IMPACT EVALUATION OF TRANSPORT INTERVENTIONS

A REVIEW OF THE EVIDENCE

David A. Raitzer, Nina Blöndal, and Jasmin Sibal

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ADB

6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel +63 2 632 4444; Fax +63 2 636 2444
www.adb.org

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Notes:
In this publication, "$" refers to United States dollars.
ADB recognizes "China" as the People's Republic of China and "Vietnam" as Viet Nam.

On the cover: Impact evaluation needs to consider the effects of transport sector interventions on various sectors (photos by ADB).

Cover design by Joe Mark Ganaban.

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Foreword

Strategy 2030 of the Asian Development Bank emphasizes the creation of knowledge from investment operations and the use of evidence from past projects to design new interventions. The Strategy also seeks a more proactive role for research to help to replicate good project practices across Asia and the Pacific region. For these ambitions to be fulfilled, evidence on the intended and unintended effects of interventions needs to be accumulated. Impact evaluation is a central means for generating evidence.

To build a broader body of evidence on "what works" in development, impact evaluation needs to be mainstreamed across a range of development investments. In recent years, impact evaluation coverage has made substantial progress in the health and education sectors. Although sectors dominated by "hard infrastructure," such as transport, account for far more development investment, the number of impact evaluations on these sectors has remained limited. Moreover, transport investments have become very complex and more oriented toward making transport sustainable and inclusive. Along with these innovations has come an increasing array of behavioral assumptions underpinning interventions, which impact evaluations can help to test.

At the same time, transport sector interventions have special challenges for impact evaluation. Many transport investments, such as highways or mass transit, are "small-n" interventions, which affect large geographies, so that there are insufficient numbers of treated and untreated units for enabling conventional statistical analyses. Transport costs condition where households and firms chose to be located, so that exposure to transport interventions can be endogenous to household and firm characteristics over long time periods. Capturing spillover effects can also be a challenge, as changes to transport costs can be transmitted across large transit networks.

This review is intended to help offer insights to orient future impact evaluations on the transport sector amidst these challenges. It attempts to characterize theories of change associated with many transport interventions, entry points for impact evaluation, impact evaluation challenges, and potential impact evaluation designs. It then reviews the impact evaluation literature to date,

in terms of methods applied, interventions covered, and outcomes evaluated, and identifies gaps for future studies to address. In the process, it offers practical examples that might inspire future studies.

The literature survey finds a rapidly growing body of impact evaluation studies related to transport. Of the 91 studies identified, more than 65% were published after 2012. Impact evaluation designs have also become diversified, with expanding use of more robust methods, such as regression discontinuity design, as well as greater use of "big data." Evidence has been offered on a range of effects of transport interventions including income, poverty, agricultural production, air quality, employment, education, health, and much more.

Yet, many evidence gaps remain. Existing impact evaluation effort has mostly pertained to road development, of which rural roads are most frequently studied, and its effects on socioeconomic outcomes. There is much less attention to urban transport, and there is limited literature on non-road interventions. Efficiency and behavior change interventions central to the "avoid–shift–improve" approach, which seeks to reduce the need for travel, shift travel toward public transit, and reduce traffic bottlenecks, have also received less attention. Nor have effects via intermediate services, such as health or educational facilities, been often evaluated, when "corridor" approaches increasingly seek to link other investments with transport.

With "big data" increasingly available, it is hoped that the creative examples identified in this review can help to inspire new impact evaluation studies that address evidence gaps on transport. This work is more relevant than ever, as transport investments increasingly seek to experiment with high level technologies, such as intelligent transport systems, and increasingly focus on behavior change interventions, such as transport demand management, pricing, driving restrictions, and road safety measures. Impact evaluation can play a critical role to ensure that these innovations can be tested to help transport operations improve over time. This review helps to show where future impact evaluation investments can best fill evidence gaps and the methods that may be applied to do so.

Yasuyuki Sawada
Chief Economist and Director General
Economic Research and Regional Cooperation Department
Asian Development Bank

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Abbreviations

ADB	—	Asian Development Bank
DiD	—	difference-in-differences
EIRR	—	economic internal rate of return
GMM	—	generalized method of moments
ITS	—	interrupted time series
ITT	—	intent-to-treat
IV	—	instrumental variable
OLS	—	ordinary least square
PSM	—	propensity score matching
PRC	—	People's Republic of China
RCT	—	randomized controlled trial
RDD	—	regression discontinuity design

Key Messages

There are important untested assumptions within traditional economic models of transport. For example, ex ante economic analysis models often mechanistically project that road improvements lead to increased vehicular speed, more productive time use, and reduced transport costs. Ex post analyses are usually based on before–after comparisons that assume that all changes over time are due to the road projects and not other trends or factors. This means that assumptions about how the roads are used and how users behave are often not directly tested. Understanding these behavioral aspects is critical to making transport investments more effective.

Impact evaluation can bring new evidence to transport design choices. The approach can test basic assumptions about effects of transport on travel speeds, transport costs, time savings, employment, prices, productivity, and welfare. It can also test new ways of doing transport interventions better and shed light on the role of complementary interventions, such as contracting arrangements, maintenance schemes, road safety initiatives, and incentives to shift to more sustainable modes of transportation. It also can test transport policies and effects on pollution and other environmental outcomes.

Transport investments have been subject to a growing number of impact evaluations. Transport has been a major sector for official development assistance. Yet, the evidence on the causal effects of transport sector interventions is relatively limited, compared with the social sectors. This is particularly true for sustainable transport investments, which often seek to change transport modes from private vehicles to public transit, make traffic behavior more efficient, or reduce excess travel. At the same time, a number of new and innovative impact evaluations have emerged in recent years, and the body of studies is growing rapidly. This review identifies 91 transport impact evaluations in developing countries, of which more than 65% have been published after 2012.

Impact evaluations to date have found effects on a range of outcomes. These include effects on income, poverty, employment, education, health, gender disparities, land prices, firm productivity, migration, and much more. Both significant expected effects have been found, as well as unanticipated outcomes.

A striking pattern is that effects are variable across studies and contexts, and that impacts are more heterogenous than transport programming often assumes. The evidence offered is limited to specific contexts, periods, and types of interventions, and much of the evidence on these outcomes pertains to rural roads. More studies are needed to better understand factors conditioning effects observed.

Impact evaluations have focused increasingly on transport policies, in addition to infrastructure. A body of recent work has emerged, which evaluates a broader set of interventions, such as vehicle usage restrictions, safety interventions, and toll pricing on outcomes including driving behavior, congestion, local air pollution, and health. This new generation of impact evaluation often utilizes "big data," multiple data sources, and automated data collection to capture new variables in innovative ways.

Impact evaluation of transport has special challenges. The nature of transport is inherently challenging for impact evaluation. Not only are there problems of nonrandom placement and large facilities with few treated units, but there are also other unique problems. Transport conditions the effects of location, so it has inherently heterogenous impacts. It can also condition location and cause populations of interest to shift. At the same time, a number of methods show promise for transport sector applications, which have not been used frequently. These include regression discontinuity designs, encouragement designs, and in some contexts, synthetic controls.

Randomized evaluations can offer evidence on a broader set of transport interventions. Although large transport infrastructure often cannot be randomly assigned, encouragement designs can introduce random variation in the use of transport facilities. These designs have untapped potential to enable testing of an expanded array of assumptions and interventions, especially through pricing encouragements.

"Open data" can enable new impact evaluation possibilities. High frequency, geospatial, and "crowdsourced" data are increasingly available, and many of these data sets are relevant to transport. For example, remote sensing can now detect road network development and pollution, and ride-sharing applications can enable vehicle speed monitoring in real time. Many recent impact evaluations have started to use automatically collected data from traffic detection systems, air pollution monitors, public transit monitors, and even license plate recognition technology. These developments expand the number of impact evaluation possibilities.

There are important transport evidence gaps that future studies can address. Impact evaluation has given relatively little coverage to major areas of investment, such as urban and sustainable transportation, major transport corridors, and efficiency enhancing measures. Effects via access to public services and prices have also had little investigation. Even where evidence exists, it is often limited to a few countries and programs. With new methods and increasing openness of geospatial data, there is scope for generating more innovative impact studies.

1. Importance of Impact Evaluation for the Transport Sector

The existing body of research on the causal effect of transport sector interventions is limited, but growing. To date, the effects of transport sector projects have mostly been modeled using mechanistic and/or unverified assumptions about how people and markets behave (ADB 2013a, Lacono and Levinson 2008). For example, project economic analysis typically uses baseline traffic counts and engineering specification of road improvements to mechanically project changes in travel speeds, costs, and time savings, without considering how drivers actually behave, or how external trends condition effects. Broader economic modeling, such as the use of computable general equilibrium models, is usually rooted in strong assumptions that markets operate in a perfectly competitive manner without frictions or transaction costs, under assumed elasticities of substitution, and often with assumed shocks from interventions.

Impact evaluation, on the other hand, empirically measures the causal effects (and the statistical significance of those effects) of an intervention (or "treatment" as termed in the impact evaluation literature) on outcomes of interest, while minimizing assumptions to the degree feasible. Rather than use assumptions to create a model, impact evaluation is an approach that can be used to test assumptions, especially concerning how behavior conditions effects. The assumptions can relate to inputs such as alternative means of contracting and maintenance, core infrastructure functionality, complementary measures, or alternative transport approaches. They can relate to outcomes such as changes in transport behavior, modal choices, congestion, travel costs, market prices, accidents, and emissions. Or they can relate to longer-term goals such as improvements to employment, income, poverty, pollution, education, and health.

Given the wide range of questions it can help to answer, impact evaluation has much potential to enhance future project design. Recent evaluations have used random assignment to explore the effect of road safety initiatives, auditing

mechanisms, and transport subsidies. There is considerable scope to refine understanding of assumptions for sector programming through more rigorous estimation of treatment effects.

This report aims to help orient future impact evaluation work in the transport sector by reviewing what has been produced against what might be possible. Its intended audience includes those who have interest in evidence on "what works" in transport, either as consumers of insights, or as contributors to knowledge via future impact evaluations. To do so, this report offers a brief review of impact evaluation considerations for transport interventions, impact evaluations performed to date, and future directions for impact evaluation studies. It first characterizes transport sector interventions and theories of change to identify potential impact evaluation questions. Then it reviews methodological considerations and potential applications. In the sections that follow, 91 completed impact evaluations are reviewed in terms of interventions and outcomes covered, as well as methods applied. From these sets of information, gaps in intervention and outcome/impact coverage are identified, and future directions for impact evaluation are proposed.

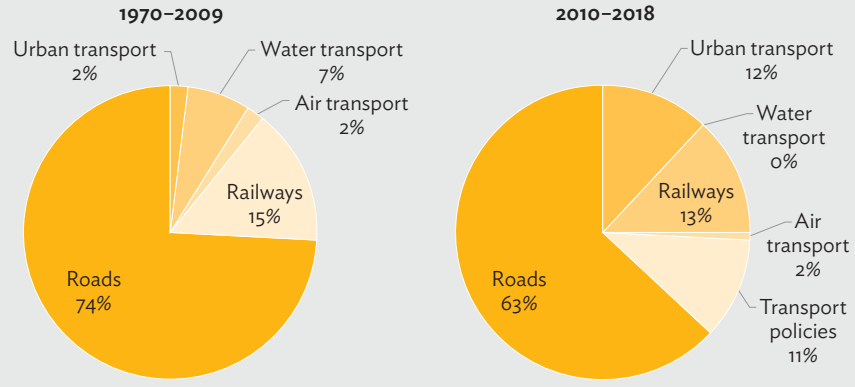
2. Types of Transport Sector Interventions

Globally, the transport sector has been one of the largest areas of public investment. In the People's Republic of China (PRC), for example, annual investment in transportation infrastructure is over 10% of total public expenditure (ADB 2017b). Within official development assistance, transport takes a leading share of project expenditures.

