ECONOMIC IMPACT EVALUATION OF HIGHWAY IMPROVEMENTS IN THE REPUBLIC OF GEORGIA USING A ROBUST QUASI-EXPERIMENTAL DESIGN AND GIS

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ABSTRACT

We present the results of a rigorous quasi-experimental design economic impact evaluation of the more than US$ 200 million improvement of approximately 220 km of highway in the Republic of Georgia by the Millennium Challenge Corporation, constructed between 2008 and 2010. The evaluation methods were implemented: a treatment-control difference-in-difference, a dose-response continuous treatment approach that estimated project impacts across geography, and a matched difference-in-difference using Propensity Score Matching (PSM). Data sources included a 12-round traffic count and speed survey, a village-level survey of 960 settlements, and 36 rounds of a quarterly household-level survey, as well as high-resolution GIS road network data. It is found that the roads improvements increased the volume of traffic by an average of 44.2 vehicles per day (4.2%), while the average speed increased by 13.6 km/h (24.4%). The project also led to a 26.9% increase in the number of industrial facilities (i.e. canneries, factories, agricultural processing facilities, and similar enterprises) near the project roads. We do not observe changes in cropping patterns or land use at the community level. The project had impacts on the prices of a number of food products on local markets, but in a complex way. No strong evidence is observed on income, consumption, asset ownership, employment, or utilization of health and education services. The study contributes to the literature by presenting the results of rigorous quasi-experimental design methodology that further utilizes highly accurate GIS data to improve the precision and allow for the estimation of impacts across geography.

Keywords: impact evaluation, impact assessment, quasi-experimental design, difference-in-difference, economic development, GIS
INTRODUCTION

The importance of transport infrastructure, particularly road infrastructure, in economic development is widely recognized in the development economics literature. Where road networks are poorly developed, transportation costs are high, inhibiting investment, innovation, the competitiveness of the private sector in export markets. High transportation costs can also affect households, reducing real incomes, and limiting access to health, education, and employment (1).

Given the economic importance of road network improvements for economic development in developing countries, it is not surprising that often the majority of foreign aid provided is for road related projects: for example, the African Development Bank invests almost 80% of its portfolio in infrastructure (2). Since the onset of the global financial crisis in 2008 and with rising road materials costs, fiscal pressures on official infrastructure development assistance support have greatly intensified, while demands from external stakeholders and developing countries in a world of rapid urbanization have only increased.

Consequently, the focus on results-based evaluation systems for road infrastructure to provide tangible evidence that the designed infrastructure has met and is meeting the objectives originally set for it, such as poverty reduction, is unprecedented (2). In this context, the use of quasi-experimental design evaluations is in increasing demand because of their robust ability to reduce estimation bias. In addition, due to rapid increases in the resolution and availability of GIS or geospatial data in developing country contexts, the use of such data is particularly applicable for infrastructure evaluation models because of its potential to estimate project impact variation across geography. Yet developing quasi-experimental road evaluation methodologies using GIS data for high-accuracy quantification of accessibility is a developing field that has not been fully explored (3).

This paper presents the results of a large-scale, rigorous impact evaluation of the more than US$200 million improvement of approximately 220 km of highway in the Republic of Georgia. Further, the study contributes to the literature by presenting the results of rigorous treatment-control, pre-post double-differences quasi-experimental design methodology that further utilizes highly accurate GIS data to improve the precision and allow for the estimation of impacts across geography.

