Road Access, Fertility, and Child Health in Rural India

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Expansion in access to public infrastructure can have varied, microlevel impacts. In this paper, we use a discrete and quasi-random change in the access to paved roads through a large-scale rural road construction program in India to study how road access impacts fertility decisions and investments in child health. We find that increased access to paved roads at the district level decreases fertility, improves investments in children, and lowers infant mortality. We also provide evidence that highlights the mechanisms that drive this effect. First, we show that local roads improve access to health care facilities and raise immunization rates, which reduces infant mortality. Then, we demonstrate that last-mile road connectivity has contrasting effects on employment across gender. Overall, the evidence suggests that rural roads can help accelerate demographic transition through their effects on fertility and infant mortality.

Introduction

Rural roads can provide several pathways to economic development. For instance, better road connectivity can increase employment, bolster livelihoods, and reduce poverty. Higher employment rates, particularly among women, increase the opportunity cost of having a child (Becker 1960) and incentivize households to have fewer children. Improvements in road connectivity can also facilitate the expansion of public and private transport services (Asher and Novosad 2020), mitigate mobility barriers, and potentially improve households' access to formal health care. In doing so, rural roads can raise the rates of both institutional deliveries and immunization among children (Aggarwal 2021), which could reduce infant mortality. A decline in infant mortality could, in turn, further reduce fertility,[1] because it allows households to more easily achieve their desired family size (Kalemli-Ozcan

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2003). Better road infrastructure stands to shape both fertility decisions and infant mortality and, in doing so, likely hasten the pace of demographic transition.

However, the net effect of road-building programs on demographic transition[2] is theoretically ambiguous. After all, if this infrastructure spending can induce an economic upturn and raise household incomes (Lenz et al. 2017), then it could make childcare more affordable to these households and, therefore, incentivize them to have children when they otherwise may not. Evidence from both developed (Sobotka, Skirbekk, and Philipov 2011) and developing countries (Adsera and Menendez 2011) suggests that fertility declines during economic downturns, with a corresponding increase in periods of economic growth. Moreover, the construction of new roads could also lead to increased (vehicular) pollution in nearby areas, which can increase infant mortality. Thus, it is not obvious how either fertility or infant mortality would respond to the provision of better road infrastructure, depending upon the relative salience of the mechanisms involved. As such, the total effect of these mechanisms on the rate of demographic transition remains an open empirical question.

In this paper, we provide causal evidence on the impact of all-weather rural roads on fertility. We make use of a discrete and quasi-random change in the stock of these *paved* roads in India arising from the Pradhan Mantri Gram Sadak Yojana (PMGSY). Launched in 2000, the PMGSY is a large-scale road construction program that aims to provide paved roads to erstwhile unconnected habitations within Indian villages while prioritizing habitations that lie above specific population cutoffs.[3] Although actual road construction under the PMGSY may be decidedly nonrandom because of factors such as political patronage, the use of population cutoffs provides a source of exogenous variation in the probability that a village will receive a PMGSY road. Specifically, we use the distribution of village populations—the fraction of villages in any given region that lie above the relevant population cutoff at the baseline—as an instrument for actual road construction. We use this measure in conjunction with rich administrative data to shed light on the effects of rural roads on demographic transition as well as the mechanisms that may be involved therein.

Our analysis reveals that the provision of paved roads enhances households' access to health care facilities, increases immunization rates among children, and reduces infant mortality. We find that fertility falls in response to improvements in road connectivity, which is consistent with prior theoretical analyses (Kalemli-Ozcan 2003; Ranganathan, Swain, and Sumpter 2015). Notably, fertility falls although female employment declines following road construction, while male employment increases. These employment dynamics can reduce the intrahousehold bargaining power of women, which may place upward pressure on fertility (Eswaran 2006). As such, our results suggest that the reduction in fertility as a result of declining infant mortality may be more salient than any changes because of intrahousehold bargaining. We also find that contraceptive use remains unchanged, even though it has historically been a dominant mechanism through which other infrastructure interventions, such as electrification (Grimm, Sparrow, and Tasciotti 2015) and televisions (Tasciotti, Sulehria, and Wagner 2022), have reduced fertility.

Related literature

Our work is related to three strands of the economics and demography literature. The first strand concerns itself with how economic growth shapes fertility and infant mortality. Empirical analyses in this area, such as the studies by Sobotka, Skirbekk, and Philipov (2011) and Currie and Schwandt (2014), reveal that fertility in high-income countries may be procyclical, that is, it rises during periods of economic growth and declines during times of distress. Similarly, Adsera and Menendez (2011) find that fertility is procyclical in their sample of 18 Latin American countries, while Ferreira and Schady (2009) present analogous evidence for low-income countries in Asia and Africa. In all three contexts, the decline in fertility during times of economic hardship can be explained by the fall in household incomes, which inflates the cost of childcare and dominates any reduction in the opportunity cost of having children. Whenever the income effect dominates the substitution effect, fertility is positively associated with economic progress.

However, the income and substitution effects represent only the direct mechanisms through which economic growth can influence fertility. There is also a strong indirect mechanism, whereby the former affects the latter by way of infant mortality. Several papers have previously shown that economic growth and infant mortality are inversely related (Cutler, Deaton, and Lleras-Muney 2006; Bhalotra 2010; Paxson and Schady 2005; Baird, Friedman, and Schady 2011; Miller and Urdinola 2010). Moreover, Kalemli-Ozcan (2003) posits that if infant mortality declines, a fertility decline will follow. They argue that this occurs because households become more certain about their children's survival in times of low infant mortality, which renders it easier for them to achieve their desired family size with fewer births. Ranganathan, Swain, and Sumpter (2015) test this hypothesis by fitting a nonlinear, simultaneous equations model to data from over 200 countries and find that gross domestic product growth can lower infant mortality, which may subsequently drive down fertility. This indirect mechanism runs contrary to the direct mechanisms; the former can reduce fertility, while the latter can increase it.

The fertility response to economic growth can also differ across income and demographic groups. For instance, Anukriti and Kumler (2019) find that in India, impacts of tariff cuts imposed by trade reforms differ by women's "status" (i.e., income group, caste, and education level).

"Low-status" women experience increased employment and simultaneously have higher fertility and lower child mortality (especially for female children) under tariff cuts, while the opposite is true in the case of "high-status" women. Furthermore, Kim and Prskawetz (2010) show that fertility increases in Indonesia amid high(er) unemployment, primarily because households value the pecuniary benefits of having more earning members. As long as the pecuniary benefits vary across geographic and demographic groups, the fertility response to economic progress will likely be correspondingly heterogeneous.

Another related strand of literature deals with the impacts of public infrastructure investments. On the one hand, such investments can create employment opportunities for both men and women, drive up the opportunity cost of having children, and, consequently, reduce fertility. Empirical support for these effects comes from interventions such as rural electrification (Dinkelman 2011; Grimm, Sparrow, and Tasciotti 2015; Grogan 2016; Sedai et al. 2021), the advent of cable TV (Jensen and Oster 2009), and Internet connectivity (Hjort and Poulsen 2019). Cable TVs can also affect fertility through another channel: the broadcasted programs can increase households' exposure to family planning methods, which could subsequently increase contraceptive use (La Ferrara, Chong, and Duryea 2012; Tasciotti, Sulehria, and Wagner 2022). On the other hand, infrastructure spending can help alleviate poverty (Khandker, Bakht, and Koolwal 2009; Gibson and Rozelle 2003; Lenz et al. 2017; Parikh et al. 2015), improve household welfare (Khandker, Barnes, and Samad, 2013; Saing 2018; Medeiros, Saulo Marques Ribeiro, and Vasconcelos Maia do Amaral 2021), and facilitate access to institutional health care (Aggarwal 2021) and schooling (Khandker and Koolwal 2011). Moreover, improvements in health infrastructure, such as via malaria eradication programs, can also increase fertility (Lucas 2013; Apouey, Picone, and Wilde 2018) by boosting fecundity among the beneficiary cohorts (Bhattacharjee and Dasgupta 2022). Therefore, infrastructure programs that affect both employment and access to health care have downstream effects on fertility that are not obvious.