The focus on transport within the projects of the Asian Development Bank (ADB) typifies these patterns in many ways. Transport has been one of ADB's main sectors over the last 5 decades, with transport operations reaching over 20% of total ADB investment in 2017. Although the largest share of ADB transport sector spending remains on roads, other areas are growing more rapidly (Box 1). By 2020, ADB's lending for public transport, railways, and other transport subsectors

Box 1: ADB Transport Sector Lending

Transport is one of ADB's major sectors, and it accounted for 21% of 2017 investment. At the same time, the nature of transport investment is changing. Urban transport and investment in improved transportation policies are growing from small shares of the portfolio to reach large shares of investment.



Sources: ADB (2010); Authors' calculations from ADB data.

(ADB 2010) is expected to overtake ADB's lending for roads. A relatively recent feature is the emergence of transport policies as an investment focus, which goes beyond the traditional emphasis on hard infrastructure.

Transport development is often considered as an integral part of other development processes (ADB 2017b). For example, transport is increasingly recognized as a driver of the development of economic corridors, regional economic integration, and trade. Logistics management to this end is becoming a focus for transport. Sustainable transport is considered as key to reducing pollution problems and greenhouse gas emissions by alleviating congestion and making transport more efficient. Road safety campaigns are spreading as means of ensuring health benefits and reducing externalities. Gender equity is a growing emphasis in transport operations through attention to safety, security, and appropriate physical designs (ADB 2013b). More attention is also being given to integrating transport with other types of complementary interventions, such as those targeting public services, livelihood improvement, or business development. In addition, dedicated efforts are being made to improve transport policies by promoting nonmotorized transport, mainstreaming climate change considerations, reforming pricing, and harmonizing national procedures with international conventions and standards.

This means that investment in transport is increasingly oriented toward innovation and behavior change. A core element of sustainable transport initiatives is the "avoid–shift–improve" approach, which is intended to reduce the growth of congestion through altered transport behavior, including reduced motorized trips, shifts to more efficient public transit, and more efficient vehicle use (ADB 2010). Transport demand management, pricing, driving control policies, and intelligent traffic systems are key elements in improving transport efficiency and implementing these changes. Impact evaluation can play a key role in testing how such behavior change may be achieved and whether innovations work as intended. In addition, intelligent transport systems can also provide more data to enable new impact evaluation possibilities.

3. Theory of Change for the Transport Sector

Similar to many other donor organizations, ADB has not explicitly articulated a complete theory of change for transport interventions, but it has expressed elements of a theory of change in various ways. At the aggregate level, "results indicators" are listed in the ADB Results Framework (ADB 2013c). These indicators are intended to provide a means of tracking progress over time based on administrative data, without attempting to assign causality.

For the transport sector, there is one main "level one indicator" of "development progress" phrased as "paved roads (kilometers per 10,000 people)." This is considered as indirectly related to two indicators of "intraregional trade in total Asia and Pacific trade (%)," and "carbon dioxide emissions (metric tons per capita)." Below this are "level 2 indicators," which are direct outputs, such as the following:

- Use of roads built or upgraded (average daily vehicle-kilometers in the first full year of operation)
- Use of railways built or upgraded (average daily ton-kilometers in the first full year of operation)
- Roads built or upgraded (kilometers)
- Railways constructed or upgraded (kilometers)
- Urban rail- and bus-based mass transit systems built or upgraded (kilometers)

For each project, economic analysis is conducted, including calculation of an economic internal rate of return (EIRR) for the project investment. The EIRR is based on the consumer surplus generated by the road investment, according to a model. The consumer surplus usually consists of (i) reduced travel costs (including the value of time) on "nonincremental" levels of traffic that would exist without the project, due to faster, more efficient travel; and (ii) the "incremental" benefits from additional travel due to improved transit, approximated as half

the benefit per travel unit of the "nonincremental" travel. Although the model may be parameterized based on observed traffic and transport costs before the project, the effects on travel speeds and generated travel are mechanistically assumed ex ante as a function of infrastructure, and the effects of behavior and other mitigating factors are not usually considered. This means that real world effects may strongly diverge from these assumptions. In addition, only a small subset of possible effects is considered.

More broadly, each project has a logical framework, or "design and monitoring framework," which lays out inputs, activities, outputs, outcomes and impact, key risks, assumptions, and interlinkages. These are the core elements of a *theory of change* at the project level. A theory of change can be drawn together explicitly for the sector, as is illustrated in Figure 1 for land transit.

Economic analysis models imply that key expectations in the theory of change of many transport projects include that they increase average travel speeds, lower transport costs, and increase transport volumes (ADB 2017a). The increased speed leads to time savings, which in the case of human transport, translate into more labor participation, as well as increased leisure. Lower mobility costs enable better access to schooling and health services, benefiting human capital, employment, and welfare. Reduced transport costs also allow lower input costs and higher output prices, so that firms are more profitable and employ more workers. Reductions in the costs of transporting goods also are intended to lead to lower prices for consumers.

Increased efficiency from shifts to public transport is anticipated to reduce congestion. Less congestion, more fuel efficiency, and switches to cleaner fuels are expected to lead to reduced pollution, including release of greenhouse gases that cause climate change. Policies, such as driving restrictions and biofuel blending mandates, are anticipated to help amplify these effects. Appropriate road design features are also anticipated to reduce accidents, and better maintenance is expected to help all the other impact pathways. It is also expected that potential negative effects, such as increased deforestation due to better forest accessibility, encroachment into natural areas, illegal wildlife trade, or negative effects on local communities are mitigated by environmental and social safeguards.

At the same time, all of these expectations are contingent upon behavioral assumptions. Whether travel speeds increase depends on how the infrastructure is utilized. For example, if a road is widened, but private cars are parked in the area of widening, travel speeds may not increase to the degree expected without the parking response. Expected increases in travel speeds and volumes

Figure 1: Theory of Change for Land Transport Sector Interventions

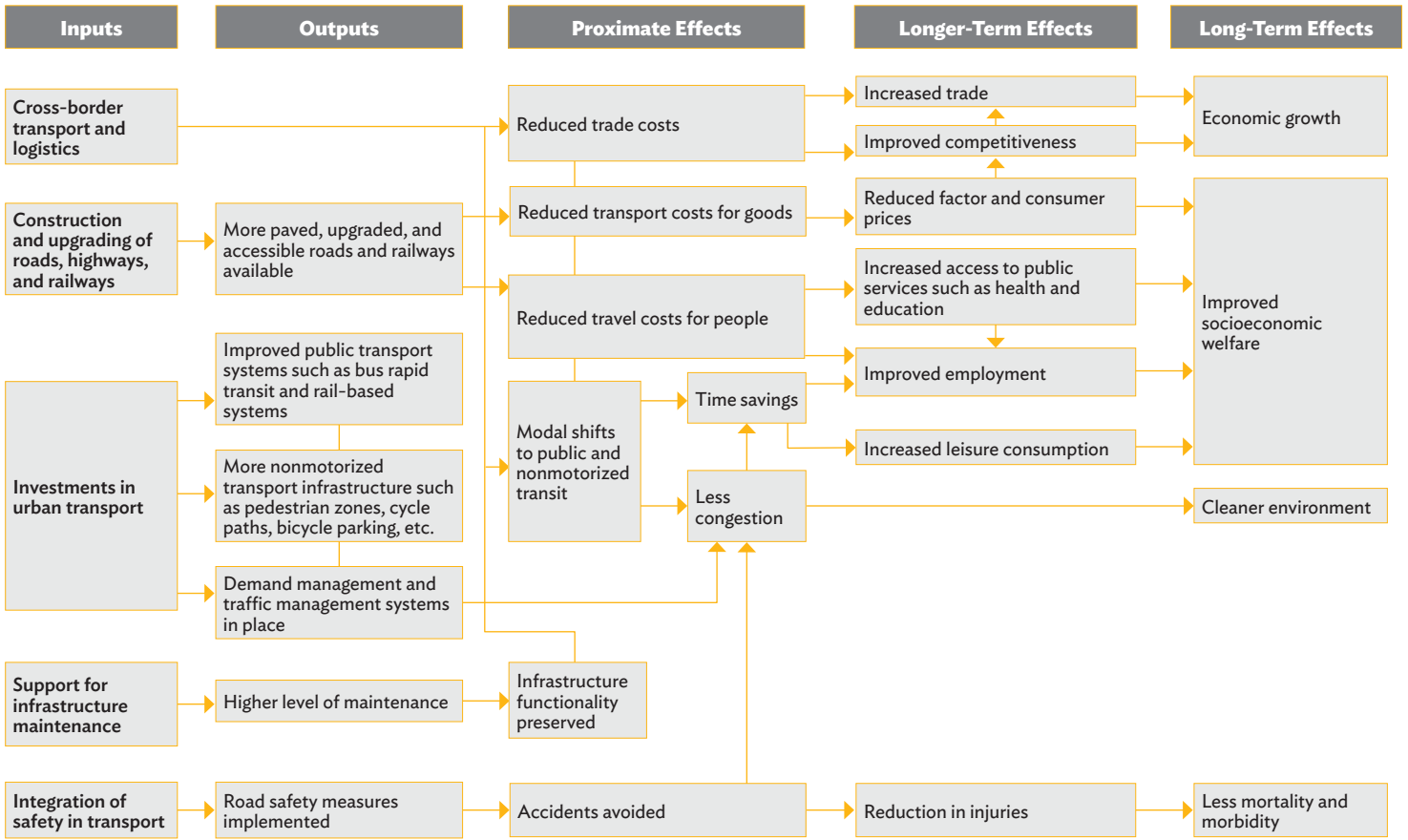


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Figure 1 continued

Assumptions				
For Overall Program	**For Inputs to Lead to Outputs**	**For Outputs to Lead to Proximate Effects**	**For Proximate Effects to Lead to Longer-Term Effects**	**For Longer-Term Effects to Lead to Long-Term Effects**
Appropriate program design	Intervention is properly implemented and maintained.	• The new/improved infrastructure is used sufficiently to increase connectivity and access as expected. • Maintenance initiatives are efficient and sustainable. • Reduced travel time and cost are sufficient to increase use and develop markets and services. • Safety interventions are effective and sustainable. • Urban transport initiatives are successful in making people switch from private to public means of transport and to more environment-friendly means of transport.	• Lack of connectivity is a deciding factor inhibiting market, business and industry development, and employment. • Well-maintained roads reduce travel time, and cost is sufficient to increase use to a degree that can facilitate such development. • The effect of road safety interventions is bigger than the negative effect following accidents due to improved roads and higher speed. • The switch from private to public means of transport, and to more environment-friendly means of transport is large enough to decrease congestion and improve air quality in urban areas.	• Markets and businesses develop, and employment increases sufficiently to improve average household and welfare. • Increased market development, business, employment, and new industrial zones combined are able to contribute to economic growth. • The reduction in accidents is sufficient to improve health. • The above effects are able to materialize given other external factors. • Improvement in air quality is sufficient to affect health in urban areas.

Source: Authors' drawing on ADB (2010).

may not occur for a host of reasons beyond simple project engineering, such as bottlenecks elsewhere in the road network, poor traffic management, unanticipated developments along the road, maintenance issues, excessive road traffic generated, or conversely, external developments that limit demand/traffic. Road safety interventions may have effects offset by increased risks from faster vehicular speed and generated traffic. The effects of improved accessibility on natural ecosystems may depend on how governance of land and other natural resources conditions behavior. Many of these effects depend on how exogenous factors evolve and the presence of complementary interventions.