BACKGROUND

In September 2005, the Millennium Challenge Corporation (MCC), a US Government foreign aid agency, signed a five-year, $295.3 million Compact with the Government of Georgia to improve two main barriers to economic growth in rural areas of Georgia: a lack of reliable infrastructure and the slow development of businesses, particularly agribusiness. Approximately $200 million of the Compact funds were designated to improve a key regional transport route that connects the Capitol of Georgia, Tbilisi, to both Turkey and Armenia, and which also runs through one of the poorest rural agricultural regions of Georgia. Known as the Samtskhe-Javakheti roads (SJ roads) project, since the road length reaches its connections to Turkey and Armenia in Samtskhe-Javakheti Region, the route was originally a highway maintained during the Soviet era, but which was in a very poor condition by 2006 (see Figure 1). The SJ road improvement runs through one of the poorest regions of Georgia: per capita income is
significantly below the national average, with more than 40 percent of the population having a
daily income of $2 or less in 2009 (4). Agriculture consists primarily of potatoes but also
cabbages, carrots and grain, with some cattle breeding for export (dairy products are mostly
consumed or sold locally) (5). By 2005, the SJ road condition has deteriorated to the point that
some sections measured International Roughness Index (IRI) as high as 16.6, with a total travel
time from Tbilisi to Turkey of more than 8 hours.

FIGURE 1 Location of SJ roads improvement in Georgia, connecting Tbilisi to Turkey
and Armenia

Improvements began in the spring of 2008, and were largely completed by December 2010. To
assess the efficacy of its investments in this area, MCC commissioned a rigorous economic
impact evaluation of the SJ roads activity, which was conducted since June 2006 by NORC at
the University of Chicago.

EXPECTED ROAD IMPROVEMENT OUTCOMES
The outcomes that the evaluation considers stem from the existing literature on economic and
social impacts of rural infrastructure improvements in developing countries, program logic
expectations from MCC, and the available data. These outcomes are comprised of five
categories as follows:

Transportation-related outcomes
We measure this using traffic counts, vehicle speeds, and self-reported travel times to points of
interest; a wide range of previous studies have considered similar outcomes (6) in Bangladesh,
(7) in Morocco, and (8) in Tanzania. In addition, the road improvement should reduce transport costs, and thus potentially increase access to public transportation if suppliers of transport respond to market prices. We thus consider both household-level expenditure on transportation, and the frequency of minibuses to various locations. Reductions in transportation costs have been found by (9) in Peru, and (10) in Bangladesh.

**Investment, employment, and land use**

An important channel by which road improvements lead to economic and social benefits is through increased investment and employment. A number of studies have found beneficial impacts of roads improvements on off-farm employment, including (11) and (12). Additionally, we would expect changes in land use towards the new investment activities, as well as potential changes in cropping patterns to favor crops with higher transportation costs, as these become relatively cheaper to produce.

The related outcomes that our evaluation considers are the number of industrial facilities at the community level, as well as whether the most common land use in the community has changed. In terms of employment, we consider household-level employment in the form of the percentage of adults with regular work.

**Market prices**

Another observable channel by which the roads improvements can affect outcomes is through the market prices of goods that are transported along the roads. These effects are somewhat complex, as roads improvements could either increase or decrease prices depending on the structure of the market and who bears the transaction costs (13). While our price data is limited, our data do allow us to analyze the impact of the project on consumer prices of wheat, beef, milk, potatoes, and honey.

**Household welfare**

Ultimately, the benefits of the road improvement should be observable in terms of benefits to households. The most direct measure of economic impact at the household level is household income, which we consider here. A number of previous studies have found positive impacts on income (14), (11), (15) and (16). However, income can be difficult to measure and many studies thus focus alternatively or additionally on household consumption, including (11) and (17). We consider total consumption per household member as well.

Moreover, both consumption and income are susceptible to measurement error and bias, and in some cases focusing instead on ownership of durable assets can be a more reliable alternative. Positive impacts of rural roads on asset ownership have been observed by (18), (19) and (11). We thus use an asset ownership index as an additional measure of household welfare. The asset ownership index is calculated using a principal components transform of survey data on 28 types of durable assets that are typically owned by Georgian households, including refrigerators, televisions, and stoves. This approach has since been widely used in the literature (20).

**Access to health and education**

Another important set of social outcomes that arises from roads improvements are those related to improved access to public services. Improvements related to health services have been
observed by (14), (7), and (21). In terms of education, (7) finds improvements in primary education enrollment rates in Morocco, while (22) identify increases in primary school completion rates in Vietnam. The outcomes we consider are the likelihood that treatment in a clinic, household, or from a doctor’s visit is obtained in the case of illnesses at the household level, as well as the likelihood that all primary school aged children in the household attend school.