Lastly, our paper is related to the growing literature on PMGSY. Asher and Novosad (2020) adopt a regression discontinuity design and find that PMGSY roads improve the availability of transport services while inducing workers to move away from agriculture toward other secondary and tertiary sectors. Similarly, Shamdasani (2021) shows that the arrival of PMGSY roads leads to erstwhile remote farm enterprises scaling up their operations by hiring more, not necessarily local, workers and adopting modern farming techniques. Garg, Jagnani, and Pullabhotla (2022) find that this reallocation of agricultural workers across space increases the incidence of farm fires, which drives up infant mortality in nearby areas. However, there is mixed evidence on the impact of PMGSY on employment outcomes. Asher and Novosad (2020) identify no change in aggregate village-level employment in the aftermath of PMGSY roads. In contrast, Lei, Desai, and Vanneman (2019) find that employment rises in villages that receive rural roads, with women's employment increasing the most in regions that have more relaxed gender norms. Aggarwal (2018) undertakes a district-level analysis and shows that employment increased only among teenagers, with no effects on other age groups. Additionally, she observes that PMGSY roads increase the variety of goods consumed by households, which can be explained by a reduction in barriers to the mobility of people and goods as a result of better availability of transport services. Likewise, Adukia, Asher, and Novosad (2020) find that PMGSY roads increase enrolment in primary and secondary schools, while Aggarwal (2021) shows that these all-weather roads inflate the rates of in-hospital deliveries and child immunization. We complement this literature by illustrating how these roads affect households' fertility choices.

Program details

PMGSY, a large-scale national-level road construction program, was launched by the Central Government of India in December 2000. The program aimed to ensure all unconnected habitations with more than 500 residents[4] are connected to the nearest commercial center by an all-weather road. A habitation is the smallest rural unit in India, and an unconnected habitation is defined as one located half a kilometer or more from an all-weather road or a habitation that is connected by an all-weather road. The roads constructed as a part of the program connect unconnected habitations to the nearest connected habitation, all-weather road, market center, or block headquarters. Thus, the program's main mandate is to provide last-mile connectivity by single, small-lane roads to residents of otherwise unconnected habitations and to ensure that eligible habitations can access basic economic and social services by an all-weather road (PMGSY, Online Management and Monitoring System [OMMS]). Though the program targets habitations, our research focuses on villages.[5]

Although the program is funded by the Central Government, it relies heavily on state- and district-level participation and coordination in its implementation.[6] As a first step, the existing road network and unconnected villages were identified at the block level, and a plan was drawn to ensure basic access to the identified habitations. The plan was then approved by the local government at the district level (the Panchayat) and, subsequently, by the state- and national-level authorities. The districts were tasked with generating a priority list by ranking unconnected villages in descending order of population and forwarding it to the relevant state-level authority. The state-level authority generated a priority list across districts, once again ranking eligible villages by population, and vetted the district-level implementation plans. Villages were prioritized if their population was at or above a program-specified cutoff. The program aimed to provide roads to all villages with a population of 1,000 by 2003, villages with a population between 500 and 1,000 by 2007, and those with a population between 250–500 by 2012 (Asher and Novosad 2020). Next, the state authority forwarded the district-level implementation plans to the national authority, which provided final sanction before implementation. Therefore, as per the guidelines, the two main criteria to be considered at every level of planning and implementation were baseline access to all-weather roads (i.e., identifying unconnected villages) and village population.

However, in practice, as Asher and Novosad (2020) point out, other factors also influenced the allocation.[7] For example, populations of villages within 500 m of each other could be combined, villages on the least-cost path of connecting a village that is being prioritized could receive road connectivity, and local phenomena like the existence of a weekly village market could affect the allocation decision. In practice, most states did not comply with the PMGSY guidelines, and some disregarded the population thresholds completely. Asher and Novosad (2020) worked with the National Rural Roads Development Agency—the national-level agency responsible for overseeing the program—to identify six *complier* states, namely Chhattisgarh, Gujarat, Madhya Pradesh, Odisha, Maharashtra, and Rajasthan. For clean identification, we restrict our analysis to these six states, following Asher and Novosad (2020) and Garg, Jagnani, and Pullabhotla (2022). It is worth noting that almost all our results also carry over to the full sample of Indian states.[8] In Table 1, we present descriptive statistics for all outcomes and covariates of interest for both our sample and the entire country. The main takeaways are that the complier states have marginally higher fertility, fewer years of schooling among adults, fewer female-headed households, lower employment, greater transport barriers, higher contraceptive use but a greater unmet need for family planning, worse immunization, and more intensive road construction under PMGSY when compared to national averages. Yet, across most margins, the gap in means between our sample and the national average is less than 10 percent of the latter, except in the case of years of schooling (complier states are 20 percent worse) and differences in household religion (complier states contain relatively more Hindus and fewer Muslims).

Data

Rural roads

We obtained data on road construction from the Socioeconomic High-Resolution Rural–Urban Geographic Platform for India (SHRUG), a collection of data sets that encompass economic, demographic, and electoral indicators at the village and town levels.[9] To measure baseline access to

TABLE 1 Sample characteristics versus national averages

	Compliers		All states		Difference in means
	Mean	SD	Mean	SD	
Panel a: Woman-level data (NFHS-4)					
Fertility (births per year)	0.16	(0.095)	0.16	(0.099)	−0.0019***
Total children ever born to woman	2.55	(1.66)	2.59	(1.75)	−0.042***
Infant mortality rate	0.087	(0.25)	0.081	(0.24)	0.0065***
Woman's current age (years)	32.3	(8.66)	32.4	(8.59)	−0.12***
Age at first childbirth (years)	18.0	(6.87)	18.3	(7.00)	−0.33***
Years of schooling	4.21	(4.50)	4.87	(4.85)	−0.66***
Hindu household	0.94	(0.24)	0.78	(0.42)	0.16***
Muslim household	0.033	(0.18)	0.11	(0.31)	−0.073***
SC / ST household	0.44	(0.50)	0.40	(0.49)	0.041***
Households have a female head	0.092	(0.29)	0.13	(0.33)	−0.036***
Wealth Quintile (1 = poorest; 5 = richest)	2.36	(1.23)	2.53	(1.27)	−0.17***
Household owns a motor vehicle	0.38	(0.49)	0.33	(0.47)	0.048***
Transport barriers to healthcare (Index)	0.16	(0.71)	0.086	(0.77)	0.074***
Use of family planning methods (Index)	0.063	(0.95)	−0.069	(0.97)	0.13***
Unmet need for family planning (Index)	−0.013	(1.00)	0.090	(1.10)	−0.10***
Access to ASHAs (Index)	−0.071	(0.34)	−0.086	(0.31)	0.015***
Household decisions (Index)	−0.11	(0.73)	−0.043	(0.73)	−0.070***
Share of villages with paved roads in 2001	0.49	(0.22)	0.56	(0.25)	−0.067***
Share of villages with PMGSY Roads	0.13	(0.097)	0.070	(0.080)	0.058***
Panel b: Child-level data (NFHS-4; aged 0–5 years)					
Female child	0.48	(0.50)	0.48	(0.50)	−0.00012
Child's birth order (high = more siblings)	2.22	(1.40)	2.36	(1.55)	−0.13***
Breastfeeding duration (months)	18.2	(12.8)	18.2	(13.0)	0.014
Vaccine (index)	−0.087	(0.78)	−0.11	(0.80)	0.019***
Antenatal visits during pregnancy	4.02	(4.09)	3.86	(4.22)	0.15***
Panel c: Individual-level data (NSS rounds 61–68)					
Current age (years)	27.4	(19.3)	27.3	(19.2)	0.038
Employment rate	0.49	(0.50)	0.48	(0.50)	0.013***
Attending school or college (aged 14–22)	0.29	(0.45)	0.31	(0.46)	−0.019***
Only doing domestic work	0.21	(0.41)	0.23	(0.42)	−0.020***
Main income source is agriculture	0.54	(0.50)	0.49	(0.50)	0.048***
log(per-capita total expenditure)	6.94	(1.03)	7.06	(1.07)	−0.12***
Medical expenditure (as a share of the total)	0.056	(0.16)	0.050	(0.15)	0.0064***
Individuals	572,761		2,062,953		2,635,714

NOTE: See the Data section for more details on variable construction.
*, **, and *** denote significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

paved roads, we sourced data from the Village Directory of the 2001 Population Census, which records the types of roads in each village. SHRUG also includes data on the provisioning and construction of roads under PMGSY between 2002 and 2015. These data were sourced from the OMMS for the program. A village *receives* a PMGSY road in year y if it does not have access to paved roads at the baseline and the construction of the new road is completed up until year $y - 1$.

Although the data on roads are available at this granular level, that is not the case for most of the outcome variables that were considered in our analysis. Rather, representative data on health care, employment, and household consumption are only available at the district level.[10] As such, we aggregated data on PMGSY roads to the district level to construct our final measure. For each district d in any given year t between 2003 and 2015, we defined $\log(PMGSY)_{dt}$ by computing the percentage of all eligible villages in the district that had received a PMGSY road by the previous year, adding one to this result, and then applying the natural log transform. This is a cumulative measure of improvements in road connectivity, which lies between 0 and 1.[11] For all roads delivered after 2013, we restricted attention only to those that were approved under the PMGSY-I regime.