Moreover, many projects aim to promote modal shifts and alternative means of improving mobility. For example, a rail or public transit project may expect to shift passengers from private vehicles, and thereby reduce congestion, as an alternative to increasing private transit mobility. Assumptions about shifts are inherently behavioral and may not adhere to mechanistic projections.

Impact evaluation can help to test these assumptions and inform understanding of the benefits of specific approaches and investments. It can help to reveal the kinds of complementary measures necessary and the contexts under which expected effects are realized. Moreover, as discussed in section 1, impact evaluation is also needed to test mechanisms that underlie each of the steps in the causal chain. These mechanisms could be campaigns to increase road safety or pricing structures that make beneficiaries opt in or out of a service like use of public transport—i.e., factors that affect whether the outputs in column 2 (of Figure 1) turn into outcomes. Table 1 shows examples of how impact evaluation can be applied to each of the focus areas of ADB's Transport Operational Plan.

Table 1: Impact Evaluation and the ADB Sustainable Transport Initiative Operational Plan

ADB's Sustainable Transport Initiative Operational Plan	Opportunities for Impact Evaluation
Investments in Urban Transport	
• Safe, secure, accessible, rapid, efficient, and user-friendly public transport systems • Nonmotorized transport infrastructure • Integrated urban transport and land-use planning • Demand management • Traffic engineering and management systems	Impact evaluation can test measures intended to foster changes in transport behavior, such as modal switches and traffic efficiency enhancements, and can capture leakage and rebound effects. It can also reveal longer-term effects on socioeconomic outcomes, such as educational attendance, employment, and female empowerment.
Addressing Climate Change in Transport	
• Shift to railways, inland waterways, mass transit systems, and nonmotorized transport • Strategic investments to shorten journey distances • Support for accessing global climate change funds • Mainstream climate adaptation measures into transport operations	Less carbon-intensive transport often depends on avoid–shift–improve approaches. Avoid approaches, such as driving restrictions, have been the focus of many evaluations. Shift measures can be subject to further testing, especially when they can be varied through incentives. Improvement measures often can be piloted in particular sites or times, and thus are amenable to rapid experimental impact evaluation. Air pollution is increasingly a focus of transport impact evaluation, and can be characterized using existing air quality monitoring systems in many locations.
Road Safety and Social Sustainability	
• Engineering and behavioral approaches to safe design, construction, operation, and maintenance of roads • Intelligent transport systems and development of road safety management capacity and road safety performance measurement • Improve rural bus services and nonmotorized transport • Gender mainstreaming within transport • Pro-poor transport investment and pricing • Improved social safeguards	Impact evaluation can be used experimentally to test different contracting arrangements, maintenance schemes, road safety initiatives, and similar campaigns, and test willingness to pay for public transport. Gender-targeted interventions, such as female-only transport services, can also be tested.
Cross-Border Transport and Logistics	
• Simplify and harmonize national procedures and operations with international conventions and standards • Address bottlenecks in freight mobility and reduce turnaround time of cargo vehicles • Streamline transport connections at gateways, ports, and feeder connections • Create dry port facilities and logistics centers • Assist in planning and investment programs to create a competitive regional railways network	Impact evaluation can help test interventions to relieve trade constraints when they are deployed on pilot basis, or when knowledge/access to facilities is not yet universal. They can also test effects of transport infrastructure on trade outcomes if functionality changes at specific points in time or differentially across locations.

Sources: Authors; ADB (2010).

4. The Challenges of Evaluating Impacts of Transport Interventions

The core challenge of impact evaluation, which empirically identifies the effect attributable to an intervention in terms of magnitude and statistical significance, is to control for confounding factors and isolate the effects of the focal intervention. A primary confounding factor is *endogenous placement*. Transport infrastructure is generally strategically placed to promote growth where it is most needed, in areas with the greatest potential gains from increased connectivity, or in areas favored for other reasons. That introduces project placement bias, and thus makes it more difficult to identify a credible comparison group.[1]

Ex post EIRR estimates are usually calculated for transport projects after completion, based on reflexive (before–after) comparisons of transport speeds, volumes, and costs. The limitation of this approach is that the project is not the only factor causing changes over time. The other causes of changes, including overall trends, are confounded with the effects of the project, so that important basic assumptions of the economic analysis model are not directly tested.

In many other sectors, placement bias and confounding of trends may be eliminated by randomized assignment of the intervention in a randomized controlled trial (RCT). However, for road infrastructure, this is more challenging. Transport infrastructure is a part of overall transport networks, so that random assignment or sequencing of infrastructure project components may not be conducive to overall network functionality. Second, whereas eligibility criteria can be altered for inexpensive interventions targeting households without permanent project consequences, altering rollout of large, long-lived investments may have large costs and implications for functionality over many years.

[1] Project placement bias is a common source of selection bias (self-selection being the other main source).

This may be further exacerbated if transport infrastructure is part of a broader package of "corridor" investments that take place over a broadly similar time frame, such as investments in power supply, water supply, health services, and educational facilities. This in turn, creates great challenges for establishing the impact of the transport intervention specifically, as the interventions may all covary.

A second challenge is that some types of transport sector interventions are "small n" and involve few treated units—for instance, the construction of one port, one metro station, or improvements to one road agency.[2] This is problematic because it reduces spatial variation in treatment that underpins impact identification, so that it is more difficult to achieve sample (statistical) power. Even if many individual users may be surveyed with many observations, the intervention will have high intracluster correlation that reduces sample power when standard errors are adjusted to account for the small number of treated clusters.[3] This is a substantial issue for the most concentrated transport projects, such as ports, airports, railways, and core national highways.

Moreover, transport interventions are often part of larger networks and impose spatially variable levels of "treatment." When a new road is constructed, for example, the increase in connectivity experienced by a particular firm or household varies according to the specific location along the road and whether there are alternative routes to population centers. Thus, the "treatment" of many transport interventions is actually continuous, rather than binary, which needs to be considered when identifying potential comparison groups.

An additional source of complexity is that location is also endogenous, at least over longer time horizons (Boarnet 2007). A well-established tenet of location theory is that transport costs condition where firms and workers are located (Krugman 1998). It follows that firms can relocate to self-select into the transport intervention if effects on transportation costs are beneficial to them or if they are better equipped to benefit. The effect can be further amplified if transport benefits become reflected in property prices that shape locational choices. This means that panel data may face problems of bias, if relocation in response to treatment causes substantial differential attrition. Although the effect may not be as obvious in panels of aggregate or administrative statistics, such statistics may also be affected by bias due to differential changes in the composition of observed units.

[2] For further discussion of the small n challenge, see White and Philips (2012).
[3] White and Raitzer (2017) discuss this issue and provide examples in Chapter 7 of their book.

The most profound problem may be violation of the assumption of standard unit treatment value that is central to conventional impact evaluation. Part of this assumption is that there are no spillover effects from treated to untreated groups. However, transport infrastructure sometimes has general equilibrium effects, which violate this core assumption. This is particularly the case with large arterial facilities. Those facilities may divert traffic from other routes, attract investment that may have occurred elsewhere, affect prices in the overall economy, and alter labor and factor market outcomes. General equilibrium effects can be modeled with structural approaches, but these rely on many more assumptions than is typical for the empirically driven approach of impact evaluation.

5. Impact Evaluations to Date

This report attempts to characterize impact evaluations conducted to date on transport interventions in developing countries. To this end, a search was carried out covering the following sources:

- Impact evaluation repository of the International Initiative for Impact Evaluation (3ie)[4]
- Over 1,500 papers in the EconLit database
- "Snowball searches" of reference lists of impact evaluation studies identified and studies that cite studies identified
- Websites: Inter-American Development Bank, Center for Global Development, International Food Policy Research Institute, Innovations for Poverty Action, and the World Bank's Development Impact Evaluation (DIME)[5]

As such, the search covers major authoritative databases, but it is not exhaustive, and important studies may be missed. However, many studies that are widely recognized are likely to be captured.

The search only included empirical studies that attempt to control for selection/placement bias and other confounding factors, using methods described by White and Raitzer (2017). From the search, the review identified 91 studies that qualified as methodologically rigorous impact evaluations—59 of which evaluate projects in Asia.[6] At the same time, the body of studies is growing rapidly, with more than 65% produced after 2012.

[4] The repository is based on a very comprehensive review of academic databases, organizational databases, websites, and more. Both the repository and protocol can be found at http://www.3ieimpact.org/.

[5] Information was also obtained directly from relevant staff at some of these organizations.

[6] The full list of studies can be found in Appendix 2.

The completed studies cover many interventions (Figure 2), which broadly fall into four categories:

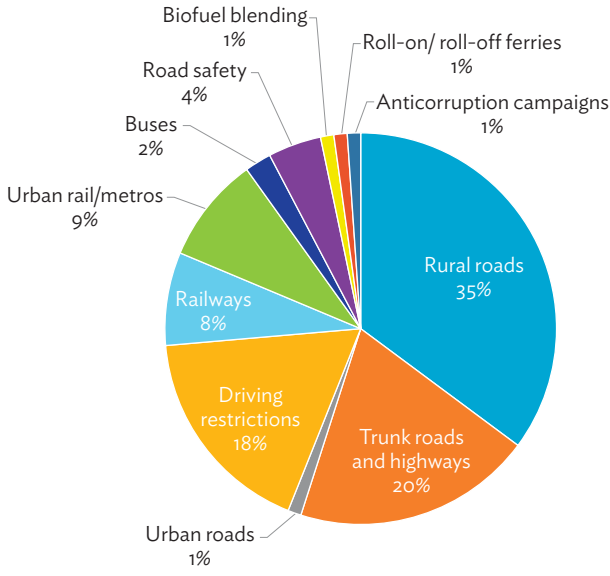
(1) **Roads**: The majority (51) of the studies evaluate road projects. Most examine rural roads (32), while somewhat fewer (18) evaluate trunk roads/highways, and a single study evaluates urban street improvement.

(2) **Driving restrictions**: There are 16 studies that evaluate the effects of congestion/pollution-oriented driving restrictions, such as "coding" of license plates, on different outcomes.

(3) **Railways and public transit**: A total of 17 studies evaluate public transportation in some form, of which 7 evaluate rail (including an ADB study from Uzbekistan [Box 2]), 8 evaluate urban rail/metro systems, and 2 evaluate bus effects.

(4) **Complementary interventions**: The remaining 7 studies focus on road safety interventions (4 studies), biofuel blending (1 study), roll-on/roll-off ferries, and an anticorruption campaign related to road construction (1 study).

Figure 2: Interventions Evaluated in Transport Impact Evaluations
(% of studies)



Note: Percentages are out of 91 studies identified.
Source: Authors.

The number of studies is substantially larger than the number of interventions evaluated, as there are several projects on which multiple impact evaluations have been conducted, as the eligibility rules are clear and public data are available for estimating impacts. For example, the Prime Minister's Rural Roads Scheme in India is the subject of six impact evaluations, and driving restrictions in Beijing have also been subject to six impact evaluations. This means that fewer interventions have been evaluated than the overall number of 91 impact evaluations suggests.

The identified pool of impact evaluation studies of transport interventions is limited and substantially lower than for other sectors, especially social sectors. This may be partly because of the challenges described in the previous section.

Box 2: An Impact Evaluation of Investment in Large Transport Infrastructure: The Case of the Railway Connection in Uzbekistan

The Asian Development Bank Institute carried out an impact evaluation of railway development in Uzbekistan. It explores the effect of rail infrastructure on regional economic performance. The analysis employs a difference-in-differences approach to estimate the effect of a new railway in Uzbekistan on regional gross domestic product (GDP), including value added of agriculture, industry, and services.