**EVALUATION METHODOLOGY**

A central consideration of any impact evaluation is its approach to establishing the causal impact of the intervention. This is because for most interventions, the outcomes of interest are affected not only by the intervention itself but by a range of other factors as well. Thus, the evaluation must develop an approach to identifying the extent to which the observed changes are due to the non-project factors. The approach of the evaluation to inferring causality is referred to in the economics literature as the “identification strategy;” the broader evaluation literature sometimes uses the term “attribution.”

We utilize two alternative approaches for this identification strategy. The first is a more widely used technique in the literature, while the second is rarer and represents a more recent contribution to the methodology of causal impact of road improvements.

**Difference-in-difference**

A common approach in the literature is to use a binary treatment variable in the context of a standard treatment and control set-up. At the outset of the program, a selection of similar comparison roads is selected. A treatment sample of individuals or communities is selected from within a certain radius of the improved roads, with another comparison sample drawn from within the same radius of the comparison roads, representing the counterfactual. Thus, individual observations are defined as having either been treated or untreated, and impact evaluation calculates an average treatment effect over the treated population, sometimes incorporating propensity score matching techniques to reduce the potential for selection bias (23). This is a widely used approach in the roads evaluation literature; some recent examples of papers that have used these methods include (24), (25), (26), (27).

**Continuous treatment**

An alternative approach is to define treatment in terms of continuous variable. The justification for this approach is that the effects of roads improvements are spatially mediated. Unlike some other kinds of interventions, roads improvements do not reduce travel times and costs for a well-defined set of beneficiaries in a uniform way. Rather, the extent to which travel times and costs are reduced depends on the particular location of the beneficiary, with some experiencing greater reductions than others depending on the importance of the road in travelling to destinations of interest. This approach distinguishes between treated individuals in terms of having received higher or lower “doses” of the treatment depending on their location. Using a continuous treatment approach also requires that the measure of treatment must be specified. One option is to use GIS data to calculate approximate travel times between potential project beneficiary and the treatment and comparison roads. This approach is considerably rarer in the literature and as a methodology is still being developed, taking a variety of approaches to defining the treatment variable (25), (28), (10), and (29).
The present evaluation incorporates both approaches. The principal advantage of the first approach is that provides coefficients that are more readily interpretable, within a framework that is easy to understand and communicate. However, in the case that benefits are not experienced uniformly across space, difference-in-difference may obscure the true impact, while a continuous treatment approach can measure variation in the degree of impact with increasing accessibility. In addition, while the continuous treatment and difference-in-difference estimates are both subject to potential selection bias, these potential sources differ in each case.

**Selection of Comparison Roads**
Comparison roads were selected using PSM from an inventory of 117 road segments for which data on a variety of characteristics was available from RDMED, the Georgian government roads agency. Our application of PSM in this case is to estimate a logistic regression model of the probability that a road is part of the treatment group as a function of observable characteristics. The following characteristics that were used in the PSM specification:

- Average Daily Traffic Volume per road segment, RDMED
- Length of Segment
- Mean Elevation of Segment
- Standard Deviation of Elevation of Segment (Topographic Variation)
- Maximum Elevation of Segment
- Minimum Elevation of Segment
- Mean Spatial Density of Georgian Villages within 20 Kilometers of Segment
- Travel time to Nearest City
- Travel time to Nearest Large Town
- Travel time to Tbilisi

**DATA**
To measure these outcomes, the evaluation makes use of three different datasets: a traffic dataset including vehicle counts and speeds, a community-level survey to measure outcomes at the level of the community, and a household survey to investigate outcomes at the household level.

