)
Life Expectancy at Birth (yrs)	65.90	67.69	66.65	66.78
	(3.075)	(2.776)	(1.867)	(2.735)
Income per Capita, in 1000 rub	11.96	11.27	10.34	11.23
	(8.427)	(6.349)	(2.680)	(6.369)
Healthcare Financing, in 1000 rub	7.491	5.001	5.059	5.868
	(7.669)	(3.287)	(2.779)	(5.201)
Ob Gyn per 10000 wmn in fert age	5.436	4.773	5.138	5.106
	(1.407)	(1.011)	(0.854)	(1.145)
Percent of Urban Population	67.14	68.56	72.90	69.34
	(14.23)	(12.60)	(10.89)	(12.79)
Percent below Poverty Line	20.30	16.05	16.50	17.63
	(8.866)	(5.134)	(4.523)	(6.724)
Maternity Hospital, count	1.643	2.367	3.292	2.390
	(1.747)	(3.764)	(2.196)	(2.810)
Vodka Consumption per Capita (litres per cap)	12.86	11.87	12.46	12.38
	(4.077)	(4.277)	(4.061)	(4.117)
Neonatologists per 1000 infants	32.90	29.73	35.99	32.64
	(11.32)	(7.478)	(8.557)	(9.486)
Observations	82			

mean coefficients; sd in parentheses

Table A3—Summary Statistics in 2013 (After Treatment)

	Never Treated	To-Be-Treated	Treated	Total
0-1 yr Mortality	9.866	8.000	7.800	8.594
	(4.415)	(2.165)	(1.515)	(3.137)
0-28 days Mortality	5.797	5.033	4.492	5.143
	(2.626)	(1.892)	(1.013)	(2.047)
0-6 days Mortality	3.790	3.297	2.904	3.355
	(2.259)	(1.501)	(0.765)	(1.683)
Perinatal Losses	10.26	9.383	9.483	9.717
	(2.775)	(2.987)	(1.506)	(2.565)
Stillbirths	6.503	6.123	6.604	6.395
	(1.536)	(1.921)	(1.399)	(1.644)
28-365 days Mortality	4.069	2.967	3.308	3.451
	(3.178)	(0.770)	(0.909)	(2.029)
Births, count	13552.7	28958.8	27977.4	23292.2
	(12705.8)	(28053.2)	(18589.2)	(21956.6)
Life Expectancy at Birth (yrs)	69.18	70.80	69.83	69.96
	(2.934)	(2.584)	(1.815)	(2.590)
Income per Capita, in 1000 rub	25.13	23.84	21.91	23.73
	(13.84)	(8.540)	(4.755)	(9.962)
Healthcare Financing, in 1000 rub	12.14	10.62	8.942	10.66
	(8.581)	(5.750)	(1.675)	(6.266)
Ob Gyn per 10000 wmn in fert age	5.396	4.761	4.998	5.051
	(1.471)	(1.056)	(0.788)	(1.175)
Percent of Urban Population	66.35	69.17	74.07	69.60
	(15.20)	(12.82)	(10.25)	(13.27)
Percent below Poverty Line	15.56	12.34	13.06	13.67
	(6.582)	(3.594)	(3.038)	(4.896)
Maternity Hospital, count	1.276	2	2.583	1.916
	(1.334)	(3.384)	(2.244)	(2.519)
Vodka Consumption per Capita (litres per cap)	9.931	8.868	9.075	9.300
	(4.404)	(3.843)	(2.977)	(3.815)
Neonatologists per 1000 infants	30.38	28.78	34.85	31.10
	(10.41)	(7.722)	(6.816)	(8.799)
Observations	83			