The study focuses on regional effects, spillover effects, which include effects on surrounding regions, and connectivity effects in the hub region and regions at far ends of the railway. The study separately examines the effects of anticipation of the railway, the launch of the railway, and postponed effects of railway connection.

The results indicate that railway connectivity increased regional GDP growth rates in affected regions by 2%, an effect driven primarily by increases in industry value added (approximately 5%) and services value added (approximately 7%). Agricultural value added is found to be increased by 1%.

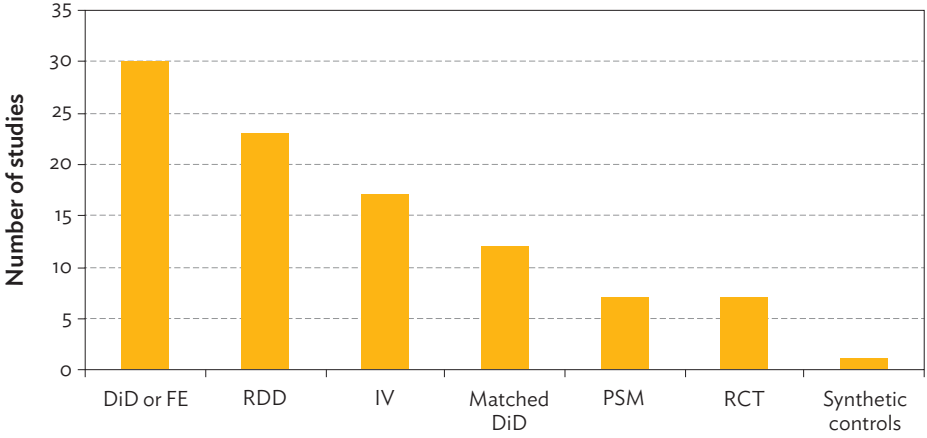
Source: Yoshino and Abidhadjaev (2015).

6. Common Impact Evaluation Designs in the Transport Sector

A range of impact evaluation designs is possible for transport (Table 2 and Appendix 3 provide descriptions).[7] These include both experimental and nonexperimental approaches. Given the challenges of randomizing the assignment of transport infrastructure, existing studies have mainly used a range of quasi-experimental methods. Many of the studies have used secondary data from before and after transport interventions in areas with and without the interventions.

Over half of the studies identified use difference-in-differences (DiD) estimation, often in combination with propensity score matching (PSM), or as related fixed effects designs (Figure 3). That includes studies based on survey data such as

Figure 3: Overview of Methods for Transport Sector Studies



DiD = difference in differences, FE = fixed effects, IV = instrumental variables (including endogenous treatment regressions), PSM = propensity score matching, RCT = randomized controlled trial, RDD = regression discontinuity design.
Note: Studies may use more than one method.
Source: Authors.

[7] White and Raitzer (2017) offer a more detailed description of the designs and methods discussed in this section.

Table 2: Impact Evaluation Designs for Transport Interventions

Experimental designs	Simple randomized controlled trial (RCT)	Randomization is the "gold standard" for impact evaluation, as it can eliminate all forms of bias, in theory. However, randomization at individual or household intervention is generally not feasible for transport infrastructure interventions. Case Study 1 offers an example where it was feasible to apply.
	Cluster- or matched-pair RCT	Cluster- or matched-pairs randomization, where assignment to the intervention is at the level of the community or district, might be a feasible approach for certain types of rural interventions, although in practice no such experiments have been implemented thus far.
	Encouragement design	Encouragement designs create random variation in the use of an intervention of interest by implementing an informational or other "nudge" that affects utilization on a randomized basis. This can recover an unbiased local average treatment effect even when the intervention itself cannot be randomized. These approaches can be used for transport via pricing incentives and other measures.
Nonexperimental designs	Regression discontinuity design (RDD) and interrupted times series	RDD exploits discontinuities in eligibility for an intervention with respect to an assignment variable. RDD can be used for transport policies that have discontinuities in implementation, such as driving restrictions that vary over time, or travel fare exemptions in certain periods. RDD was used to examine the impact of driving restrictions in Mexico City (Davis 2008). Similarly, interrupted time series approaches may be used for transport infrastructure that become effective at a defined point in time, such as a bridge, as the point of time creates a sharp discontinuity.
	Instrumental variables	Instruments use a variable that predicts exposure or participation in an intervention, but does not affect outcomes directly, as a means of proxying exogenous variation in the intervention. Finding a valid instrument is challenging, and not always feasible. Researchers can consider program placement rules for a possible instrument. Case Study 4 provides an example.
	Propensity score approaches	The propensity score is the estimated probability of having an intervention given the observable characteristics from a regression model of participation. Propensity score approaches balance estimated probabilities before making comparisons. Propensity score techniques are nearly always possible, although they are more at risk from selection bias than other methods. It is more useful in combination with time variant approaches, such as difference-in-differences (DiD).
	Difference-in-differences (DiD) and fixed effects models	These methods take the trend in a sample not exposed to an intervention as the trend that would occur for the treated sample in the absence of the intervention. They can be used if there are baseline data, though should preferably be used in conjunction with a matching procedure or model with covariate. These methods may potentially be used to investigate urban infrastructure and policy reforms if there is spatial variation. Case studies 2 and 3 provide examples of DiD.
	Synthetic controls	Synthetic control techniques can use a long time series of pre-intervention observations to "train" a weighting algorithm to identify weights that allow a pool of comparison observations to approximate the outcome trends in one or more treated units. The treatment effect is the difference in differences between the synthetic control and the treated unit. Placebo tests are used in place of conventional statistical significance.

Source: Authors.

Mu and van de Walle's (2011) study of market development for communes with and without rural road infrastructure featured in Case Study 3, as well as studies based on administrative data such as the Yoshino and Abidhadjaev (2015) study on the effect of Uzbek railways on regional gross domestic product (GDP) as described in Box 2. These approaches take the difference in outcomes over time for the treated population net of difference over time for the comparison (without intervention) population as the average treatment effect on the treated. This eliminates baseline differences from the impact measures.

The main limitation of this approach is that the validity of the results hinges on the assumption that the development of the outcome variables in treatment and comparison areas would have followed the same trend in the absence of the transport intervention (the *parallel trends assumption*). The addition of either propensity score matching, which improves baseline balance or supplemental control variables in the fixed effects approach helps to improve control for the effects of other observed factors and trends. However, even with these additions, DiD and fixed effects models cannot control for the time-variant effects of unobserved confounders or interaction effects between treated and comparison areas. As noted previously, the challenge of transport-induced differential attrition is a substantial potential violation of the parallel trends assumption, which may not be easy to solve.

Regression discontinuity design (RDD) is the second most frequently used approach. This technique depends on the presence of a clear rule determining placement, access to, exposure to, or usage of a transport intervention, which is related to an "assignment variable," where there is a cutoff value. Populations just above and below the cutoff value that conditions eligibility should be considered very similar, so that a discontinuity in variable values at the cutoff reveals the intervention effect. This technique has been used principally for evaluating transport policies for which such a discontinuity is present, such as for driving restrictions that become active during certain hours of the day or for very specific locations, or for policies that have been shifted or waived suddenly during specific periods (Fu and Gu 2016). The limitation of RDD is that its validity depends on whether the assignment rule effectively conditions intervention eligibility in a manner that is independent of the outcome of interest. As RDD also estimates only a local average treatment effect at the assignment threshold, applications based on timing (also known as *interrupted time series*) may only reveal short-term effects as well.

Instrumental variables (IV) is the third most frequently used approach. The approach here is to identify a variable that is correlated with the infrastructure intervention or its output (e.g., road quality), but not with the outcome variable (e.g., business revenue or employment). Completed studies have used a variety

of IV. In Papua New Guinea, for instance, the year a district was linked to the national highway system was used as an instrument for access to rural roads in a study examining the impact of rural road connectivity on poverty (Gibson and Rozelle 2003). For a study of roads in Indonesia, the government road maintenance budget was used as an instrument for road quality in a study of the impact of road quality on local economic activity as described in Case Study 4 (Gertler et al. 2015). Historical plans for road development (Volpe Martincus, Carballo, and Cusolito 2017) and distance between locations to be connected (Bird and Straub 2014) have been used as well. The challenge with the use of an IV approach is that few instruments completely fulfill the "exclusion restriction"—that impact only occurs through the intervention of interest—while being predictive of the intervention.

A number of recently completed studies, however, include various forms of experimental designs on interventions with a clear behavioral orientation. Such studies examine various stages of the causal chain and the underlying assumptions, rather than necessarily examining final welfare outcomes per se. Examples include RCTs on transport subsidies in Ethiopia (Box 3), road safety promotion in Kenya and prevention schemes for drunk driving in India (Box 4), and different auditing schemes to combat corruption in road construction (Box 5).

In addition, there is increasing use of randomized encouragement designs to understand transport impacts (Box 3 provides an example). These designs do not randomize transport itself, but randomize allocation of an incentive to use transport, such as a subsidy and awareness campaign, or a convenience feature. That incentive becomes an instrument for using instrumental variables estimation of treatment effects of the overall infrastructure facility. When the encouragement is based on a pricing measure, this approach can also reveal how demand/uptake relates to price, which can be useful for designing tolls and user fees.

Many of the more recent studies make use of administrative or secondary data, rather than dedicated impact evaluation surveys. For example, Asher and Novosad (2018) combine various census data sets with road administrative databases by "scraping" and reconciling large numbers of individual public files and reports, and Adukia, Asher, and Novosad (2017) draw on census and standardized testing data of the public educational system. Liu et al. (2018) use data collected by automated license plate recognition, a number of studies use automated traffic speed recording (Zhong, Cao, and Wang 2017; Yang, Lu, and Qin 2016; and others), Goel and Gupta 2015 use local air quality monitoring data, and Viard and Fu (2015) use administrative data collected by televisions in Beijing.

Box 3: A Randomized Encouragement Design to Evaluate Transport Effects on Labor Markets

A randomized encouragement design is used to evaluate the effects of transport costs on the intensity of job searching behavior for unemployed youth near Addis Ababa, Ethiopia.

Objective: It is unknown to what degree transport is a limiting factor in achieving matches between skills and employment opportunities, or the degree to which transport can help to reduce urban inequity. This study evaluates if reducing transport constraints affects job search and placement outcomes, using a rigorous design.

Design: Eligible urban and peri-urban populations are stratified by key characteristics and blocked before being randomly assigned into three treatment arms. The first arm receives subsidies for travel into the city center up to 22 times over 11 weeks plus intermittent phone call encouragements, while the second receives only the phone call encouragements, and a third arm was a control. Data collection includes a baseline survey, telephone interviews, and an endline survey for all groups. Six different impact estimators are applied to the data.

Results: The study finds significant differences in job search behavior between treatment and control, with more searching in the former. In addition, there are significant effects on having permanent employment for the peri-urban population and on work hours for the urban sample.

Source: Franklin (2015).

Box 4: Using Impact Evaluation to Test Road Safety Initiatives

Experimental impact evaluation provides an opportunity to test the effect of different types of road safety interventions.

In India, researchers evaluated variations of a program aimed at ending drunk driving.

Objective: To compare the effectiveness of alternative approaches to combat drunk driving, the study tests 12 different variations of an anti drunk-driving campaign.