**Traffic Survey**
Our volumetric traffic survey was designed to record vehicle counts on a network of traffic stations on the SJ treatment roads, as well as on a set of comparison roads. The data were collected quarterly, to record variation in seasonal traffic counts, over a 3-year period for a total of 12 waves, from September 2009 until May 2012, for 8 different vehicle types in both directions. Vehicle speed was measured by conducting a test drive using a vehicle representative of the most frequent vehicle type. Traffic speed data was collected on the project roads only.
Community-Level Survey
The community-level survey, or Settlement Infrastructure Survey (SIS), was a longitudinal panel survey designed for the evaluation to measure outcomes at the level of the village or town. The survey was conducted in three rounds: a baseline in 2007, a mid-project round in 2010, and a post-project round in August 2012. The survey sample used the most recent Georgian 2002 Census to identify a sampling frame of 960 settlements (Figure 2). The instrument was comprised of the following modules:

- Geographic and demographic information
- Utilities
- Transport
- Roads
- Agriculture
- Markets and their accessibility
- Prices
- Industry and construction
- Savings and credit
- Education
- Health care
- Programs implemented in the settlement
- Climatic and environmental conditions
Finally, household level outcomes were measured using the Integrated Household Survey (IHHS), a dataset that is collected by the National Statistics Office of Georgia (GeoStat) for a variety of government and research purposes. The IHHS has been collected quarterly since 1996, and includes a broad range of information on household characteristics. The evaluation includes IHHS data collected between the first quarter of 2003 and the fourth quarter of 2011, a total of 36 rounds.

GIS Data
Highly accurate GIS data on Georgian road networks was obtained from the Georgian Roads Department in the Ministry of Economic Development (RDMED), including annual updates to these networks that RDMED conducts to support its Pavement Management System (PMS). Accurate geo-locations for all settlements in the SIS and IHHS surveys, as well as for the locations of traffic survey stations, were provided by the Georgian government.

EVALUATION MODELS
Traffic Outcomes
For the vehicle counts, we use a difference-in-difference model as follows:
\[ Tr_{it} = \beta_0 + \beta_1 V_{it} + \beta_2 \delta_t + \gamma (\delta_{post} \times \delta_{treat}) + \alpha_i + \varepsilon_{it} \]

Where:
- \( Tr_{it} \) is daily traffic count on segment \( i \) during wave \( t \) of the traffic survey
- \( V_{it} \) is a control variable for vehicle type
- \( \delta_t \) is a vector of time dummies representing 11 of the 12 survey waves
- \( \delta_{post} \) is a dummy equal to 1 for observations after construction was completed
- \( \delta_{treat} \) is a dummy equal to 1 for a segment in the treatment group
- \( \alpha_i \) is a segment-level fixed effect
- \( \varepsilon_{it} \) is a random error term

The \( \beta_i \) are parameters to be estimated, and

\( \gamma \) is estimate of the average treatment effect (ATE)

For average speed, we only have data along the treatment roads. Thus, unlike the other models that we estimate, the impact on average speed is not relative to the comparison roads but instead relative to average speeds on the treatment roads before the project. We do not view this as a major shortcoming, however, as we would not expect significant changes in average vehicle speeds to have occurred for reasons other than roads improvements. Our model is:

\[ S_{it} = \beta_0 + \beta_1 T_t + \beta_2 Q_t + \gamma (\delta_{post}) + \alpha_i + \varepsilon_{it} \]

Where:
- \( S_{it} \) is average speed on segment \( i \) during wave \( t \) of the traffic survey
- \( T_t \) is a yearly time trend
- \( Q_t \) is a vector of quarterly dummies to reflect seasonality
- \( \delta_{post} \) is a dummy equal to 1 for observations after construction was completed
- \( \alpha_i \) is a road segment-level fixed effect
- \( \varepsilon_{it} \) is a random error term

The \( \beta_i \) are parameters to be estimated, and

\( \gamma \) is estimate of the program impact

**Community-Level Outcomes**

Our modeling approach includes three specifications: difference-in-difference, continuous treatment, and matched difference-in-difference.