mean coefficients; sd in parentheses

Table A4—Regression with Full Controls

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Perinatal Center	-0.367*	-0.346*	-0.280*	-0.473	-0.195	-0.0212
	(0.202)	(0.189)	(0.166)	(0.292)	(0.203)	(0.0971)
Income per Capita, in 1000 rub	0.0191	0.0269	0.0381	0.0257	-0.0113	-0.00774
	(0.0767)	(0.0673)	(0.0581)	(0.0702)	(0.0486)	(0.0334)
Healthcare Financing, in 1000 rub	-0.0144	-0.00495	-0.00124	0.0245	0.0250	-0.00944
	(0.0362)	(0.0238)	(0.0168)	(0.0293)	(0.0268)	(0.0179)
Ob Gyn per 10000 wmn in fert age	-0.0342	-0.0363	-0.199	-0.499	-0.314	0.00212
	(0.218)	(0.215)	(0.258)	(0.442)	(0.283)	(0.121)
Percent of Urban Population	0.00713	0.0286	-0.0537	-0.156	-0.100	-0.0215
	(0.0866)	(0.0950)	(0.0714)	(0.119)	(0.0965)	(0.0462)
Percent below Poverty Line	0.0165	0.0454	0.0289	-0.0270	-0.0580	-0.0289
	(0.0680)	(0.0723)	(0.0463)	(0.0579)	(0.0418)	(0.0262)
Maternity Hospital, count	0.0577	0.107	0.0328	-0.00665	-0.0483	-0.0496
	(0.0765)	(0.0691)	(0.0526)	(0.107)	(0.0831)	(0.0337)
Vodka Consumption per Capita (litres per cap)	0.0440	0.0369	0.0473	0.0749	0.0286	0.00712
	(0.0509)	(0.0380)	(0.0325)	(0.0455)	(0.0323)	(0.0296)
Neonatologists per 1000 infants	-0.0315	-0.0209	-0.00958	-0.0288	-0.0189	-0.0106
	(0.0348)	(0.0301)	(0.0247)	(0.0241)	(0.0152)	(0.0124)
Observations	378	378	378	378	378	378
R^2	0.450	0.385	0.331	0.461	0.446	0.306
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A5—Adding Fixed Effects and Controls One-by-One

	(1) 0-6 days Mortality	(2) 0-6 days Mortality	(3) 0-6 days Mortality	(4) 0-6 days Mortality	(5) 0-6 days Mortality
Perinatal Center	-0.379*	-0.178	-0.304*	-0.261*	-0.279*
	(0.203)	(0.123)	(0.170)	(0.149)	(0.143)
Constant	3.168***	3.133***	2.950***	3.835***	11.00
	(0.182)	(0.0219)	(0.0679)	(0.0818)	(8.767)
Observations	378	378	378	378	378
R^2	0.011	0.006	0.317	0.630	0.636
Oblast FE	No	Yes	Yes	Yes	Yes
Time FE	No	No	Yes	Yes	Yes
Oblast Timetrend	No	No	No	Yes	Yes
Controls	No	No	No	No	Yes

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A6—Testing for Differential Trends, 24+30 Sample

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Overall Timetrend	-1.307***	-0.819**	-0.455*	-0.818**	-0.389**	-0.489***
	(0.384)	(0.364)	(0.268)	(0.357)	(0.184)	(0.154)
Overall Timetrend X Treated	0.236	0.0192	0.0417	0.263	0.242*	0.217*
	(0.239)	(0.220)	(0.160)	(0.221)	(0.130)	(0.111)
Observations	159	159	159	159	159	159
R^2	0.448	0.376	0.355	0.424	0.277	0.234
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Oblast FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

Errors clustered at oblast level; Omsk region excluded because treatment happened in 2009

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A7—Response to Treatment if High-Tech Facilities Already Exist (in 11 treated regions)

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Perinatal Center	-0.288	-0.299	-0.128	0.210	0.340*	0.0103
	(0.243)	(0.212)	(0.170)	(0.279)	(0.199)	(0.109)
Perinat Center X No High-Tech Exists	-0.125	-0.249	-0.329	-1.346***	-1.000***	0.124
	(0.351)	(0.352)	(0.273)	(0.288)	(0.277)	(0.156)
Observations	378	378	378	378	378	378
R^2	0.445	0.375	0.323	0.470	0.458	0.311
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A8—Allowing for Differential Effects if the Center is one of 9 Centers Built From Scratch

	(1) 0-1 yr Mortality	(2) 0-28 days Mortality	(3) 0-6 days Mortality	(4) Perinatal Losses	(5) Stillbirths	(6) 28-365 days Mortality
Perinatal Center	-0.412*	-0.407*	-0.195	-0.114	0.0814	-0.00480
	(0.227)	(0.212)	(0.172)	(0.282)	(0.215)	(0.106)
Perinat Center X Built from Scratch	0.194	-0.00678	-0.229	-0.788*	-0.534	0.201
	(0.362)	(0.365)	(0.306)	(0.468)	(0.380)	(0.153)
Observations	378	378	378	378	378	378
R^2	0.445	0.373	0.320	0.456	0.440	0.312
OblastFE	Yes	Yes	Yes	Yes	Yes	Yes
TimeFE	Yes	Yes	Yes	Yes	Yes	Yes
OblastTimetrend	No	No	No	No	No	No
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses

Errors clustered at oblast level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A9—Difference between Urban and Rural Areas

	(1) Infant Mortality Urban	(2) Infant Mortality Rural
Perinatal Center	-0.227	-0.617*
	(0.324)	(0.360)
Oblast FE	Yes	Yes
Time FE	Yes	Yes
Controls	Yes	Yes
Observations	357	357
R^2	0.850	0.747