National Family and Health Survey

We relied on the National Family and Health Survey (NFHS) for child health care and health outcome data. The NFHS is a nationally representative survey administered by the Ministry of Health and Family Welfare and the Indian Institute of Population Sciences. We utilized two of the five rounds for which data are available, namely NFHS-4 (2015–2016) and NFHS-5 (2019–2021).[12] We focused on NFHS-4, which covers over 500,000 households across the country and is representative at the district level. NFHS-4 contains questions on fertility, child and maternal mortality, family planning, immunization, nutrition, and access to institutional care. The corresponding outcome variables are constructed as follows.

Fertility: To compute fertility, we used the retrospective birth history available for each woman in the NFHS. For each woman w, we first identified all the years when she was aged between 16 and 49. Then, for each such year, we defined a binary outcome that took value 1 if she had given birth in that year and 0 otherwise. The resulting data set was a woman-level panel: Each observation denoted whether she had given birth at a specific age (between 16 and 49). For any woman in our data, the number of observations depends on her age during the interview year; the higher her age at the time of the interview, the more times she appeared in the final data. For each birth, we defined infant mortality as another binary outcome that took value 1 if the child had died before reaching 12 months of age and 0 otherwise. Therefore, infant mortality was missing for all years when a woman did not give birth. It was similarly undefined for all children who were alive and less than 12 months old at the time of the interview.

Child health: We utilized data on outcomes that were only available for children aged 0–5 years at the time of the interview. *Breastfeeding duration* refers to the number of months that the child has been breastfed. Similarly, the number of prenatal care visits by the mother, which we denoted as *antenatal visits*, was known for most children of that age group. In contrast, most data on immunization were available only for children aged 12–23 months (aged 1–2 years). These data included responses from survey questions on whether the child received vaccines for polio, BCG, diphtheria, and tetanus; the only exception was the question on vitamin A, which was asked in reference to each child aged 0–5 years. Each question admitted a yes/no response that was encoded as a binary outcome variable. We then combined the information contained in all these responses into a *vaccine index* constructed using a generalized least squares approach outlined in Anderson (2008).[13] This index summarized how a child compared with peers of the same age in terms of immunization; a higher index score indicated that the child had received more vaccines than an average child of that age.

Delivery conditions: The survey questionnaire contained information on the respondents' most recent birth, such as whether a child was delivered in a health care facility. Whenever this was not the case, the questionnaire asked if the distance to the facility was a contributory factor. The response to this question was indicated by a binary outcome denoted as *delivery center far*, which took value 1 when the child was not delivered in a health care facility because it was too far and 0 otherwise. We also denoted the natural log of the total out-of-pocket expenditure associated with the most recent birth by *log*(*Delivery Cost*).

Family planning: Each respondent was asked whether she intended to use any family planning methods and if she had used family planning methods in the past. Both questions admitted a yes/no response, which meant it was not possible to know the noninterview years in which the respondent had used family planning methods, if ever. We aggregated the responses to both questions through a summary index, denoted as *FP use*, and constructed analogously to the *vaccine index*. The *FP use* index described whether a woman was more (or less) likely to have used (or intended to use) family planning methods compared to the overall population as of the interview year. Likewise, respondents were asked whether they had an unmet need for family planning methods. Three variations of this question were asked in the survey, and we combined the responses to all three versions through a summary index, denoted as *FP unmet need*, where higher values indicate a greater unmet need.

Access to care: Respondents were also asked whether the distance to public health care facilities was a problem in addition to a question regarding the availability of transport to these facilities. We grouped the responses to both questions into a *Transport* index. Unlike the other indices, higher values of the *Transport* index are normatively worse; they suggest that respondents faced greater mobility barriers in accessing public health care.

Household decisions: We constructed an index on women's bargaining power in household decisions by combining information on whether she had the power to determine (i) how her earnings were spent; (ii) how her spouse's earnings were spent; (iii) her health care; (iv) whether she could visit a health center alone; and (v) big household purchases. Higher values on the resultant *Decisions* index signified that the woman had a greater say in household decision-making.

National Sample Survey

We drew data for labor market outcomes and household consumption from surveys conducted by the National Sample Survey Office of India. These quinquennial surveys are representative at the level of regions, which are collections of adjacent districts with similar agroclimatic conditions. We made use of all survey rounds for which district identifiers were available, that is, starting from the 61st (2004–2005) up until the 68th (2011–2012). The outcome variables were constructed as follows.

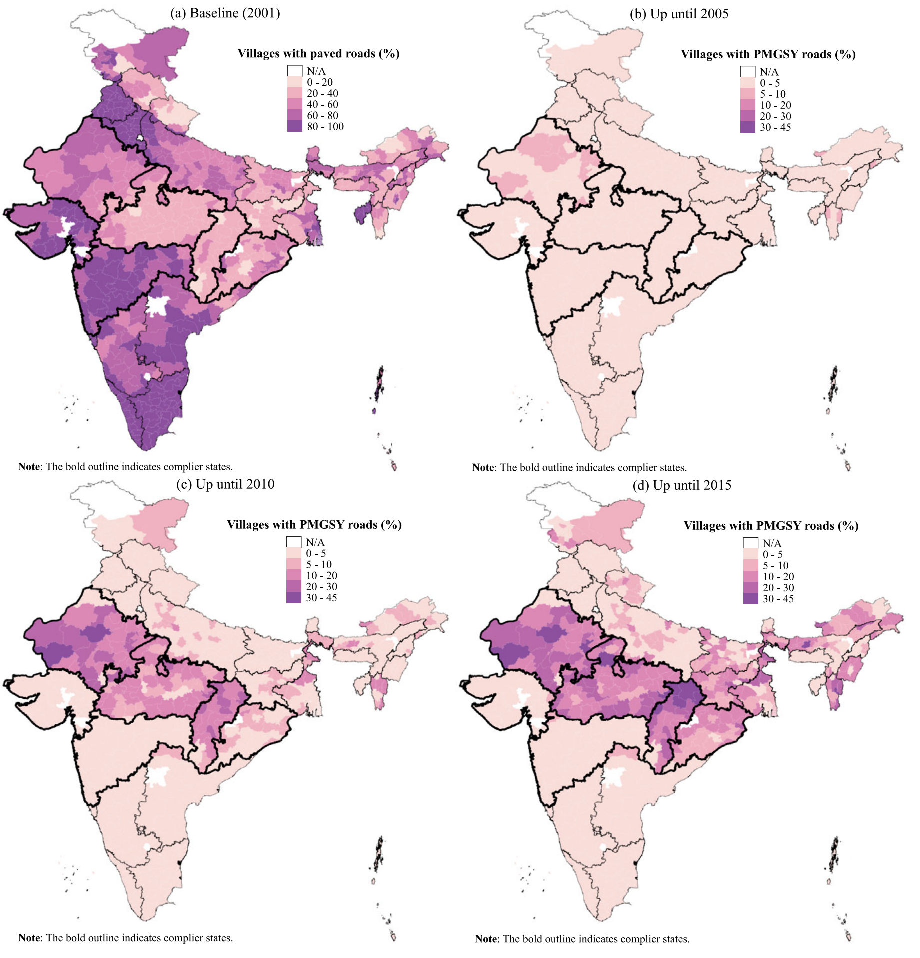
Employment: All respondents in a household were asked if they were (i) employed; (ii) unemployed but looking for work; or (iii) not part of the labor force. We defined *employment* as a binary outcome that took value 1 for employed individuals and 0 otherwise. However, we left employment as undefined when the respondent was either below the minimum working age or their employment status was unclear.[14] Similarly, we defined indicators for whether the individual worked in the agricultural sector, and if they were engaged solely in unpaid household work.

Consumption: The survey recorded household expenditure on several types of goods and services in the preceding 12 months. We computed *log*(*Annual Expenditure*) by summing together all consumption expenditure, dividing it by the number of household members, deflating this amount using the consumer price index with the base year 2010, and applying the natural log transform to this result. Finally, we defined the *share of medical expenditure* as the ratio of total expenditure on medical goods and services to total household expenditure.