**Difference-in-difference**

Our empirical model for the difference-in-difference estimation is as follows:

\[ Y_{it} = \beta_0 + \beta_1 X_i + \beta_2 \delta_{2007} + \beta_3 \delta_{2010} + \beta_4 \delta_{2012} + \gamma (\delta_{2012} \times \delta_{treat}) + \alpha_i + \varepsilon_{it} \]

Where:
- \( Y_{it} \) is outcome \( Y \) for community \( i \) at time \( t \)
- \( X_i \) is a vector of community control variables
- \( \delta_{2007}, \delta_{2010}, \delta_{2012} \) are time dummies corresponding to each survey round
\[ \delta_{treat} \] is a dummy equal to 1 for the treatment group
\[ \alpha_i \] is a community-level fixed effect
\[ \varepsilon_{it} \] is a random error term
The \( \beta_i \) are parameters to be estimated, and
\[ \gamma \] is estimate of the average treatment effect (ATE)

The impact of the project is measured using the coefficient on the interaction term \( \gamma \) between treatment status and time period. Thus, in effect we ask how outcomes differ for the treatment group following the treatment, as compared to outcomes for the treatment group prior to the treatment and the control group both before and after the treatment. Here, the treatment group is defined as all settlements within 30 minutes travel time of one of the improved roads, while the comparison group is defined as all settlements within 30 minutes travel time of a control road.

**Continuous treatment**
Using the same notation, the continuous treatment model is:

\[
Y_{it} = \beta_0 + \beta_1 X_i + \beta_2 \delta_{2007} + \beta_3 \delta_{2010} + \beta_4 \delta_{2012} + \varphi (\delta_{2012} \times D_i) + \alpha_i + \varepsilon_{it}
\]

Where \( D_i \) is the travel time between cluster \( j \) and the nearest project road.

Here our estimate of impact is given by \( \beta_4 + (\varphi \times D_i) \). For an outcome that is increasing in the treatment, we expect \( \beta_4 \) to be greater than zero and \( \varphi \) to be less than zero, reflecting the fact that the impact is smaller as \( D_i \) increases.

**Matched difference-in-difference**
As described in above, the matched difference-in-difference approach uses a restricted sample to reduce the potential for selection bias. For independent variables in the first stage regression we used: population, elevation, distance to nearest city, distance to the nearest treatment or comparison road, and dummies reflecting whether agricultural or trade are major sources of employment, the presence of industrial facilities, and recent incidence of natural disasters.

**Additional considerations**
Our Community-Level Outcome models make use of the panel nature of the data by using a fixed effects specification, thus effectively controls for any characteristics of the communities that do not change over time, but that might affect outcomes. We include a number of control variables to account for factors that could change over time and affect our outcomes. These are as follows: log of population; incidence of natural disaster; road maintenance; whether or not almost all of the settlement is engaged in agriculture; and whether or not most of the settlement is involved in wholesale or retail trade. In addition, we include dummies for whether the settlement is a major producer of various crops in our price regressions, and a dummy indicating whether there is an industrial facility present in the settlement except where the number of industrial facilities is the dependent variable.

**Household-Level Outcomes**
As in the previous case, we include difference-in-difference, continuous treatment specifications, and matched difference-in-difference specifications. For the purposes of the evaluation, the
structure of the data is a repeated cross-section, but with the longitudinal aspect of the data imposing additional correlation between outcomes measured at different points in time from the same household. As a result, the appropriate empirical specification is a mixed effects model with a fixed effect for the cluster and a random household effect.

Difference-in-difference
The empirical model for the difference-in-difference model is as follows:

\[ Y_{ijt} = \beta_0 + \beta_1 X_{ij} + \beta_2 \delta_t + \beta_3 \delta_{post} + \gamma (\delta_{post} \times \delta_{treat}) + \alpha_j + \tau_i + \varepsilon_{ijt} \]

Where:
- \( Y_{ijt} \) is outcome \( Y \) for household \( i \) in cluster \( j \) at time \( t \)
- \( X_{ij} \) is a vector of household controls
- \( \delta_t \) is a vector of time dummies
- \( \delta_{post} \) is a dummy equal to 1 in the post-treatment period
- \( \delta_{treat} \) is a dummy equal to 1 for the treatment group
- \( \alpha_j \) is a cluster-level fixed effect
- \( \tau_i \) is a household-level random effect
- \( \varepsilon_{ijt} \) is a random error term
- The \( \beta_i \) are parameters to be estimated, and
- \( \gamma \) is estimate of the average treatment effect (ATE)

Note that because the treatment is defined at the cluster level, we do not control for treatment status alone, since this is subsumed in the cluster level fixed effect.