Standard errors in parentheses

Errors clustered at oblast level. Urban and rural mortality missing for Khanty-Mansi, Nenets and Yamalo-Nenets autonomous regions

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A10—Cost-Benefit Analysis of a Perinatal Center in an Average Region

Benefits	
Lives Saved	
Average births in an oblast in 2013	23,292
Average lives saved (average births times 0.391 reduction in infant mortality)	9.11
Value of Life	
GDP , mln rb	71,406,400
Working age population, count	85,161,578
GDP per worker, rb	838,481
Livetime work duration (ages 16-59), years	43
Value of Life (multiplying work duration by GDP per worker), mln rb	36
Present Value Benefits (over 40 years' lifetime of a hospital), mln rb	10,286
Costs	
Operational	
Average Monthly Wage of Doctors and Nurses, rb	29,557
Yearly Wages of 600 Workers (conservative value), mln rb	213
Yearly Wages with Additional 5.4% OMS (workers' insurance), mln rb	224
Maintenance (30% on average from yearly wages), mln rb	320
Present Value of Future Operational Costs, mln rb	10,038
Investment	
Total Capital Investment per Center, mln rb	2,064
Present Value Total Costs, mln rb	12,102
Interest rate (Bank of Russia avg interest rate to non-finance organizations in roubles for more than 3 yrs)	8.25%
Discount Rate Adjusted for Average Inflation of 7%	1.25%
Present Value Factor for Future Income Flow of 40 Years	0.04
Net Present Value, mln rb	-1,816
Percent Return	-15.00%

Table A11—VSL Sensitivity Analysis of Returns to a Perinatal Center

VSL, million rb	Number of Births in a Region: 1,000	10,000	15,000	20,000	30,000	40,000	50,000	70,000	90,000	100,000	130,000
20	-98%	-80%	-70%	-60%	-39%	-19%	1%	42%	82%	102%	163%
25	-97%	-75%	-62%	-49%	-24%	1%	27%	77%	128%	153%	229%
30	-97%	-70%	-54%	-39%	-9%	21%	52%	113%	173%	204%	295%
35	-96%	-65%	-47%	-29%	6%	42%	77%	148%	219%	254%	361%
40	-96%	-60%	-39%	-19%	21%	62%	102%	183%	264%	305%	426%
45	-95%	-54%	-32%	-9%	37%	82%	128%	219%	310%	355%	492%
50	-95%	-49%	-24%	1%	52%	102%	153%	254%	355%	406%	558%
55	-94%	-44%	-17%	11%	67%	123%	178%	290%	401%	457%	624%
60	-94%	-39%	-9%	21%	82%	143%	204%	325%	447%	507%	689%
65	-93%	-34%	-1%	32%	97%	163%	229%	361%	492%	558%	755%
70	-93%	-29%	6%	42%	113%	183%	254%	396%	538%	608%	821%
75	-92%	-24%	14%	52%	128%	204%	280%	431%	583%	659%	887%
80	-92%	-19%	21%	62%	143%	224%	305%	467%	629%	710%	953%

Table A12—Discount Rate Sensitivity Analysis

Discount Rate	Number of Births in a Region: 1,000	10,000	15,000	20,000	30,000	40,000	50,000	70,000	90,000	100,000	130,000
1.25%	-96%	-64%	-45%	-27%	9%	46%	82%	155%	228%	265%	374%
1.50%	-96%	-64%	-46%	-28%	9%	45%	81%	153%	226%	262%	371%
1.75%	-96%	-64%	-46%	-28%	8%	44%	80%	151%	223%	259%	367%
2.00%	-96%	-64%	-47%	-29%	7%	42%	78%	149%	220%	256%	363%
2.25%	-96%	-65%	-47%	-29%	6%	41%	77%	147%	218%	253%	359%
2.50%	-96%	-65%	-47%	-30%	5%	40%	75%	145%	215%	250%	355%
2.75%	-97%	-65%	-48%	-31%	4%	39%	74%	143%	212%	247%	351%
3.00%	-97%	-66%	-48%	-31%	3%	38%	72%	141%	210%	244%	347%
3.25%	-97%	-66%	-49%	-32%	2%	36%	71%	139%	207%	241%	343%
3.50%	-97%	-66%	-49%	-32%	1%	35%	69%	137%	204%	238%	339%
3.75%	-97%	-67%	-50%	-33%	0%	34%	67%	134%	201%	235%	335%
4.00%	-97%	-67%	-50%	-34%	-0%	33%	66%	132%	199%	232%	332%
4.25%	-97%	-67%	-51%	-34%	-1%	32%	64%	130%	196%	229%	328%
4.50%	-97%	-67%	-51%	-35%	-2%	30%	63%	128%	193%	226%	324%
4.75%	-97%	-68%	-52%	-35%	-3%	29%	61%	126%	191%	223%	320%
5.00%	-97%	-68%	-52%	-36%	-4%	28%	60%	124%	188%	220%	316%
5.25%	-97%	-68%	-52%	-37%	-5%	27%	58%	122%	185%	217%	312%
5.50%	-97%	-69%	-53%	-37%	-6%	26%	57%	120%	183%	214%	308%