Descriptive statistics

Figure 1 illustrates the spatial distribution of paved roads both before and after the PMGSY program. Because we concerned ourselves only with states that complied with the program rules, the actual sample is demarcated by thick borders. The first panel demonstrates that before the PMGSY, there was substantial heterogeneity in access to paved roads across states such that in the median district, approximately 57 percent of all villages had paved roads. Subsequent panels show the extent of cumulative PMGSY road construction within a district up until 2005, 2010, and 2015. Notably,

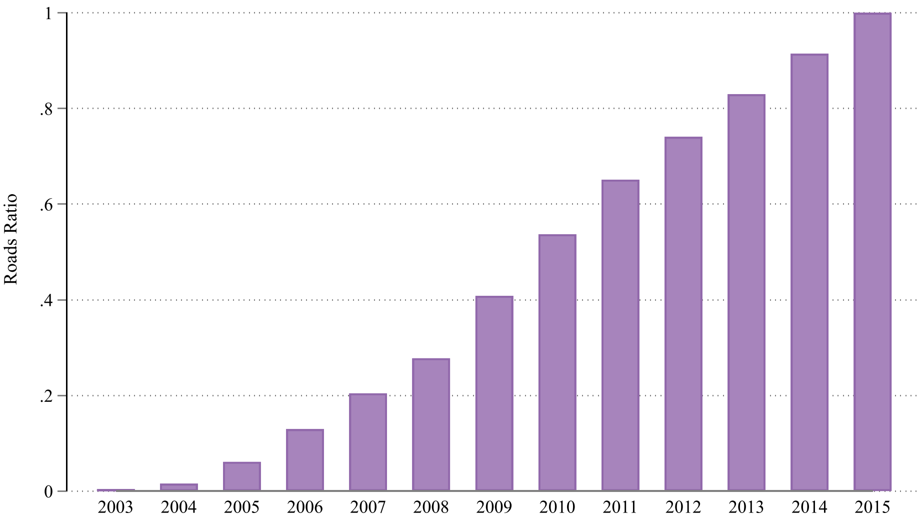
FIGURE 1 Road construction within districts over time



very few roads were constructed in the first few years of the program, with most of the new roads concentrated in the northwestern state of Rajasthan. Road construction picked up pace in the late 2000s, with significant changes in states that lagged behind pre-PMGSY. This was followed by relatively modest gains between 2010 and 2015. We demonstrate this in Figure 2, which plots cumulative road construction across all districts as a simple ratio, namely the total road construction in a given year divided by the total road construction in 2015. Road construction grew at its fastest between 2006 and 2010. On the whole, there appears to be much variation in local road connectivity over space and time.

Table 1 presents summary statistics for both the variables of interest and the covariates we employed in our analysis. Since we are interested in the impact of roads on many of these outcomes, it is instructive to visualize

FIGURE 2 Cumulative annual road construction under PMGSY



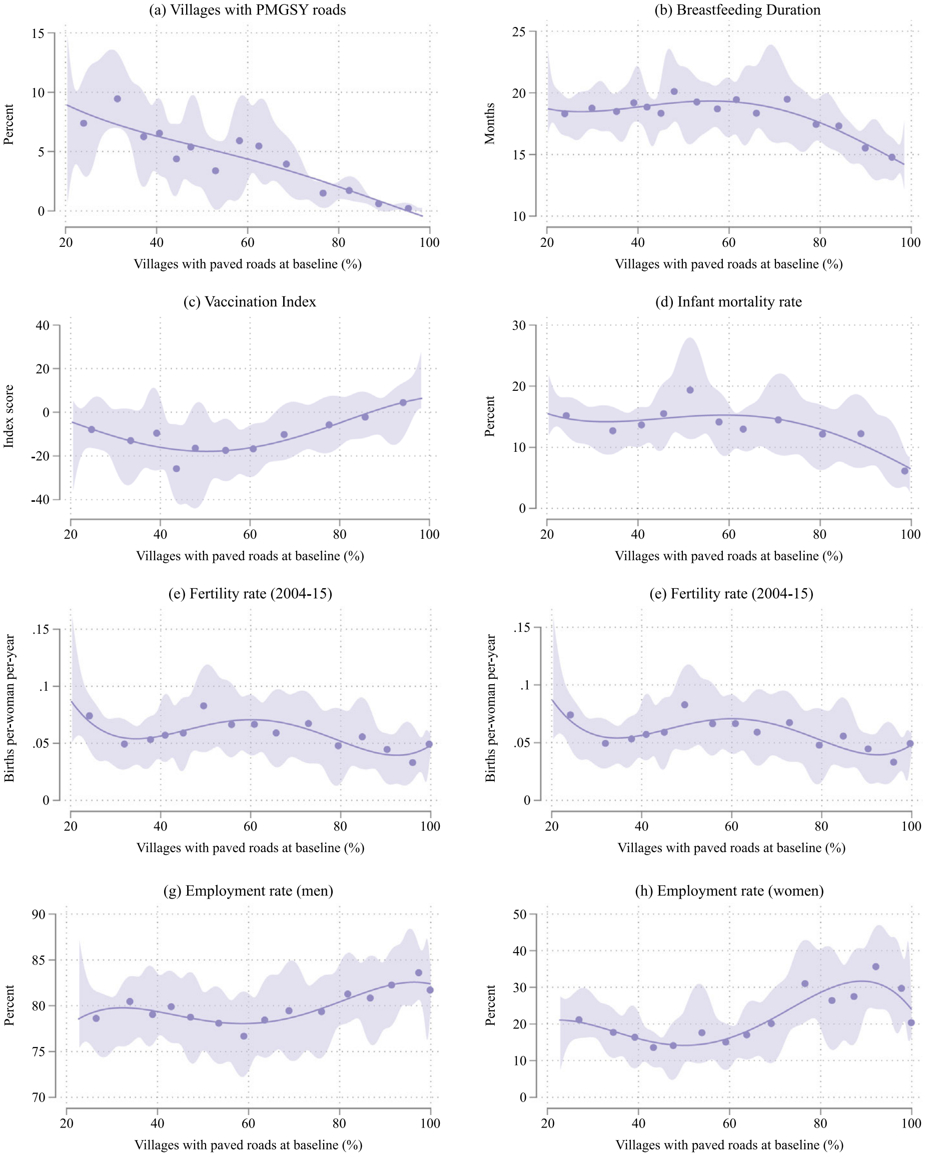
how these outcomes vary across districts that had different levels of road access before the PMGSY. This is done in Figure 3, which plots the mean of these outcomes for different bins of districts (grouped by their level of pre-PMGSY road access). None of the outcomes of interest, evaluated after the PMGSY's launch, exhibit a clear linear relationship with the level of pre-PMGSY road connectivity within the district. The intent of our analysis is to determine whether this is because the provision of PMGSY roads led to a convergence in outcomes across districts, or because rural roads do not significantly affect these outcomes.

Methods

Identification strategy

Our objective is to identify how improvements in local road connectivity affect fertility. For this, we exploited variations in the stock of local roads because of the PMGSY. As illustrated under Programme Details, there were differences in the timing and extent of road construction under the program across districts. The quasi-randomness in this variation stemmed from the fact that, conditional on not having paved road connectivity at the baseline (2001), villages above arbitrary population thresholds were prioritized for the construction of new roads. The thresholds themselves were time-varying, with the initial threshold of 1,000 people (until 2003) being reduced to 500 (until 2007) and then finally to 250 (until 2012). As we limited our attention to states that complied with program rules, the change in road access within a district from year t to year $t + 1$ was driven by the

FIGURE 3 Baseline availability of paved roads and downstream outcomes



fraction of villages that were to be prioritized, which itself is depended only upon the distribution of rural population in the district at the baseline.

To evaluate how an outcome like fertility evolved in response to the availability of paved roads, we used variation in road construction from (i) within a district over time and (ii) between districts. As such, we adopted a *continuous* analog of the difference-in-difference (DiD) framework to estimate the effect of the treatment (read: PMGSY) on the outcome of interest. It was continuous in the sense that the intensity of treatment—the fraction of villages that received PMGSY roads—varied across treated units (districts), unlike in a classical DiD where all treated units would receive the same treatment.[15] Our regression specification was as follows:

$$Y_{ivdt} = \beta_1 \log(\text{PMGSY})_{dt} + \mathbf{X_{ivdt}}\gamma + \delta_d + \tau_t + \epsilon_{ivdt} \tag{1}$$

where Y_{ivdt} refers to the outcome of interest at time t for individual i living in village v in district d. For instance, in the case of fertility, at any time t, the outcome (Y_{ivdt}) took the value 1 if woman i gave birth in year t and 0 otherwise. $\log(\text{PMGSY})_{dt}$ is a measure of cumulative district-level road-building under PMGSY. As mentioned in Programme Details, it was derived by first adding one to the percentage of all eligible villages in district d that had received a PMGSY road before year t and then applying the log transform. The main parameter of interest was β_1, which captured the effect of providing 1 percent of all eligible villages in the district with a paved road.