Design: A randomized experiment and a structural model of perpetrator learning are used to test the effect of police roadblocks. The study varies the frequency, location, and personnel deployed at checkpoints across a total of 12 overlapping treatment groups. During 2010 and 2011, police stations in 10 districts of Rajasthan were randomly assigned to either one of the treatment groups or a comparison group, which received no intervention.

Results: Drivers are found to learn quickly of the existence of checkpoints and respond strategically by changing route, as checkpoints set up in rotating, or surprise locations are found to be significantly more effective in reducing accidents and deaths than fixed location checkpoints. The rotation approach is found to reduce night accidents in the surrounding area by 17%, and night deaths by 25% over a 2-month campaign and for the subsequent 6 weeks.

Source: Banerjee, et al. (2014).

continued on next page

Box 4 continued

In Kenya, researchers examined the effect of information nudges to confront reckless driving by bus drivers.

Objective: This study tests the effectiveness of using nudges to empower passengers to speak up against reckless bus drivers.

Design: A randomized experiment includes almost 2,300 long-distance minibuses serving 12 major cities. Half of these buses are randomly assigned to receive a set of stickers encouraging passengers to take action against dangerous driving. The other half of buses comprised the control group. Insurance claim information is used as a main outcome variable.

Results: The campaign is found to reduce insurance claims by between 4.5 and 6.4 percentage points from a baseline rate of 10% annually, and claims that involved injury or death are found to be halved.

Source: Habyarimana and Jack (2009).

Box 5: Monitoring Corruption: Evidence from a Field Experiment in Indonesia

Objective: The experiment tests the effects of auditing mechanisms on proxies for corruption in road construction projects in rural Indonesia.

Design: A randomized design is used to examine the impact of three different interventions on "missing expenditures," defined as unexplained differences between independent cost estimates and recorded costs:

(i) Increased use of external audits of village road projects and advance information of such audits at village meetings
(ii) Use of written invitations for community members to participate in village accountability/ monitoring meetings
(iii) Use of written invitations as above plus provision of an anonymous form to provide comments on the road project

Results: The study finds that substantially increasing the use of external audits from 4% of road projects to all road projects reduced expenditure discrepancies from almost 28% to just over 19%. Increased community involvement in meetings is found to have an effect only on expenditures related to labor, but little overall effect. The combination of increased involvement and anonymous forms has an effect only when village authorities had no role in distributing forms and invitations, suggesting that such campaigns are less likely to be effective where elite capture is present.

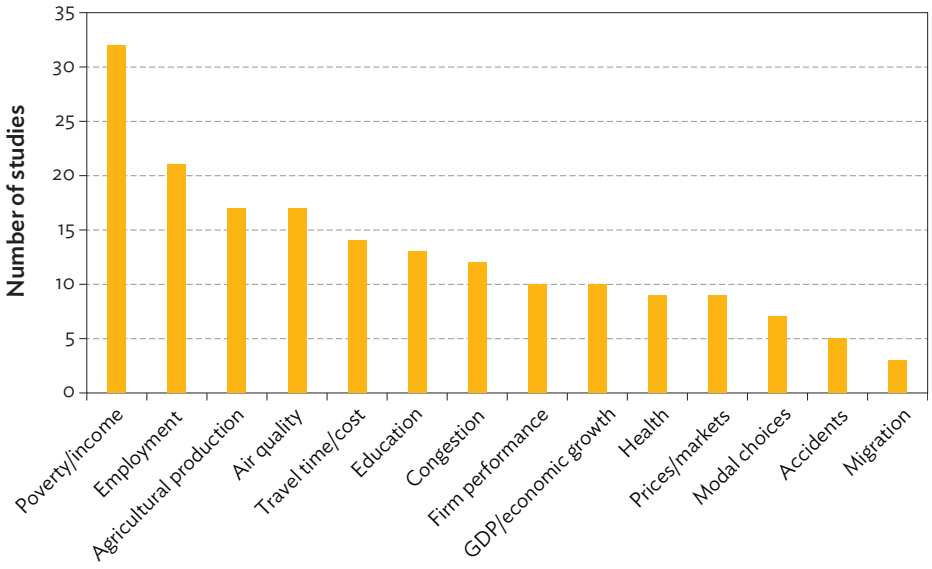
Source: Olken (2007).

7. Outcomes Measured

The outcomes quantified to date can roughly be grouped into five categories: (1) indicators of household-level income and poverty; (2) indicators of employment; (3) indicators of air quality; (4) effects on education and health; and (5) effects on agriculture, prices, and markets (Figure 4). Many studies estimate several outcomes from one or more of these three categories.

The most frequently occurring outcome is household poverty or income, including measures of consumption and expenditure, followed by employment. A more recent body of literature has emerged on air quality, using monitoring data.

Figure 4: Outcome Variables in Transport Impact Evaluations



GDP = gross domestic product.
Note: Studies may evaluate more than one outcome.
Source: Authors.

Most of the studies reviewed find significant effects on at least one of the outcomes investigated. Some of the key findings are as follows:

(1) *Transport can have important effects on income.* Rural road rehabilitation in Peru was found to enhance nonagricultural income opportunities from wage-employment sources (Escobal and Ponce 2002). New roads were found to increase mean household income by 28% and contributed to decreasing income inequality in Nepal (Charlery, Qaim, and Smith-Hall 2016), as well as increase asset ownership (Bucheli, Bohara, and Villa 2016). Reduced transport costs were found to lead to significant increases in household revenues from crop revenue, livestock sales, and nonagricultural income in Nigeria (Ali et al. 2015). Improved ferry integration with roads was found to increase income in the Philippines (Francisco and Helble 2017). A national rural roadbuilding program in India was found to have negligible effects on income/consumption using village-level data (Asher and Novosad 2018), but strong effects using household panel data (Shamdasaniy 2016, Aggarwal 2014).

(2) *Rural road infrastructure may reduce household poverty*. Income effects have been found to be inclusive in a number of studies. Improvements in road quality were found to lead to faster consumption growth and lower rates of poverty in rural Ethiopia (Dercon et al. 2009) and Indonesia (Gertler et al. 2015). Access to roads was found to reduce poverty by reducing travel time to key social services and economic activity by bringing the road network closer to poor villages in Papua New Guinea (Gibson and Rozelle 2003). The poor were found to especially benefit from rural roads in Viet Nam (Mu and van de Walle 2011) and Bangladesh (Khandker, Bakht, and Koolwal 2009) as well.

(3) *Improved transport can lead to increased wage employment.* Rural road rehabilitation was found to lead to increase in industrial activity and employment in Georgia (NORC at the University of Chicago 2013). Increases in wage sector employment and decreases in agriculture self-employment have been observed in Palau (Akee 2006), Bangladesh (Mahmud and Sawada 2015), India (Asher and Novosad 2018), and Indonesia (Yamauchi et al. 2011, Gertler et al. 2015). Transport subsidies were found to increase likelihood of finding permanent employment in Ethiopia by 6 percentage points (Franklin 2015). Farm roads and rural road rehabilitation were found to significantly cut travel time, leading to increases in number of hours worked per week in Bhutan, Nicaragua, and Armenia (Blöndal 2015, Rand 2011, MCC 2015).

(4) *Firm performance can be conditioned by transport infrastructure.* Road infrastructure was found to significantly increase firm flexibility in dealing

with suppliers (Datta 2011) and firm productivity in India (Ghani, Goswami, and Kerr 2013). Road development in Colombia was found to significantly impact firm exports and employment (Volpe Martincus, Carballo, and Cusolito 2017), and road infrastructure has also been observed as impacting export performance of Chilean firms (Volpe Martincus and Blyde 2013).

(5) *Agricultural performance can be strongly affected by transport connectivity.* The adoption of improved varieties of rice was found to be increased by improved road connectivity in Bangladesh (Ali 2011), agricultural technology adoption was found to rise in India (Aggarwal 2014), and agricultural input use was found to be increased by road access in Nepal (Shrestha 2017). Increases in commercialization (agricultural sales) were also observed in the same studies. Donaldson (2018) found that nearly all agricultural productivity changes in colonial India can be explained by railroad development. Rural road paving was found to lead to lower input and transportation costs, higher agricultural output prices, and increased agricultural production in Bangladesh (Khandker, Bakht, and Koolwal 2009). In India, improved rural roads were found to lead households to diversify into higher return crops, intensify application of complementary inputs, and increase sales of agricultural outputs (Shamdasaniy 2016).

(6) *Arterial transport development can lead to economic growth.* Generally, proximity to transportation networks has been found to have a significant positive causal effect on per capita GDP growth (Yoshino and Abidhadjaev 2015; Banerjee, Duflo, and Qian 2012), ranging from 2% in Uzbekistan (Box 2) to 33% in one study from the People's Republic of China (PRC) (Wang and Wu 2015). High-speed rail in the PRC was found to increase income by 9% (Zou, Chen, Xiong 2018). Road expansion in Brazil was also found to result in increased concentration of economic activity and population (Bird and Straub 2014).

(7) *Improved road infrastructure may enhance educational outcomes.* Enhanced transport has been found to lead to increased school enrollment or attendance in Bangladesh, Brazil, India, Peru, and the Philippines (Khandker, Bakht, and Koolwal 2009; Mukherjee 2012; Iimi 2015; Sengupta, Coondo, and Rout 2007; Valdivia 2011; Francisco and Helble 2017). Increases in post-primary enrollment were found in Indonesia (Yamauchi et al. 2011). Although enrollment of older children was observed to decline in India, Aggarwal (2014) and Adukia, Asher, and Novosad (2017) found that children who stay in school longer perform better on standardized tests.

(8) *Transport interventions can have important effects on health.* Roads can facilitate increased access to and use of medical facilities in Georgia and India (Lokshin and Yemtsov 2003; Sengupta, Coondo, and Rout 2007; Banerjee and Sachdeva 2015), resulting in better health outcomes. Road safety interventions in several countries were also found to significantly reduce accidents and injuries (Habyarimana and Jack 2009; Habyarimana and Jack 2012; Banerjee et al. 2014; Otero and Rau 2017). Alcohol and tobacco consumption were found to fall due to improved transport access in the Philippines (Francisco and Helble 2017). A public transit system in Colombia was also found to result in a significant decline in homicide rates and decrease in violence (Cerda et al. 2012).

(9) *Transport development can contribute to gender equality.* Female employment has been found to respond to transport access in El Salvador and Peru (Torero, Almanzar, and Nakasone 2016; Valdivia 2011). In India, female participation in community groups was observed to be increased by road access (Banerjee and Sachdeva 2015). Iimi (2015) found stronger educational effects of road access on girls than boys in Brazil, and Francisco and Helble (2017) found similar patterns for improved ferry–road integration in the Philippines. Households headed by women were observed to benefit more strongly from road access than households headed by men in Papua New Guinea (Wiegand et al. 2017).

(10) *Transport infrastructure can affect prices.* Agricultural input and output prices were found to be affected by road development in Bangladesh (Khandker, Bakht, and Koolwal 2009), although price effects were conditioned by mobile phone penetration in Sierra Leone (Casaburi, Glennerster, and Suri 2013). Improved road networks were found to have significant impacts on development of local markets, resulting in increases in the number of small and medium-sized enterprises in Viet Nam and Georgia (Mu and van de Walle 2011; Lokshin and Yemtsov 2003).

(11) *Driving restrictions need to be carefully crafted to have positive impacts on air quality.* Although vehicle restrictions based on "coding" of license plate numbers or other driving restrictions are common in many countries, Ye (2017) finds no effects on air quality in Lanzhou, PRC, and there is evidence of such policies increasing air pollution in Colombia (Zhang and Umanskaya 2017) and Mexico (Salas 2010). At the same time, there is evidence that driving restrictions reduce pollution significantly in Beijing, where they are accompanied by restrictions on ownership of more than one vehicle (Viard and Fu 2015; Sun, Zheng, and Wang 2014; Wichmann

and Yang 2017). Another study also finds that high-occupancy vehicle lanes in Jakarta significantly reduce congestion (Hanna, Kreindler, and Olken 2017). Fu and Gu (2016) find large effects on pollution from road toll pricing changes in the PRC.