Continuous treatment
Using the same notation as above, the continuous treatment model is:

\[ Y_{ijt} = \beta_0 + \beta_1 X_{ij} + \beta_2 \delta_t + \beta_3 \delta_{post} + \varphi (\delta_{post} \times D_j) + \alpha_j + \tau_i + \varepsilon_{ijt} \]

Where \( D_j \) is the travel time between cluster \( j \) and the nearest project road. In this case the impact of the project is given by \( \beta_3 + (\varphi \times D_j) \). As above, for an outcome that is increasing in the treatment, we expect \( \beta_3 \) to be greater than zero and \( \varphi \) to be less than zero, reflecting the fact that the impact is smaller as \( D_j \) increases.

Matched difference-in-difference
We match at the community rather than the household level, since households remain in the sample for one year only. Here, the variables in our first-stage regression are: settlement elevation, settlement population, distance to the nearest treatment or comparison road, and distance to the nearest major city.

Additional considerations
We opt for a limited set of household-level control variables in our models because of endogeneity concerns: many of the household characteristics that could explain variation in the levels of our outcome variables could also be affected by the treatment. Our control variables
are thus as follows: household size; age and education of the household head; and a dummy variable indicating whether any member of the household is employed in agriculture.

**Interpretation of the coefficients for community and household level models**

For the difference-in-difference and matched difference-in-difference models, the value of the coefficient $\gamma$ on the interaction term between the treatment dummy and the post-treatment period time dummy is an estimate of the average treatment effect (ATE) - that is, the average change in the outcome in question that results from the SJ roads improvement.

For the continuous treatment model, the interpretation is more complex, as the magnitude of the impact for a particular community or household depends on its distance from the nearest treatment road. As shown in the methodology section, the model’s estimate of the magnitude of the impact is given by $\beta + (\varphi \times D_t)$, where $\beta$ is the coefficient on the dummy variable indicating the post-treatment period, $\varphi$ is the coefficient on the interaction between distance from the treatment road, and $D_t$ is the distance of the particular community or household from the nearest treatment road. The intuition is that $\beta$ reflects the impact of the treatment for a household located immediately along a treatment road, while for every minute of travel time for a community to the nearest treatment road, the impact of the SJ road improvement changes by $\varphi$ units.

For an outcome that is impacted by the treatment, we thus expect the two coefficients to be of opposite signs. If $\beta$ is positive, meaning the treatment increases the value of the outcome in question, $\varphi$ should be negative, since a higher value of $D_t$ should result in a smaller impact.

In our presentation of the results below, for brevity we omit the results for the control variables and include only the coefficients on our impact measures. For the difference-in-difference and matched difference-in-difference model, we report $\gamma$, the average treatment effect. For the continuous treatment model we report $\beta$ and $\varphi$, the coefficients on the treatment time period dummy and the treatment time dummy interacted with distance from the nearest project road. The results include the associated t- or z-statistics calculated from robust standard errors.

**ECONOMETRIC RESULTS**

**Traffic Results**

Our traffic count and speed outcomes are presented below (Table 1). In both cases, the results are of the expected sign and statistically significant. Following the completion of construction, the average number of vehicles increased by 44.2 vehicles per day, while the average speed recorded along the project roads was higher by 13.6 km/h. This corresponds to a 4.1% increase in daily traffic compared to the mean across the pre-treatment periods for the treatment roads, and a 24.4% increase in average vehicle speed.
TABLE 1 Traffic Impact Results

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of vehicles per day</td>
<td>44.20414***</td>
</tr>
<tr>
<td></td>
<td>(3.35)</td>
</tr>
<tr>
<td>Average vehicle speed</td>
<td>13.55***</td>
</tr>
<tr>
<td></td>
<td>(5.72)</td>
</tr>
</tbody>
</table>

t-statistics in parentheses
*, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Community Level Results
As we would expect, we see a significant impact of the project in reducing travel times: travel times to Tbilisi as well as to local markets are reduced substantially; the difference-in-difference estimate indicates a reduction in driving to Tbilisi of 39.6 minutes, and a 43.6 minute reduction in driving time to local markets. The continuous treatment model finds that a community located 30 minutes from the treatment road would experience reductions of 83.6 in the travel time to Tbilisi, and 25.9 minutes in the travel time to the local market. We see a smaller reduction in travel time by minibus to the district center. However, the availability of public transportation as measured by the frequency of minibuses has not increased.