To account for confounding factors, we included a vector of household and demographic control variables ($\mathbf{X_{ivdt}}$). This consisted of indicators for a woman's age in year t, religion, the woman's caste group, and whether the woman was the household head. There were likely unobservable, idiosyncratic differences between districts that would affect both fertility and road construction under PMGSY.[16] We included district fixed effects (δ_d) to control for such time-invariant differences. Furthermore, we added time-fixed effects (τ_t) to account for the average effect of other concurrent developments on fertility.

An extension: Roads within small geographic clusters

We were able to define a more granular measure of road construction, which relied on the GPS location of each NFHS village. This location was displaced by up to 5 km in any arbitrary direction, but within the district boundaries, to maintain respondents' anonymity. For each NFHS village v, we used the GPS coordinates by first constructing a circle with a 5-km radius centered around those coordinates and then mapping all census villages within the SHRUG data set whose geographic centers lay within this circle to the NFHS village. The matched census villages constituted the v's neighborhood. We subsequently defined our village-level measure of PMGSY roads analogously, that is, we computed the percentage of eligible villages in the neighborhood that received PMGSY roads up until the previous year, added one to this, and applied the log transform. We did not solely use this village-level measure as our primary measure because it had no corollary in the NSS data; village identifiers were completely absent in the latter. Our regression equation with this measure corresponded to Equation (1):

$$Y_{ivdt} = \beta_1 \log(\text{PMGSY})_{vt} + \mathbf{X_{ivdt}}\gamma + \nu_v + \tau_t + \epsilon_{ivdt}, \tag{2}$$

where ν_v denotes village fixed effects, which allowed us to control for time-invariant differences across villages that could shape outcomes such as fertility. Therefore, β_1 denotes the marginal effect of road connectivity improvements within the neighborhood of village v. $\log(\text{PMGSY})_{vt}$ is constructed as described above.

Addressing endogeneity: Instrumental variables

The pace of road construction under PMGSY likely varied systematically across districts, such that districts with more efficient public administration built roads more quickly. If so, high values of log(PMGSY), at least during the early years of our sample period, would have been highly correlated with the efficiency of the local administration. It was also possible that the quality of local administration would have determined the extent to which other concurrent schemes, such as the Janani Suraksha Yojana (JSY),[17] would affect fertility. Unfortunately, there was no numeric measure of the efficiency of local public administration in this setting. As such, if we were to use log(PMGSY) as is, any estimated effect would have suffered from endogeneity concerns.

The direction of the bias because of endogeneity was not obvious. For instance, suppose that districts with better public administration had lower preprogram fertility and greater road construction. Suppose, also, that road construction actually reduced fertility. In this case, the districts with more roads would have presumably experienced a smaller reduction in fertility because they had a lower base. We would have consequently obtained an underestimate of the true effect of roads on fertility.

We tried to address the endogeneity concern by using an instrumental variables (IV) approach, whereby we instrumented for actual road construction by using the fraction of villages in the district that should have received priority under the program rules as of the previous year. Recall that *priority villages* are those where the population at the baseline was at least as large as the program-specified cutoffs, which were either 1,000, 500, or 250 people. As population cutoffs under the PMGSY decreased over time, the fraction of priority villages would have either increased or remained the same. More importantly, the fraction of priority villages was unlikely to suffer from the same endogeneity concerns once we controlled for district fixed effects because this fraction relied on population counts from 2001, while the outcomes we observed pertained to later years. We implemented the IV starting with the following first-stage regression:

$$\log\,(\text{PMGSY})_{dt} = \alpha_1\ \text{PriorityVillages}_{dt} + \delta_d + \tau_t + \zeta_{dt}. \tag{3}$$

Then, we used the predicted values of $\log(\text{PMGSY})_{dt}$ to estimate Equation (1). The same process was used to estimate Equation (2). In effect, we used the part of the $\log(\text{PMGSY})_{dt}$ that was correlated with $\text{PriorityVillages}_{dt}$

to identify the effect of rural roads. We expected this correlation would be strong because our sample consisted of only those states that complied with program rules, that is, they prioritized the construction of roads in villages that met or exceeded the population cutoffs.

Identifying assumptions

The validity of our identification strategy depends upon several crucial assumptions. First, the parallel trends assumption is the idea that outcomes would evolve at the same rate across districts if the PMGSY had not been implemented. Here, we followed the literature (Aggarwal 2018, 2021) and conducted a placebo exercise to allay concerns about the existence of pre-trends, which are sufficient evidence to reject the assumption. We used data on outcomes from years before the PMGSY rollout to see whether future road construction was a strong predictor of these outcomes. For instance, we regressed fertility between 1996 and 2000 on values of $\log(\text{PMGSY})_{dt}$ from 2004 to 2010. If there were no pre-trends, the coefficient on the $\log(\text{PMGSY})_{dt}$ should have been statistically insignificant.

We also ran variations of estimating Equations (1) and (2), where we relaxed the assumption of parallel trends between districts. In the case of Equation (1), we included district-specific linear time trends, which allowed outcomes in each district—independently of the PMGSY—to grow at different rates over time. In Equation (2), we included district-year fixed effects, that is, we controlled for any confounders that manifested in a given district at any point in time.[18]

Results

In this section, we first present results that detail the effect of rural roads on fertility and then discuss the associated mechanisms.

Fertility

Table 2 shows how improvements in last-mile road connectivity affect household decisions to have an additional child. Column 1 of panel (a) corresponds to our benchmark specification, as given in Equation (1). We interpret the coefficient as follows: If the average district provides paved road access to all erstwhile unconnected villages, then fertility will decline by 0.006 percentage points. This is to say, in a random sample of 1,000 women, we would expect to see six fewer children being born each year. For context, the outcome mean of 0.119 implies that we can expect 119 children to be born to this cohort of women in a given year. Therefore, if all unconnected villages receive paved roads, then fertility will decline by 5 percent. The consequent decline in average family size will reduce the total cost borne by households in raising kids, which can allow households to

TABLE 2 Rural Roads and fertility

	OLS			Instrument variable		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): District						
log(PMGSY)	−0.0062***	0.0031	−0.0066**			−0.0080***
	(0.0017)	(0.0033)	(0.0026)			(0.0024)
PMGSY priority villages				5.54***	−0.035***	
				(0.26)	(0.013)	
Observations	1231029	276593	1231029	1231029	1231029	1231029
Outcome Mean	0.119	0.185	0.119	1.407	0.119	0.119
Outcome SD	0.324	0.389	0.324	1.147	0.324	0.324
Kleinbergen-Paap F-Stat						462.832
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District trends	No	No	Yes	No	No	No
Sample period	2004-15	1996-2000	2004-15	2004-15	2004-15	2004-15
Panel (b): 5 KM cluster						
log(PMGSY)	−0.0012*	−0.0015	−0.00050*			−0.011***
	(0.00066)	(0.0012)	(0.00029)			(0.0033)
PMGSY priority villages				1.33***	−0.014***	
				(0.13)	(0.0044)	
Observations	1187223	267106	1187223	1187223	1187223	1187223
Outcome Mean	0.119	0.185	0.119	1.229	0.119	0.119
Outcome SD	0.324	0.389	0.324	1.661	0.324	0.324
Kleinbergen-Paap F-Stat						107.153
District FE						
Year FE	Yes	Yes	No	Yes	Yes	Yes
District trends	No	No	Yes	No	No	No
Sample period	2004-15	1996-2000	2004-15	2004-15	2004-15	2004-15

NOTE: Standard errors are clustered at the district level. This table presents OLS estimates of the effect of PMGSY roads on the probability of a sample respondent conceiving a child in any given year. For details of variable construction, please refer to the Data section. The estimating equations in panel (a) are of type (1) and those in panel (b) are of type (2), as outlined in the Methods section. Controls include: household size, wealth quintile, religion and social category, whether the household is headed by a woman, the respondent's age in that year, her fertility history and her BMI at the interview time.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

increase per-capita investments in these children. This, in turn, can lead to greater human capital attainment among these children—proxied by years of schooling and health conditions—and hasten the arrival of other benefits of economic growth, which are predicated upon individuals having sufficiently high human capital (Bloom, Kuhn, and Prettner 2019; Bloom, Canning, et al. 2019).

In column 2 of panel (a), we undertake the placebo exercise detailed in the discussion on the identifying assumptions by using data on fertility from 1996 to 2000 and road construction from 2004 to 2008. As the coefficient on the log(PMGSY) was not significantly different from zero, we found no evidence to suggest there were pre-trends. Similarly, in column 3, we run a variant of Equation (1), albeit with district-specific linear time trends. Here, we found that our result was robust to this change. Therefore, we have no reason to believe that the parallel trends assumption is violated here.