(12) *Mass transit can substantially improve air quality.* The Delhi metro was found to significantly reduce local air pollution (Goel and Gupta 2015), as was the Beijing metro (Guo and Chen 2018) and urban rail in Taipei,China (Chen and Whalley 2012). Urban rail in cities in the PRC was found to significantly reduce automobile energy consumption (Lin and Du 2017).

(13) *Road infrastructure can reduce migration.* Improvement of rural roads has been found to reduce out-migration due to better living conditions in Tanzania and Palau (Gachassin 2013; Akee 2006). Urban street improvement also reduced planned migration reported in Mexico (Gonzalez-Navarro and Quintana-Domeque 2016). As migration can lead to large income gains for poor populations (Bryan, Chowdhury, and Mobarak 2014), these findings suggest that welfare effects of roads must be large to substitute for potential gains from migration.

(14) *Improved roads can affect property markets.* Road surface improvements in Mexico were found to have increased property values by 16% and land values by 54% (Gonzalez-Navarro and Quintana-Domeque 2016). Agricultural land prices in Nepal were also found to increase with road development (Shrestha 2017).

(15) *Transport development can have unanticipated effects.* Vehicle driving restrictions were found to increase crime rates in Ecuador (Carrillo, Lopez- Luzuriaga, and Malik 2018). A study of railways in the PRC found a negative impact on development of the service sector, because economic activities were diverted to the newly connected cities (Qin 2014). Although most studies show that road networks reduce inequality, in the PRC however, one study found that road development also led to a negative GDP growth in non-targeted peripheral counties (Faber 2014). Road rehabilitation in Kazakhstan was found to increase accidents, injuries, and mortality (CAREC Institute Research Program 2010).

At the same time, many findings have been documented in relatively limited contexts, and are in some cases contradicted by other studies. The most common focus for the reviewed studies is rural roads, so many of the above findings on rural roads may not be valid for urban and arterial investments, which have been evaluated less frequently.

8. Evidence Gaps

The relatively limited number of studies to date for many transport interventions suggest that there are large gaps in evidence for the sector. As most of the evidence available concerns rural roads, the gaps are greatest for urban and large interventions.

Coverage gaps

- *Urban transport*: There is a body of research emerging on urban transport policy measures, such as driving restrictions, but the body of research on urban infrastructure is mostly limited to a few studies in the PRC; Taipei,China; India; and Mexico. Although ADB and other development actors are moving increasingly toward investment in urban transport and focusing more on environmental outcomes, existing studies mostly evaluate roads and rural roads in particular. This is partly because concerted financing of urban transport has grown more recently than other investments such as roads, and it may be in part due to the small-n problems of evaluating urban transport facilities.

- *Non-road transport:* Most impact evaluations focus on roads, especially rural roads, so that the evidence on projects related to rail, urban mass transit, and sea or air travel is far more limited. There is a nascent body of work emerging on metros, bus rapid transit, buses, and other transit forms. A few ongoing and recent studies include an experimental component to explore complementary interventions, such as subsidies to fares or information nudges to shift to ridership. However, the absolute number of studies remains limited.

- *Complementary interventions:* Achieving sustainable road safety and reductions in morbidity and mortality from road accidents is increasingly recognized as important, but this all depends on achieving behavioral

change. Only a relatively small number of studies have assessed this. Box 4 outlines some examples that illustrate how road safety can be explored further through impact evaluation. Similarly, measures to address gender disparities in transport or enhance female safety and ridership have had little attention.

- *Behavioral and efficiency-enhancing measures* are central to the avoid–shift–improve approach that guides much urban transport development. These include congestion-reducing measures such as pricing, incentives for modal shifts, and enhanced traffic demand management. Few of these mechanisms have been tested.

- *Improvements to logistics, ports, and trade facilitation* have not often been subjected to impact evaluation. There is little evidence on airports, seaports, border facilities, or other infrastructure investments, nor on trade and logistic-related policy reforms.

- *Operation and maintenance* is considered a widespread challenge for infrastructure projects, including in transport. None of the identified studies explore the impact of different maintenance funding or contracting systems. The study of auditing mechanisms shown in Box 5 provides an example of how this might be done. Similarly, there is little evidence on the effects of engaging local communities or specific subgroups (such as women) in either construction or maintenance.

Outcome gaps

Only a subset of outcomes represented in the theory of change presented in this report have been assessed.

- *Effects on infrastructure quality* are not frequently evaluated. At the basic level of outputs, there can be differences in how mechanisms underlying the causal chain, such as different contractual mechanisms, affect longevity and functionality of the transport infrastructure constructed. These relationships have been rarely tested.

- *Effects on travel time and vehicle operating costs* do not have much investigation via rigorous impact evaluation techniques, even though these parameters underpin many economic analyses. This means that there is limited direct verification of whether basic assumptions used to justify road investments actually hold true under real world driver behavior. Effects

on congestion also have relatively little evaluation. There is much scope to feed rigorously estimated effects on these parameters into the consumer surplus models used for economic analysis to see if project EIRRs are realistic, but this has not happened often.

- *Effects on market prices* have not been quantified frequently, especially outside of agriculture. This is true both for producers and for consumers. This is a major gap in understanding, as many downstream effects on economic activity, labor demand, productivity, and employment depend at least in part on effects on prices, due to reduced transport costs. Effects on markets are also under-evaluated.

- *Effects via access to intermediary services,* such as education and health facilities, have limited investigation. Relatively few studies have evaluated whether school attendance and use of medical facilities increase when transport connectivity is improved. These pathways may be important for impacts via long-term enhancement of human capital.

- *Effects on the employment search process and commuting patterns* have had few studies. Although there is a pool of studies on more aggregate employment patterns and outcomes, fewer studies have evaluated the mechanisms by which households shift time use and attempt to access new employment options. This is an important gap, as reduced travel time and costs can be expected to lead to both increased labor supply due to a wider array of accessible employment options, and labor demand due to effects on firm costs and productivity.

- *Effects on businesses* have been rarely assessed. Relatively few studies appraise effects of transport development on business outcomes, such as sales, revenue, profits, or productivity. These are important channels by which transport development should lead to economic development, employment, and welfare outcomes. Similarly, there are few studies that assess broader effects on competitiveness or trade.

- *Effects on social capital* have received little attention. As transport development can affect patterns of movement, migration, employment, and access to services, there may be long-term consequences for community relations and social networks. Only a few studies have evaluated effects on participation in groups and community activities. Evaluating these outcomes depends on the use of appropriate instruments from a range of social sciences.

- *Effects on female empowerment* have had relatively limited investigation. Although some studies have evaluated effects on education, labor market participation, and health practices separately for females, or have performed subgroup analysis on households headed by women, there is little analysis of effects on gender roles within households. Analysis of whether transport interventions lead to changes in female decision-making roles, independence, and empowerment is largely absent from the literature.

- *Environmental effects other than on air quality* have also not been extensively evaluated. Development of transport systems can make natural ecosystems more easily accessible and can potentially induce deforestation, other forms of land-use change, or poaching in natural areas. Rigorous impact evaluations have not often focused on these outcomes.

9. Future Studies

Transport is a challenging area for impact evaluation, but there is also substantial scope to apply additional methods beyond those used in impact evaluations for the sector to date. Methods that may be further applied in the context of large transport interventions include quasi-experimental small-n approaches and experimental encouragement designs. These techniques can help to address evidence gaps identified in the previous section.

Many of the studies identified rely on administrative unit statistics, such as at the district level, and apply those statistics in difference-in-differences (DiD) or instrumental variables (IV) models over long periods. Caution is needed in using these approaches, due to the endogeneity of unit composition over time, which can be a source of unobserved variation that biases estimates. Over shorter panel periods, this problem should be less pronounced. Many of the DiD models applied do not perform matching to reduce differences in the base period between treated and comparison units, or use many control variables in a two-way fixed effects approach. To reduce reliance on the parallel trends assumption, one of these approaches should be used whenever possible in future studies. Some of the DiD models also do not cluster standard errors at the unit of assignment (e.g., across all those exposed to a particular transport intervention), so that standard errors are underestimated, and significance is overestimated. Future studies should pay attention to this aspect.

Two quasi-experimental small-n approaches have promise for the transport context, but have not been used extensively to date. The need for these approaches becomes more evident if standard errors are appropriately clustered, as significant effects may be more difficult to estimate in the case of large infrastructure. Interrupted time series approaches may be used when transport facilities, such as a large bridge, new port, or new logistics measure, come online at a specific time, and time series data are available at high frequency before and after the intervention. The discontinuity at the time of intervention effectiveness may provide an impact measure. This technique has been applied

successfully for urban transit in Taipei,China and high-occupancy vehicle lanes in Jakarta, and has promise for further similar use.

Synthetic controls can be used when there are time series observations for at least one treated unit and multiple comparison units. The counterfactual becomes a weighted average of the comparison units that allows pre-intervention trends to be replicated. This approach could be used for major road segment development, if comparison "donors" to the synthetic controls that are not affected can be identified. It may also be applicable for ports and and other major infrastructure. Care needs to be taken to use the technique in contexts where changes in the units' composition endogenous to transport would also not bias estimates.

Although regression discontinuity design has been applied for impact evaluation of transport policies, its use for infrastructure remains rare. Many road interventions or segments for road improvement are selected via systematic processes, such as multicriteria analyses. When there is a quantitative basis of selection, a meaningful approval threshold, and many treated units (such as in the case of rural roads or feeder bus lines), regression discontinuity designs become possible to utilize. These designs provide an unbiased estimate of treatment effects for populations close to the approval threshold.

Box 6: Evaluating the Impact of Road Development on Household Welfare in Rural Papua New Guinea

An innovative impact evaluation that draws on spatial and administrative data evaluates the impact of quality and access of the road network in Papua New Guinea on rural household welfare over the period between 1996 and 2010. The study offers an example of how existing data can be analyzed to understand road infrastructure impacts at a large scale.

Design: The analysis uses two nationally representative cross-sectional household surveys to obtain variables on households, including consumption. This is combined with geographic information system characterization of road segments including the surface types (sealed, gravel, dirt) and road conditions (good, fair, poor) from administrative road databases. Geolocated data from the national census are applied to link the household survey data to road characteristics. A village fixed effects model is employed to correct for endogenous placement of road infrastructure programs, and an innovative correlated random coefficients quantile regression method is used to investigate whether road improvement benefits the poor.

Results: Improved road conditions are found to have a positive impact on household consumption. There are also significant observed effects on structural transformation from subsistence farming to engagement in market-oriented economic activities. Household investment in housing and school enrollment of children are also found to increase. The improvements are found to be larger among poorer, less-educated, and female-led households.

Source: Wiegand et al. (2017).

In terms of experimental approaches, encouragement designs can create random variation in utilization of large-scale transport facilities, even if the facilities themselves are not randomized. This variation can then be exploited to recover unbiased treatment effects. Although there are few examples to date, there are many possibilities to introduce randomization in public transport fares/subsidies, information treatments, and other elements affecting use.