Impacts of the project on outcomes related to investment and land use at the community level are shown below (Table 2). We see a substantial impact of the program on the number of industrial facilities within the settlement, with an increase due to the program of 0.51 facilities and a slightly weaker finding using the matched difference-in-difference model. This finding is confirmed by the results using continuous treatment, which finds that a community located 30 minutes from the nearest road would have an expected increase of 0.65 facilities. In terms of the other land use variables, we find no significant impact of the project.
Finally, we consider impacts on commodity prices in the settlement. As described in the methodology section, the impact of the road improvement on the price of a commodity may be different in communities where that commodity is produced as compared to those where it is not. Thus, we include both the treatment variable, and the interaction of the treatment variable with a dummy indicating whether or not production of the commodity is common in the community. The interpretation is that the coefficient on the treatment variable reflects the impact in communities where the commodity is not produced, while the sum of the two coefficients shows the impact in communities where the commodity is produced. Note that our data on production do not include potatoes or honey specifically, so we proxy these using vegetable production.

The results are shown below (Table 3). All three models indicate statistically insignificant results for wheat. The price of beef shows a statistically significant increase in all three models, but with a large and negative coefficient on the interaction term for both difference-in-difference models. Thus, in areas where livestock production is common the road improvement tends to induce a fall in the price of beef. The results for milk show the same pattern, though they are mostly not statistically significant. The price of potatoes appears to fall slightly, with no difference in vegetable producing areas. Finally we see the largest impact on the price of honey, with our difference-in-difference estimate illustrating a 1.62 Georgian Lari/kg decrease. The data suggest that this decrease is smaller in areas where honey production is common, though the statistical significance is not strong. The continuous treatment model does not confirm this finding.

### TABLE 2 Community-level investment and land use impacts

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Difference-in-difference</th>
<th>Matched difference-in-difference</th>
<th>Continuous Treatment: Post-Treatment Dummy</th>
<th>Continuous Treatment: (Distance * Post-Treatment Dummy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Industrial Facilities within Settlement</td>
<td>0.512***</td>
<td>0.455***</td>
<td>0.716***</td>
<td>-0.00230***</td>
</tr>
<tr>
<td></td>
<td>(3.69)</td>
<td>(3.09)</td>
<td>(7.97)</td>
<td>(-6.08)</td>
</tr>
<tr>
<td>Change in most common usage of land</td>
<td>0.0690</td>
<td>0.0537</td>
<td>-0.245***</td>
<td>-0.00188</td>
</tr>
<tr>
<td></td>
<td>(1.32)</td>
<td>(0.96)</td>
<td>(-8.12)</td>
<td>(-1.27)</td>
</tr>
<tr>
<td>Wheat planting common</td>
<td>0.0263</td>
<td>0.0261</td>
<td>-0.0239</td>
<td>-0.000138</td>
</tr>
<tr>
<td></td>
<td>(0.88)</td>
<td>(1.17)</td>
<td>(-1.09)</td>
<td>(-0.20)</td>
</tr>
<tr>
<td>Corn planting common</td>
<td>0.0496</td>
<td>0.0564</td>
<td>0.0432</td>
<td>-0.000108</td>
</tr>
<tr>
<td></td>
<td>(1.16)</td>
<td>(1.21)</td>
<td>(1.64)</td>
<td>(-1.05)</td>
</tr>
<tr>
<td>Grape planting common</td>
<td>0.0333</td>
<td>0.0424</td>
<td>-0.0251</td>
<td>0.0000364</td>
</tr>
<tr>
<td></td>
<td>(0.87)</td>
<td>(1.04)</td>
<td>(-1.17)</td>
<td>(0.33)</td>
</tr>
<tr>
<td>Vegetable planting common</td>
<td>0.0879</td>
<td>0.0773</td>
<td>0.0548*</td>
<td>-0.000171</td>
</tr>
<tr>
<td></td>
<td>(1.72)</td>
<td>(1.44)</td>
<td>(1.69)</td>
<td>(-1.20)</td>
</tr>
</tbody>
</table>