The next three columns correspond to the instrument variable design, which allowed us to identify the salience of any endogeneity concerns in the Ordinary Least Squares (OLS) estimates. Column 4 presents the first stage regression, which establishes that the fraction of priority villages in the district is a strong predictor of actual road construction under PMGSY within that district. Column 5 presents the reduced-form effect of (the share of) priority villages on fertility, which is negative and in line with our findings so far. The IV estimate of the effect of rural roads on fertility, contained in column 6, is larger than the OLS estimate; it amounts to an expected decrease of eight births in a random sample of 1,000 women.[19] This is a nontrivial effect; given that overall fertility in these six states declined by four percentage points from 2001 to 2014, if all unconnected villages were to get PMGSY roads, then the resultant drop in fertility would be equivalent to 20 percent of this overall decline.

Panel (b) presents analogous results using the village-level measure of rural roads, estimated using Equation (2). From a qualitative standpoint, both the district- and village-level changes in local roads had the same effect. However, there was a clear difference in magnitude in most cases. For instance, from the OLS estimate in column 1, we infer that the effect of providing roads to all villages within a 5-km radius on fertility is one-fifth as large as the effect of providing roads to all villages in the district. However, endogeneity concerns are much more pronounced in the village-level measure of roads, as signified by the IV estimate in column 6 is 10 times larger than the OLS estimate in column 1. The IV estimate suggests that providing paved roads to all villages within a 5-km radius can produce a fertility decline tantamount to an annual decline of 11 births in a sample of 1,000 women. Nevertheless, we cannot rule out the hypothesis that an equivalent change in the district and village levels produces the same effect on fertility, which suggests that for household fertility decisions, last-mile connectivity in proximate areas matters more than in farther-away areas.

Our finding that the provision of roads leads to reductions in fertility aligns with the literature on big infrastructure projects (Khandker, Bakht, and Koolwal 2009; Kim and Prskawetz 2010; Grimm, Sparrow, and Tasciotti 2015). However, we demonstrate in the following sections that the reasons behind this decline in fertility differ, to varying degrees, from those discussed in prior work.

Infant mortality

Roads can affect fertility by influencing infant mortality rates. For example, if roads reduce the transport barriers to health care facilities for households,

TABLE 3 Rural Roads and Infant Mortality

	OLS			Instrument variable		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel (a): District						
log(PMGSY)	−0.0076**	0.0018	0.0027			−0.017***
	(0.0031)	(0.0048)	(0.0044)			(0.0042)
PMGSY priority villages				5.46***	−0.091***	
				(0.27)	(0.023)	
Observations	135855	52905	135855	135855	135855	135855
Outcome mean	0.128	0.161	0.128	1.433	0.128	0.128
Outcome SD	0.334	0.368	0.334	1.153	0.334	0.334
Kleinbergen-Paap F-Stat						393.794
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District trends	No	No	Yes	No	No	No
Sample period	2004-15	1996-2000	2004-15	2004-15	2004-15	2004-15
Panel (b): 5 KM Cluster						
log(PMGSY)	−0.0043***	−0.0015	−0.0028*			−0.019**
	(0.0015)	(0.0022)	(0.0016)			(0.0079)
PMGSY priority villages				1.22***	−0.024***	
				(0.13)	(0.0090)	
Observations	130733	50962	130733	130733	130733	130733
Outcome mean	0.128	0.162	0.128	1.245	0.128	0.128
Outcome SD	0.334	0.368	0.334	1.670	0.334	0.334
Kleinbergen-Paap F-Stat						91.409
District FE						
Year FE	Yes	Yes	No	Yes	Yes	Yes
District trends	No	No	Yes	No	No	No
Sample period	2004-15	1996-2000	2004-15	2004-15	2004-15	2004-15

NOTE: Standard errors are clustered at the district level. This table presents OLS estimates of the effect of PMGSY roads on infant mortality. For details of variable construction, please refer to the Data section. The estimating equations in panel (a) are of type (1) and those in panel (b) are of type (2), as outlined in the Methods section. Controls include: household size, wealth quintile, religion and social category, whether the household is headed by a woman, the respondent's age in that year, her age at first childbirth and her BMI at the interview time.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

they enable households to benefit from formal health care in times of illness and could consequently reduce infant mortality. Table 3 shows the results describing the effect of roads on the former. This effect was unambiguously negative, that is, road provision leads to reductions in infant mortality. From column 1 in panel (a), we found that providing roads to all eligible villages in the district can reduce infant mortality by 0.7 percentage points. Given that the average district experiences an infant mortality rate of over 12 percent, this translates into a 5 percent reduction over the mean. Further, as shown in column 2, there was no evidence of pre-trends in infant mortality. However, column 3 shows that this result was not robust to the inclusion of district-specific linear time trends because adding them produces a null effect. This means that the years in which districts build more roads than their annual average exhibit no reduction in infant mortality. One explanation is offered by Garg, Jagnani, and Pullabhotla (2022), who found that the road-induced exodus of workers from the agricultural sector led to shortages in farm labor, which increased the incidence of farm fires and drove up infant mortality in downwind areas (relative to the PMGSY beneficiary village). Essentially, if this farm fire effect is stronger when many roads are built rapidly, it could dominate the gains from better access to formal health care that manifest otherwise.

Columns 4–6 pertain to the IV strategy. As before, we noted that the OLS estimate was biased toward zero because the IV estimate suggests that providing roads to all unconnected villages can reduce infant mortality by 2.5 percentage points, that is, by 20 percent of the mean. Panel (b) extends the analysis to the village-level measure of rural roads. The effects were qualitatively the same, albeit lower in magnitude. Notably, the effect persists even when we add district-year fixed effects in column 3, which is a much more demanding specification than its counterpart in panel (a). This finding suggests that the effect of roads on infant mortality may vary over distance, that is, the beneficial effects are more pronounced if the roads are built in nearby villages, but they are canceled out by the undesired effects when roads are built farther away.

Child delivery and health care

This section addresses the mechanisms that could explain the decline in infant mortality. First, we study whether roads improve access to health care facilities. Second, we look at investments made by households into child health, namely breastfeeding and immunization. However, we only have data on these two sets of outcomes from 2010 to 2016 because the questions are asked for children aged five years and under. We estimate the effect of roads on each of these outcomes using the village-level measure and err on the side of caution by including district-specific linear time trends. The results are presented in Table 4.

Column 1 reveals that the number of antenatal visits by pregnant mothers did not increase even after roads were built. Assuming that either the distance to the facility or the transport cost had previously kept household demand for these services low, this result suggests that access did not improve after the PMGSY. However, as the average mother already undertook four antenatal visits, which is the recommended number as per the NFHS, the absence of any change does not necessarily rule out access-based improvements.

In contrast, column 2 shows that providing roads to all unconnected nearby villages could lead to children being breastfed for 11 more days, or, equivalently, by 2.25 percent of the median. Since breastfeeding could

TABLE 4 Rural roads and child health care

	Antenatal visits	Breastfeeding	Vaccination	Delivery center too far	Log (delivery cost)
log(PMGSY)	−0.069	0.35**	0.018*	−0.0068*	−0.028
	(0.046)	(0.18)	(0.011)	(0.0040)	(0.033)
Observations	36849	35969	51238	7234	11313
Outcome mean	4.424	17.662	−0.096	0.264	4.027
Outcome SD	4.433	11.933	0.809	0.441	3.987
Village FE	Yes	Yes	Yes	No	No
Year FE	Yes	Yes	Yes	Yes	Yes
District FE	No	No	No	Yes	Yes
District trends	Yes	Yes	Yes	Yes	Yes

NOTE: Standard errors are clustered at the district level. This table presents OLS estimates of the effect of PMGSY roads on health outcomes for children aged 0-5 years. For details of variable construction, please refer to the Data section. The estimating equations are of type (3), as presented in the Methods section. Controls include: household size, wealth quintile, religion and social category, whether the household is headed by a woman, the respondent's age in that year, her age at first childbirth and her BMI at the interview time.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

contribute to lower infant mortality in the absence of clean water (Jayachandran and Kuziemko 2011), this can partly explain the decline in infant mortality. Column 3 suggests that immunization rates were also responsible for this decline since improvements in road connectivity raised the vaccination index by 0.017 points, which amounts to a 10 percent increase over the median. This aligns with what Aggarwal (2021) finds regarding immunization, although she uses a larger sample of states. Our finding strongly suggests that roads improve access to health care. Somewhat similarly, column 4 suggests that providing roads led to a smaller fraction of women reporting that the delivery center was too far. However, column 5 shows no change in the mean out-of-pocket expenditure by households on the child's delivery, that is, the affordability of care seemed to remain unchanged.[20]