New data sources are becoming available, which may enable better application of impact evaluation methods (see Box 6 for an example). First, household and other survey data are being more frequently georeferenced, so that they can be more easily associated with where transport improvements have and have not occurred. Second, project locations are being publicly disclosed with higher levels of georeferencing to improve this comparison. Third, new spatial data, such as on luminosity and air quality, allow characterization of new outcomes. Fourth, big data related to transport can be increasingly utilized, as transportation demand management systems become more sensorized and crowdsourced traffic information is increasingly collated from mobile platforms. Fifth, beyond these external data sources, the use of measurement methods from other disciplines, such as psychology and sociology, can enable additional outcomes to be captured during conventional surveys.

10. Conclusions

There exists both room and possibilities for further impact evaluations in the transport sector. Compared with other sectors, impact evaluation coverage is relatively limited, even though transport programming is becoming more complex and is embedding a wider range of behavioral components, which impact evaluation can help to test and inform. The evidence generated to date principally concerns household-level effects of road improvement in a few countries, but there is scope to evaluate many more interventions, contexts, intermediate channels, and complementary measures.

The review performed for this report finds that impact evaluation is rapidly growing on the sector. A recent body of studies has emerged that draws on administrative data sets regarding program implementation, secondary data from government surveys, and creative use of data from various other sources to analyze new questions.

A few recent randomized controlled trials (RCTs) also provide examples of how experimental approaches can be used innovatively to test both the effects of road infrastructure and the effects of complementary innovations. Similar approaches can be used to test contracting arrangements, maintenance schemes, and other information campaigns; and explore demand management systems.

There is scope to also improve the quality and quantity of quasi-experimental studies. Several techniques show promise to offer better control of confounding factors than the conventional array of IV, DiD, and fixed effects approaches, but have not yet been utilized. As georeferenced and administrative data become more openly available, the possibilities for applying these additional techniques will multiply. This opportunity should be seized to improve understanding of how transport interventions may be made more effective.

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APPENDIX 1:
EXAMPLE CASE STUDIES OF TRANSPORT SECTOR IMPACT EVALUATIONS

Case studies are included to demonstrate different types of empirical approaches, data sources, and questions addressed. Each case study is based exclusively on the published paper referenced at the end of its description. Equations, key notations, tables, figures, and their respective notes are drawn from each summarized study.

Case Study 1

Country : Mexico
Source : Gonzalez-Navarro, M. and C. Quintana-Domeque. 2016. Paving Streets for the Poor: Experimental Analysis of Infrastructure Effects. Review of Economics and Statistics. 98 (2). pp. 254–267.

Brief Overview

The study explores the effect of publicly financed infrastructure, in the form of urban residential street pavement, on property values. Via a randomized experiment, the study finds positive effects on property values, alongside an increase in ownership of vehicles and household assets, as well as improved housing. When results are applied in a cost–benefit analysis, the study finds that the increase in property values corresponds approximately to the cost of construction, which suggests efficiency in public goods provision.

Intervention Evaluated

The intervention consisted of publicly financed asphalting of residential streets in the Mexican city of Acayucan. The study exploits the city's gradual extension of street asphalting, which connects previously unpaved streets to the existing grid via separate projects. The street segments of interest were all between 300 and 1,200 meters long and 8–15 meters wide, enabling a two-way traffic flow and parking space.

Outcomes and Theory of Change Evaluated

The primary outcome variable is property price. The study also examines how increases in property price translate into increased consumption, in the form of vehicle ownership, household appliances, and home improvements.

The study uses two measures of property value: professional appraisals and homeowner valuations. To obtain the former, the authors used the services of a professional appraiser, who was also engaged for baseline and endline valuations. Non-durable goods consumption is captured through data on monthly per capita expenditure, whereas durable goods consumption is measured as household appliance and vehicle ownership.

Methods Used

The study applied a simple randomized experiment. Budget constraints meant that only half of the streets that were eligible for asphalting in 2006 could be paved. With a total of 56 such streets, 28 were randomly assigned to a treated group and 28 to a control group.

Impact was estimated through reduced-form (intent-to-treat [ITT]) and two-stage least squares (2SLS) estimates, respectively.

The reduced-form estimation is expressed in equation (1):

$$Y_{2009} = \alpha 0 + \alpha_1 Z + \alpha_2 Y_{2006} + \varepsilon_1 \quad (1),$$

where Y_{2009} is the outcome of interest in 2009, Z is the intent-to-treat indicator, and Y_{2006} is the outcome at baseline, included to improve precision. The ITT parameter is α_1 in equation (1).

The 2SLS estimates use pavement group assignment as an instrumental variable for the street being paved, where Z is the excluded instrument for an indicator D of being paved in the equation:

$$Y_{2009} = \beta_0 + \beta_1 D + \beta_2 Y_{2006} + \varepsilon_2 \quad (2)$$

The parameter β_1 in equation (2) is the ITT parameter divided by the regression-adjusted compliance rate (the fraction of units that were finally paved among those originally selected to be paved), and can be interpreted as the treatment effect on the treated.[1]

Treatment and Control Groups

All households situated by 1 of the 28 pavement projects constitute the treatment group, whereas households in non-pavement areas make up the control group. A binary indicator was constructed to indicate which households were in the treatment group.

1 This is given a range of conditions specified in the paper.

Data Analyzed

The study made use of two rounds of the Acayucan Standards of Living Survey conducted at the household level prior to, and following, the street asphalting project. Professional appraisals of residential property values were also used, as described above. The household questionnaire collected both household- and individual-level information and specifically contained a detailed consumption and income module following the Mexico National Survey of Household Income and Expenditure.

The pre-intervention survey was conducted in February 2006 and the post-intervention survey in February 2009. Both rounds were followed by professional property value appraisals. All households residing on one of the 56 streets that took part in the experiment were included in the survey. Households living in property constructed between baseline and endline were also included, allowing the authors to detect changes to neighborhood composition over time.

Sample Size

The baseline survey included 1,231 households, with a response rate of 94%. The follow-up survey covered 1,083 households of which 900 were also interviewed in 2006, while 156 were new households and 27 residing in property constructed between the survey rounds were also included in the post-intervention survey.

Key Findings

The study finds substantial increases in property values in treatment areas (Case Study Table 1.1). Professional appraisals showed land values increasing by 54% in areas benefiting from street asphalting and property values increasing by 16%. According to homeowner valuations, property values increased by 25%, while rents increased by 31%.

The results also point to a notable poverty reduction effect, with asphalting of streets positively impacting household acquisition of household appliances, motor vehicle ownership, and home improvements (Case Study Table 1.2). Whereas 2% of individuals living in control streets used collateral-based credit following project completion, 5% of those benefiting from new pavement did so, with the mean loan size for the two groups being ₱135 and ₱1,643. A negative effect on out-migration plans is also observed.

Case Study Table 1.1: Estimated Impacts of Street Pavement on Property Values

	ITT	2SLS	Mean Control (2009)
Log professional appraisal of property value	0.09***	0.16***	11.52
	(0.03)	(0.04)	(0.06)
	[548]	[548]	[253]
Log professional appraisal of land value	0.32***	0.54***	10.07
	(0.06)	(0.10)	(0.06)
	[548]	[548]	[253]
Log owner estimate of property value	0.16*	0.25*	12.01
	(0.09)	(0.15)	(0.08)
	[531]	[531]	[262]
Log rent	0.17*	0.31**	6.55
	(0.09)	(0.13)	(0.10)
	[56]	[56]	[22]
Log transaction price recent purchases	0.44	0.85	10.82
	(0.65)	(1.22)	(0.38)
	[29]	[29]	[8]

2SLS = two-stage least squares, ITT = intent to treat.

Notes: Transaction price is amount paid by new homeowners (arriving between baseline and follow up), hence the dependent variable at baseline is not included. ITT column uses assignment to pavement as independent variable. 2SLS column instruments pavement with assignment to pavement. Regressions include a constant and the corresponding dependent variable at baseline. For log rent, we use as baseline control the rent paid by the family previously living in the same house in 2006. Estimation takes survey weights into account. Standard errors clustered at the pavement-project level in parentheses. Number of observations in brackets. Significance levels reported only for ITT and 2SLS: * = significant at 10%; ** = significant at 5%; *** = significant at 1%.

Source: Gonzalez-Navarro and Quintana-Domeque (2016).

Case Study Table 1.2: Estimated Impacts of Street Pavement on Consumption

	ITT	2SLS	Mean Control (2009)
Household appliances (0-6)	0.166*	0.274*	2.36
	(0.091)	(0.147)	(0.077)
	[900]	[900]	[413]
Vehicles (car/truck/motorcycle) (0-3)	0.063*	0.104*	0.245
	(0.037)	(0.059)	(0.027)
	[900]	[900]	[413]
Home improvements (0-11)	0.258**	0.424**	0.400
	(0.112)	(0.202)	(0.064)
	[900]	[900]	[413]
Materials purchased for home improvement (=1)	0.052*	0.086*	0.146
	(0.027)	(0.046)	(0.021)
	[894]	[894]	[409]
Monthly log per capita expenditure	0.047	0.077	6.73
	(0.047)	(0.075)	(0.040)
	[864]	[864]	[403]
Monthly log sum of itemized expenditures per capita	0.035	0.057	6.62
	(0.049)	(0.079)	(0.041)
	[883]	[883]	[409]

2SLS = two-stage least squares, ITT = intent to treat.

Notes: ITT column uses assignment to pavement as independent variable. 2SLS column instruments pavement with assignment to pavement. Regressions include a constant and the corresponding dependent variable at baseline. Estimation takes survey weights into account. Standard errors clustered at the pavement-project level in parentheses. Number of observations in brackets. Significance levels reported only for ITT and 2SLS: * = significant at 10%; ** = significant at 5%; *** = significant at 1%.

Source: Gonzalez-Navarro and Quintana-Domeque (2016).

Case Study 2

Country : India
Source : Datta, S. 2011. The Impact of Improved Highways on Indian Firms. *Journal of Development Economics*. 99 (1). pp. 46–57.

Brief Overview

The study explores how firms along highways that connect the four largest cities in India were affected by improvements to road width and quality carried out between 2002 and 2005. It applies a difference-in-differences (DiD) approach in which location on an improved highway is used as one treatment variable, and distance from the road is used as another. Results show that highway improvements led to a lower average stock of input inventories, more frequent changes of supplier, and fewer transportation obstacles to production.

Intervention Evaluated

The study focuses on the Golden Quadrilateral Program, which was the central component of the first phase of the larger National Highway Development Program approved by the Government of India in 2000. Program implementation began in 2002, with 70% of the project completed by 2006.

The program set out to upgrade four national highways between the cities of Chennai, Delhi, Kolkata, and Mumbai. This transformed the four roads into the first major international-quality highways in India, with quality substantially superior to other roads in the country.

Outcomes and Theory of Change Evaluated

Three outcomes of interest related to the firms' operations are examined: (1) inventories, (2) supplier relationships, and (3) perceptions of transportation quality.

The study focuses primarily on input inventories. Firms, the author argues, will seek to minimize the level of inventory as holding large inventories is costly. At the same time, a given inventory should be of sufficient size to ensure that there will be no obstacles to the production process. Under the assumption that road quality is correlated with a more reliable supply of inputs, improved highway quality is expected to decrease mean levels of input inventory compared with firms located off improved highways.

In addition, the study focuses on the duration of relationships between firms and their main input suppliers. The author hypothesizes that poor road quality restricts the availability of suppliers, which is expected to cause firms to more often switch supplier following highway improvement. In other words, firms benefiting from road improvement are expected to experience less growth in transaction duration with current suppliers compared with firms elsewhere. The final outcome variable is a subjective firm rating of the degree to which transportation was an impediment to business activity.