A2. The Visual

We plot a range of graphs for all our outcome variables and observe the changes in trends during policy implementation. We indicate the two larger policy changes in 2011 and 2012 with red vertical lines. For a more natural exposition, each year's marker is put at the end of the year (that is, 2012 data are shown at the start of 2013), for all our outcome variables are *year-end totals.* Infant mortality data are presented in Figure A1.

Figure A1. Mortality Trends

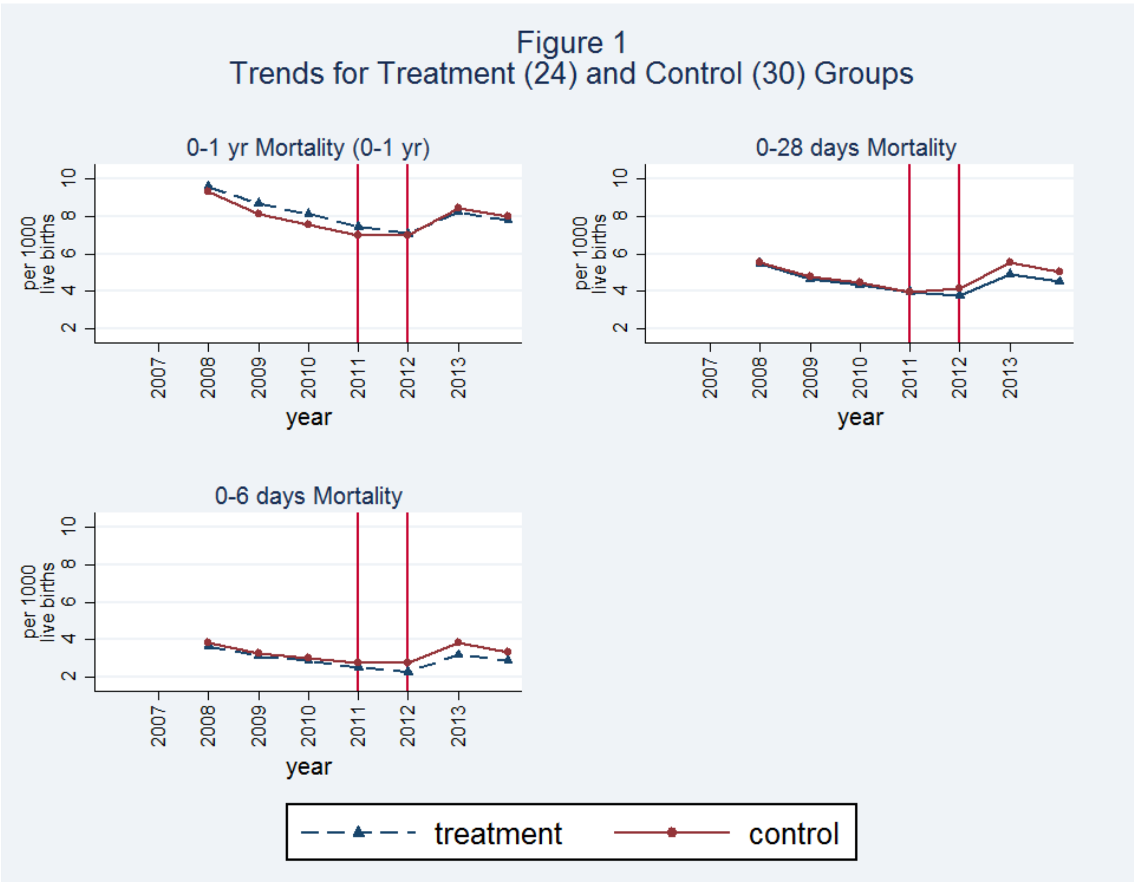

Figure A1 shows three key mortality outcomes for live born infants (measured by the mortality rate per 1000 live births). Trends in mortality are parallel and declining in both groups, prior to treatment. After 2011 and 2012 the trends diverge: as the control group rates increase on average, the treatment group rates continue to fall. After 2012, the mortality rate increases for both groups due to the change in birth accounting standards.