Labor market

We now turn to non-health-related mechanisms that can drive the fall in fertility. Specifically, we assess how employment among adults responds to the provision of rural roads and present the results in Table 5. Column 1 indicates that the effect of local roads on employment varied by gender; male employment rose in the aftermath of roads, but female employment fell. This pattern remained unchanged even in the IV design, as evident in column 2. Here, the much larger magnitudes of the latter suggest that the OLS regression provides a severe underestimate. The IV estimates indicate that if all villages with mud roads are given an all-weather road, employment among men could rise by 15 percentage points while employment among women could fall by 11 percentage points. From a normative perspective, this is a mixed result. On the one hand, a reduction in time spent on market

TABLE 5 Rural roads and labor market outcomes

	Employed		Only HH work		Currently in school	
	OLS	**2SLS**	**OLS**	**2SLS**	**OLS**	**2SLS**
log(PMGSY)	0.029***	0.15***	−0.033***	−0.12***	0.0040	0.033
	(0.0075)	(0.017)	(0.0081)	(0.017)	(0.0099)	(0.021)
Log(PMGSY) × female	−0.048***	−0.26***	0.069***	0.23***	−0.013**	−0.028***
	(0.0061)	(0.0070)	(0.010)	(0.0093)	(0.0054)	(0.0034)
Observations	178249	178249	178249	178249	50406	50406
Outcome mean	0.542	0.542	0.260	0.260	0.476	0.476
Outcome SD	0.498	0.498	0.439	0.439	0.499	0.499
p-value: female	0.012	0.000	0.000	0.000	0.328	0.828
Kleinbergen-Paap F-Stat		51.995		51.995		59.624
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes

NOTE: Standard errors are clustered at the district level. This table presents OLS estimates of the effect of PMGSY roads on employment and labor force participation among adults (18-60 years), and enrolment in school / college at the time of interview for young adults (14-22) in columns 1-2, 3-4, and 5-6, respectively. For details of variable construction, please refer to the Data section. The estimating equations are of type (1), as presented in the Methods section. Controls include: respondent's age (and square of age), marital status, education level, religion and social category, household size, ownership of land, and whether the household owns a NREGA card.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

employment grants women more time for leisure and household work. On the other hand, it weakens their bargaining power in household decisions (Anderson and Eswaran 2009) and exacerbates the problem of low female labor force participation (FLFP).

However, a decline in employment rates does not necessarily entail a fall in FLFP. To understand the effect of FLFP, we assess the change in the share of respondents engaged solely in household work. Column 4 shows that once roads were built, men were 12 percent less likely to participate only in household work, but women were 9 percent more likely to do so.[21] Given that female employment declined by 11 percent, this suggests that an overwhelming majority of the women who lose employment also drop out of the labor force. In columns 5 and 6, we explored whether the increase in employment was because of children or young adults aged between 14 and 20 dropping out of school or college, which can happen if sufficiently remunerative jobs are created (Becker 1974). Our evidence suggests otherwise, that is, any pecuniary externalities of jobs created due to PMGSY roads are not salient enough to compel adolescents to drop out of school and join the labor force.

It bears mentioning that our results on employment differed from those of Aggarwal (2018), who also studied the effect of PMGSY roads at the district level. We believe this is because of differences in our respective samples; we restricted attention to the six complier states, while Aggarwal (2018) used data from all 28 states. This is especially relevant because many of the noncomplier states, such as Bihar, have built lots of roads without fol-

TABLE 6 Rural roads and labor market outcomes (robustness); NSS rounds 50-55)

	Employed		Only HH work		Currently in school	
	Placebo	**Trends**	**Placebo**	**Trends**	**Placebo**	**Trends**
log(PMGSY)	0.026	0.027**	−0.034	−0.025*	0.12	0.0100
	(0.069)	(0.013)	(0.090)	(0.015)	(0.16)	(0.016)
log(PMGSY) × female	−0.029**	−0.049***	0.019	0.070***	0.012	−0.014**
	(0.015)	(0.0061)	(0.021)	(0.010)	(0.0094)	(0.0054)
Observations	60604	178249	60604	178249	17780	50406
Outcome mean	0.577	0.542	0.220	0.260	0.370	0.476
Outcome SD	0.494	0.498	0.414	0.439	0.483	0.499
p-value: female	0.958	0.094	0.866	0.005	0.443	0.803
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District trends	No	Yes	No	Yes	No	Yes
Sample period	1994-2000	2004-12	1994-2000	2004-12	1994-2000	2004-12

NOTE: Standard errors are clustered at the State-Region-Stratum level. This table presents OLS estimates of the effect of PMGSY roads on employment and labor force participation among adults (18-60 years), and enrolment in school / college at the time of interview for young adults (14-22) in columns 1-2, 3-4, and 5-6, respectively. For details of variable construction, please refer to the Data section. The estimating equations are of type (3), as presented in the Methods section. Controls include: respondent's age (and square of age), marital status, education level, religion and social category, household size and ownership of land.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

lowing program guidelines. Asher and Novosad (2020) also studied the effect of PMGSY roads on village-level employment using a regression discontinuity design on a sample of the six complier states. They found that overall employment did not change; moreover, they did not look at heterogeneity by gender. Although we did not report the result for brevity, we also found no change in overall employment. This is unsurprising because the opposing effects of roads on male and female employment were of similar magnitudes. Therefore, our result on employment complements their finding.

Additionally, employment effects are unlikely to be driven by the launch of India's workfare program, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which was implemented in a staggered fashion between 2006 and 2008. Imbert and Papp (2015) showed that MGNREGA led to a one-to-one crowding out of private employment, that is, people shifted away from private employers to public works. However, they did not document an increase in employment. In any case, our specifications in Table 5 included a covariate indicating whether the household owned an MGNREGA card, without which they cannot avail work under the program. This covariate allowed us to account for the availability of MGNREGA. We also tested the robustness of these results in Table 6, where we first ran placebo tests to test for pre-trends and then reran the specifications from Table 5 with district-specific linear time trends. None of the placebo tests suggest the existence of pre-trends, while the inclusion of district-specific trends does not qualitatively affect our results.

Ancillary results

As male and female employment changed in different directions, it was unclear whether household incomes changed and, if so, in which direction. Online Appendix A investigates this issue. We found no evidence of a change in incomes and, moreover, identified that PMGSY roads induced a decline in the share of households that reported agriculture as their primary source of income. This suggests that perhaps paved roads enable men to take up higher-paying jobs that can offset the foregone income from women's employment. Our finding is consistent with the studies by Asher and Novosad (2020) and Aggarwal (2018), who found that workers switched to retail and manufacturing jobs once paved roads were built within a village. Given that these jobs are more likely to be in distant urban areas, it is plausible as a result of issues such as safety and norms that men can access them more easily than women. Nevertheless, because we observed no tangible change in household incomes, any effects of roads on the affordability of childcare would have to be through indirect means, such as cheaper transportation fares.

In Online Appendix B, we ruled out other possible mechanisms that could explain our result on fertility. Briefly, we found that rural roads mitigate the transport barriers to health care without affecting contraceptive use. We also demonstrated that access to care workers, which was bolstered by a contemporary public program known as the JSY, was not systematically different in villages that received PMGSY roads compared to those that did not.

Additionally, in Online Appendix C, we illustrated the medium-term effects—those that occur with a lag of five years—of roads on all the outcomes that have been previously studied. We noted that the fertility decline persisted in the medium term, although infant mortality and other health indicators became unresponsive. This suggests that while the mechanisms operate in the short term, they can affect both contemporaneous and future fertility.

Discussion

Rural road connectivity, particularly in erstwhile isolated regions, can be the harbinger of significant change. It can improve transport networks and hasten structural transformation (Asher and Novosad 2020), enrich households' consumption baskets (Aggarwal 2018), increase the uptake of immunization and institutional care for in-utero children (Aggarwal 2021), and facilitate young children's access to education (Adukia, Asher, and Novosad 2020). However, not all changes may be desirable. Although the movement of workers out of agriculture increases mechanization on farms (Shamdasani 2021), it also leaves behind a shortfall of agricultural labor that, in certain areas, brings about an increase in farm fires, air pollution, and infant mortality (Garg, Jagnani, and Pullabhotla 2022).

Against this backdrop, in this paper, we asked how last-mile connectivity affects fertility and shed light on the possible mechanisms. We found that road provision unambiguously decreases fertility by as much as 5 percent of the mean. This change appears to be driven primarily by a roughly equivalent decline in infant mortality, which can reduce the uncertainty around child survival and decrease the household demand for additional children (Adsera and Menendez 2011). The fall in infant mortality itself can be attributed to an increase in child immunization and breastfeeding because the latter is salient. Furthermore, we demonstrated that roads improve households' access to health care facilities and posited that these access improvements could explain the uptick in immunization, reinforcing a congruent finding by Aggarwal (2021). However, we also showed that roads have mixed effects on employment; men are more likely to work once roads are built, but women are less likely to do so. The opposing effects were similar enough that aggregate employment did not change, as documented by Asher and Novosad (2020). In line with this, we found no evidence of change in household consumption expenditure. Thus, road connectivity can worsen the gender gap in employment while allowing mothers to spend more time, if not resources, on childcare.