*-, **, and *** denote statistical significance at 10%, 5%, and 1% respectively.

Binary dependent variables use linear probability models; count variables use negative binomial regression.

t-statistics in parentheses.
Overall, we do not obtain strong findings at the household level. There are no household level outcomes for which all three models indicate impact. We do obtain significant findings on the index of asset ownership from both the difference-in-difference and continuous treatment models, but this is not confirmed by the matched difference-in-difference model. Given the apparent concerns with the household level data that the other findings suggest, we do not draw conclusions from this result.

Tests of Assumptions and Robustness Checks

We undertook a number of exercises we undertook in order to test the validity of our assumptions and the robustness of the findings in the previous sections. These include a discussion and placebo test of the “common trends” assumption of our difference-in-difference and matched difference-in-difference models, as well as wide range of robustness checks where we estimate alternative specifications of the main models. For the “common trends” or “parallel paths” assumption, we took advantage of having multiple rounds of pre-treatment data to use the methodology of (30) by implementing our difference-in-difference and matched difference-in-difference models using only the two rounds of pre-treatment data. Our placebo “treatment effect” is the coefficient on the interaction term between the treatment area dummy, and the second round time dummy. The results of this exercise support the validity of the main findings.
In no cases do we find pre-treatment trends running in the same direction as the evaluation findings. For general robustness checks, we estimated an additional 27 plausible specifications where we vary the statistical assumptions that we have employed, including varying the travel-time cutoff for the inclusion of treatment and control groups (to 15- and 90-minutes, respectively), and testing 13 alternative propensity score specifications for the PSM matching. Overall, our robustness checks give us confidence in the main findings that emerge from our preferred specifications.

CONCLUSIONS
Here we summarize the findings and discuss interpretation and implications. These results can be interpreted as our estimate of the causal impact of the program on a household or community within 30 minutes travel time of one of the improved roads, relative to a household or community within 30 minutes travel time of a comparison road. Key findings are as follows:

• The road improvements successfully improved travel conditions in the project area, with an increase in vehicle count of 4.2% and a 24.4% increase in speed. We do not find a corresponding increase in either the availability of public transport, nor in travel times to regional or district centers, with the exception of a small decrease in travel time to the district center by minibus.
• We observe a significant impact of the project on increasing industrial investment in communities near the improved roads, with an increase of 26.9% for the matched difference-in-difference model.
• We do not find evidence of impact on household-level outcomes such as income, consumption, or utilization of health and education services. We believe the lack of these results is most likely due to two factors: the limitations of the household dataset, which is not ideally structured for the evaluation, and the lack of time post-treatment in our measured data.
• For commodity prices, we observe statistically significant findings in a number of cases, but with different tendencies for different products depending on whether or not the product in question is produced in the local area. The strongest findings are for honey and beef. The project tended to cause honey prices to fall overall, but increase in areas where honey is produced. For beef, we observe the opposite tendency: improving the road tended to lead to a fall in prices where beef is produced, and a rise in prices elsewhere. Milk shows a similar tendency to beef, while the project tended to increase wheat prices while decreasing potato prices. For both wheat and potatoes, the effect tended to be smaller in areas where these products are widely produced, though not statistically significantly so.

Overall the study constitutes a strong contribution to the literature for road socio-economic impact evaluations by implementing robust quasi-experimental treatment-control methods including both difference-in-difference and continuous treatment approaches utilizing high-resolution GIS data to estimate the ATE and the variation in treatment across geography.

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REFERENCES