An obvious limitation of our analysis is the need for district-level aggregation when studying employment and household consumption because more granular identifiers are absent in the data. Nevertheless, the qualitative similarities between the effects on fertility and infant mortality when we used district- and village-level measures of road access provide some confidence that the district-level results are indicative of effects at a more granular level. Another issue is that we cannot disentangle the short- and medium-term effects of roads principally because we used a cumulative measure of road construction. However, our choice ensures that we do not omit the lagged effects of roads, which are akin to economic shocks that affect fertility with a lag of between one and four years (Sobotka, Skirbekk, and Philipov 2011; Lovenheim and Mumford 2013). In line with this literature, we found that roads affect fertility in the medium term. Nevertheless, there may exist another mechanism that could explain how roads induce this effect because our principal channel—a decline in infant mortality—is no longer active in the medium term. Identifying such a mechanism may be an exercise for future research.

In a wider context, the means through which PMGSY roads affect fertility differ substantially from several other forms of infrastructure that have been well-studied in previous literature. For instance, Gertler and Molyneaux (1994) found that in Indonesia, better availability of health facilities is associated with lower fertility because of higher contraceptive use. Contraceptive use and adoption of "stopping behavior" has been the dominant mechanism in reducing fertility for several infrastructure advances, such as rural electrification (Dinkelman 2011) and the rapid spread of television programs (La Ferrara, Chong, and Duryea 2012). However, we found no evidence to suggest that contraceptive use increased in our setting. Moreover, rural roads can create employment opportunities for women (Khandker, Bakht, and Koolwal 2009; Khandker and Koolwal 2011), which can reduce the demand for children (Schultz 1969). On the other hand, we found that the provision of PMGSY roads is actually associated with a decline in FLFP. Instead, we found the fall in infant mortality enabled by improved access to health care facilities to be the major driver of a reduction in fertility. Put simply, it appears that last-mile connectivity brings to the fore the quality–quantity trade-off faced by households (Rosenzweig and Evenson 1977), whereby households decide to have fewer children, but invest more in each child. Moreover, the lack of change in contraceptive use is likely why the observed decline in fertility is smaller than when compared to interventions such as rural electrification. For example, in the Indonesian setting, rural electrification can explain up to 65 percent of the overall decline in fertility (Grimm, Sparrow, and Tasciotti 2015), while our estimates suggest that PMGSY roads cannot produce more than 20 percent of fertility decline observed in India during 2004–2015.

From a policy perspective, the effects of rural roads on child health care provide evidence for positive social externalities. These benefits are likely to compound over time because better health translates into improved educational attainment (Alderman, Hoddinott, and Kinsey 2006; Bobonis, Miguel, and Puri-Sharma 2006) and labor supply (Baird et al. 2016), which has implications for both spatial and intergenerational mobility (Ahlburg 1998). Further, as improvements in the "quality" of children through reduced mortality and increased health investments would coincide with lower fertility, rural roads have the potential to hasten the demographic transition (Cervellati and Sunde 2011). The benefits are not limited to the demand side of health care; we found suggestive evidence that rural roads improve households' access to formal health care and, hence, help resolve the supply-side constraints in the last-mile delivery of health inputs for children. More generally, across the developing world, the provision of all-weather roads has been linked to reductions in poverty (Gibson and Rozelle 2003; Dercon et al. 2009; Khandker, Bakht, and Koolwal 2009). Despite these desirable consequences, our results on employment showed that there is a strong gender dimension to the effect of roads. The mixed nature of our results underscores the need to study the multifaceted consequences, intended or otherwise, of massive infrastructure programs such as the PMGSY and to ascertain their impact on socioeconomic welfare.

Notes

1 Throughout this paper, we define fertility as the probability of a woman aged between 16 and 49 giving birth in any given year.

2 The demographic transition denotes a country's shift away from a high fertility, high infant mortality setting towards a low fertility, low infant mortality environment.

3 As of 2022, it has provided connectivity to over 90 percent of the 178,000 eligible habitations by building more than 780,000 km of roads at a cost of $48 billion during its lifetime.

4 The population criterion was based on the 2001 census and applies to all regions except those with designated special status. In the special category states (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Himachal Pradesh, Jammu & Kashmir, and Uttarakhand), designated Desert Areas, designated Tribal Areas (listed in Schedule V of the Constitution), and selected Tribal and Backward Areas (identified by the Ministry of Home Affairs and Planning Commission), habitations with a population of 250 persons and above are eligible.

5 We use village as a shorthand for *revenue villages*, which are the smallest rural administrative units in India and consists of one or more habitations. As of the 2011 Population Census, the average village in India is home to over 1,200 people.

6 A state is the second level of administration in India that has its own government with the legislative power to make specific decisions. A district is the third level of administration, with each state containing several districts.

7 As of 2023, the PMGSY has had three phases. We only concern ourselves with the first phase, where program guidelines prioritized villages exclusively on population cutoffs. Subsequent phases launched in 2013 and 2022 also use socioeconomic criteria to prioritize villages.

8 The two exceptions are (i) transport barriers to health care and (ii) immunization, where we find a null effect on a sample of all Indian states. In contrast, on a sample of the complier states, we find that transport barriers reduce and immunization increases in the aftermath of roads.

9 The data can be obtained at https://www.devdatalab.org/shrug.

10 Each state in India is made up of multiple districts, which are also administrative units. The average district is approximately 11 km^2 in size and comprises just over 1,500 villages.

11 A village was considered eligible if, at the baseline (2001), it had unconnected habitations and a population of at least 250 people.

12 We were unable to use NFHS-3 (2005–2006) because it lacks district identifiers, unlike subsequent rounds. The smallest geographic identifier that is available in NFHS-3 is the state, with the average state containing 30 districts. Other geographic identifiers were removed to preserve the respondents' anonymity because the survey included questions on HIV status. Prior rounds were also unused for two reasons. First, the number and boundaries of spatial units (districts) over which we conducted our analysis have changed markedly over time. Second, the prior rounds had smaller sample sizes that were not representative at the district level, which introduces additional errors in any comparisons over time.

13 For each outcome variable, we computed its mean and standard deviation for children of a given age residing in *control group districts*, that is, districts where no PMGSY roads had been built. We then used these computed values to standardize the outcome variable. The aggregation process is akin to taking a weighted sum of the standardized outcome variables, where the weight on an outcome is lower if it is highly correlated with other outcomes (i.e., its inclusion does not add much more information).

14 The minimum working age in India is 14 years. Employment was coded as missing for those who reported one of the fol-

lowing as their employment status: (i) beggar or sex worker; (ii) unable to work because of physical disability; and (iii) pensioner or rentier.

15 In a classical DiD framework, the construction of PMGSY roads within a district would be denoted by a binary outcome, which would take the value 1 if any roads were built and 0 otherwise. However, the continuous DiD approach defines the intensity of road construction using a measure that can take any number of different values (see the Data section for how we define our road measure).

16 For example, districts with fertile land could be more agrarian, which could create an incentive for families to bear more children so that they can work in the field. However, these areas could also be poorer, lack industry, and not be as well connected. Consequently, they could be eligible to gain more roads as a result of PMGSY.

17 The JSY was a safe motherhood intervention under the aegis of the National Health Mission, designed to promote institutional deliveries among women. It involved financial assistance of either Rs. 600 ($13) or Rs. 1,400 ($31), with the larger amount being offered to mothers if they belonged to states with high fertility.

18 For example, if local officials of some district d conducted a family planning drive in year t, the average effect of that drive on fertility across all villages in district d for each year would be accounted for by the fixed effect.

19 The OLS estimate lies well within the 90 percent confidence interval around the IV estimate, which suggests that endogeneity concerns are not very pronounced.

20 This finding could mean that households either continued to visit the same health facilities even after roads were available and other costs did not change or chose to visit more expensive and distant health facilities amid a drop in transport costs. Unfortunately, we cannot say for certain which of the two alternatives is true.

21 Although we omitted the result for brevity, we found that nearly half of the decline in female employment was because of the agricultural sector. However, men are just as likely to drop out of agriculture because the sector shrinks once roads are built and local markets are interlinked more closely (Asher and Novosad 2020). The differences in employment, we suspect, are also because the employment opportunities after road development will differ for men and women, especially if non-hyperlocal jobs become available once commute becomes easier.

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