Methods Used

Citing other studies, the author views the construction of the Golden Quadrilateral highway as a natural experiment, but acknowledges the possibility of endogenous project placement. Endogenous placement is a common challenge in measuring impact of infrastructure programs, as such projects are placed according to characteristics that differ from locations where the infrastructure is not placed.

To address bias from endogenous placement, the study employs a DiD approach using (1) a binary treatment (dummy) variable for whether a firm is located on the upgraded road or not, and (2) a continuous variable with distance of the city in which a firm is located from the nearest city on the highway as treatment variable.

As proxies to help test whether the parallel trends assumption of DiD holds, the author uses interactions between the post-treatment period and other variables, such as industry and city size, to help ensure that the results are not driven by differential trends related to variables.

Treatment and Comparison Groups

The analysis is conducted using two variables for treatment.

The first, as described above, is a dummy variable categorizing a firm as belonging to the treatment group if it is situated in a city located on an upgraded highway, and as comparison group otherwise.

The second treatment variable used is driving distance from the nearest city on the Golden Quadrilateral, in recognition of partial effects on firms located in cities partially connected by upgraded highways.

Data Analyzed

The data used come from the 2002 and 2005 rounds of the World Bank Enterprise Surveys for India. As the authors describe, "The firms surveyed were a random sample of firms in India's formal sector stratified by sector of activity, firm size and geographical location... A subset of firms in 37 Indian cities were surveyed in both years, creating a panel of firms whose responses can be compared across 2 years" (Datta 2011, 51). Of the cities included in the panel survey, 19 were located on one of the four upgraded highways while the remaining 18 were located on other national highways.

Sample Size

The panel data cover 37 cities. The analysis is undertaken on two different samples: the full sample covering 2,109 firms and a sample of 1,604 that excludes firms in the four nodal cities of greater Delhi, Chennai, Kolkata, and Mumbai.

Key Findings

The study finds positive effects of highway upgrading on firms' ability to optimize their input inventory and their choice of supplier. Location on the upgraded highways is found to lead to a reduction in inventory equivalent to at least 6 days' worth of production (Case Study Table 2.1). This supports the hypothesis that better quality infrastructure reduces constraints on firms' ability to optimize inventory levels.

Similarly, the study finds that transaction duration with input suppliers increased by an average of 3 months less for firms in the treatment group than for comparison firms located off the Golden Quadrilateral highway, supporting the hypothesis that improved quality of infrastructure increases access to a choice of suppliers (Case Study Table 2.2).

Estimations using the distance-based treatment variable revealed similar results to those based on the binary treatment variable. The quantitative findings are also supported by results that highway improvement decreased the frequency of reporting transport as a key negative factor affecting production.

Case Study Table 2.1: Estimated Effects of Location On/Off Golden Quadrilateral on Days of Inventory Held

Dependent Variable: Number of Days of Inventory of Most Important Input						
	I	II	III	IV	V	VI
Panel A: Full Sample						
Post* Treatment	–7.21**	–7.46	–9.16**	–6.10*	–5.94*	–7.48**
SE	3.26	3.32	3.57	3.18	3.28	3.34
t-ratio	–2.21	–2.25	–2.56	–1.89	–1.81	–2.24
Post	–0.11	2.02	1.01	0.09	–0.43	–1.48
SE	1.92	2.32	2.58	2.03	2.90	3.31
t-ratio	–0.06	0.87	0.39	0.05	–0.15	–0.45
Industry* Post	No	Yes	Yes	No	Yes	Yes
City Population* Post	No	No	Yes	No	Yes	Yes
Fixed Effects	City	City	City	Firm	Firm	Firm
N	2109	2109	2109	2109	2109	2109
Panel B: Sample Excluding Firms in 4 Nodal Cities and Their Suburbs						
Post* Treatment	–11.12***	–11.32***	–12.80**	–9.91***	–9.79***	–11.42***
SE	3.82	3.86	3.97	3.41	3.45	3.14
t-ratio	–2.91	–2.93	–3.22	–2.87	–2.83	–3.63
Post	–0.11	2.99	–0.51	0.09	–0.16	–4.13
SE	1.93	2.48	3.08	2.04	3.16	3.39
t-ratio	–0.06	1.21	–0.17	0.05 –	0.05	–1.22
Industry* Post	No	Yes	Yes	No	Yes	Yes
City Population* Post	No	No	Yes	No	No	Yes
Fixed Effects	City	City	City	Firm	Firm	Firm
N	1594	1594	1594	1594	1594	1594

Notes:
The four nodal cities are Delhi, Mumbai, Kolkata, and Chennai; their suburbs are Gliaziabad, Faridabad, Noida and Gurgaon (suburbs of Delhi), and Thane (a suburb of Mumbai). Standard errors reported are robust and clustered at the city level (37 clusters in Panel A; 28 clusters in Panel B).
Treatment is a dummy variable that is 1 for cities on the Golden Quadrilateral and 0 otherwise: it is excluded as it is collinear with a combination of city dummies.
The variable of interest is Post*Treatment, the interaction between being on a Golden Quadrilateral highway and the post- period.
The regressions in Columns II, III, V, and VI include the interaction between industry dummies and the post-period dummy to control for differential trends by industry.
The regressions in Columns III and VI include the interaction between the city's population in 2001 and the post-period dummy as an additional control to allow for differential trends by city size.
* indicates significance at 90% ; ** at 95%; and *** at 99%.

Source: Datta (2011).

Case Study Table 2.2: Estimated Effects of Location On/Off Golden Quadrilateral on Supplier Relationship

Dependent Variable: Number of Days of Inventory of Most Important Input						
	I	II	III	IV	V	VI
Panel A: Full Sample						
Post* Treatment	−0.253*	0.243*	−0.241*	−0.233*	−.226*	−0.229*
SE	−0.138	(.133)	(0.127)	(0.134)	(0.129)	(0.124)
t-ratio	−1.820	−1.83	−1.90	−1.740	−1.75	−1.85
Post	0.381***	0.261**	0.261**	0.371***	0.301**	0.299**
SE	(0.128)	(0.116)	(0.119)	(0.123)	(0.123)	(0.127)
t-ratio	2.970	2.250	2.190	3.020	2.440	2.360
Industry* Post	No	Yes	Yes	No	Yes	Yes
City Population* Post	No	No	Yes	No	Yes	Yes
Fixed Effects	City	City	City	Firm	Firm	Firm
N	2109	2109	2109	2109	2109	2109
Panel B: Sample Excluding Firms in 4 Nodal Cities and Their Suburbs						
Post* Treatment	−0.236*	−0.246	−0.265	−0.228*	−0.227*	−0.240
7 SE	(0.137)	(0.154)	(0.161)	(0.132)	(0.129)	(0.154)
t-ratio	−1.73	−1.60	−1.65	−1.730	−1.750	−1.56
Post	0.381***	0.214*	0.209	0.371***	0.312**	0.259*
SE	(0.129)	(0.122)	(0.127)	(0.124)	(0.126)	(0.142)
t-ratio	2.96	1.76	1.65	3.00	2.47	1.82
Industry* Post	No	Yes	Yes	No	Yes	Yes
City Population* Post	No	No	Yes	No	Yes	Yes
Fixed Effects	City	City	City	Firm	Firm	Firm
N	1604	1604	1604	1604	1604	1604

Notes:
Standard errors reported are robust and clustered at the city level (37 clusters in Panel A; 28 clusters in Panel B).
The dependent variable is the answer to the question: "How many days worth of production of your primary input do you hold as inventory?"
Treatment is a dummy variable that is 1 for cities on the Golden Quadrilateral and 0 otherwise; it is excluded as it is collinear with a combination of city dummies.
The variable of interest is Post* Treatment. The interaction between being on a Golden Quadrilateral highway and the post-period. The regressions in Columns II, III, V, and VI include the interaction between industry dummies and the post-period dummy to control for differential trends by industry.
The regressions in Columns III and VI include the interaction between the city's population in 2001 and the post-period dummy as an additional control to allow for differential trends by city size.
* indicates significance at the 10% level; ** at 5%; and *** at the 1% level.

Source: Datta (2011).

Case Study 3

Country : Viet Nam
Source : Mu, R. and D. van de Walle. 2011. Rural Roads and Local Market Development in Viet Nam. *The Journal of Development Studies*. 47 (5). pp. 709–734.

Brief Overview

The study quantifies the effect of rural road rehabilitation on commune-level market development in rural Viet Nam. DiD combined with propensity score matching (PSM) finds positive impacts on local market development with indications of stronger impact in poorer communes.

Intervention Evaluated

The intervention evaluated is the World Bank-financed Vietnam Rural Transport Project I, a rural road rehabilitation project implemented in 18 provinces of Viet Nam between 1997 and 2001. The project rehabilitated 5,000 kilometers of rural roads to help develop local market activity, connect markets to commune centers, and ultimately reduce poverty.

Outcome and Theory of Change Evaluated

The primary outcome variables concern the presence and frequency of local markets. The study explores whether road development affected the presence of other commercial establishments such as shops, bike repair shops, pharmacies, and restaurants, and examines whether there are indications of livelihood diversification away from agriculture and toward trade and service activities. School enrollment is also examined.

These outcomes are framed by what the authors call the hypothesis of "transport-induced local-market development" whereby local market development could be "an instigating factor in a process of shifting production structures to more diversified and higher value activities, improved access to various services, and broader economic development in an area" (Mu and van de Walle 2011, 710). This would positively affect off-farm opportunities, which increases perceived returns to education, and leads to increased schooling.

Methods Applied

Similar to Case Study 2, the validity of DiD hinges on the parallel trend assumption, which implies that results will be biased in the presence of time-varying factors associated with project or program placement. To lower the likelihood that this is the case, the study combines DiD with PSM. Nonparametric kernel matching is used with all nonparticipants as comparison communes and weights are assigned according to a kernel function of the predicted propensity score. As a robustness check, the authors also conduct a propensity score weighted DiD estimation.

Treatment and Comparison Groups

Roads were purposively placed for the treatment group by the project. Comparison communes are identified among nonproject communes located in the same districts as the treatment communes through PSM.

Data Analyzed

The study is based on the Survey of Impacts of Rural Roads in Vietnam carried out in four rounds starting with baseline data collected in June 1997 and three follow-up surveys in 1999, 2001, and 2003. With the surveying returning to the same locations in each round, the data set makes up a panel of 200 communes and 3,000 households in six of the 18 provinces that took part in the project.

The authors note that their analysis is based primarily on commune-level data from the first and last survey rounds. They exploit common features of the household component of the roads survey and the nationally representative Vietnam Living Standards Survey from 1998 to estimate baseline consumption expenditure for the study households, which are used to create an indicator of commune-level welfare.

Sample Size

The sample consists of a panel of 200 communes and 3,000 households in 29 of 38 potential survey districts surveyed in 1997, 1999, 2001, and 2003.

Key Findings

The study reveals significant impacts on the presence and frequency of local markets and supports the hypothesis of "transport-induced local-market development." Roads are found to cause a switch from agricultural to nonagricultural, mostly service-related, activities (Case Study Table 3.1). However, these impacts took time, and only became measurable in 2003.

Positive effects are found on educational outcomes, particularly on primary school completion rates, which increase by 25% by 2001. Smaller effects are found on secondary school enrollment, although these did not appear until 2003. The study also finds notable differences between poorer and less-poor project communes, with higher impacts observed among the poorer communes.

Case Study Table 3.1: Estimated Effects of Road Improvement

	2001						2003					
	DD	t-ratio	PS kernel matched DD	t-ratio	PS weighted DD	t-ratio	DD	t-ratio	PS kernel matched DD	t-ratio	PS weighted DD	t-ratio
Markets												
Market	0.00	0.02	0.03	0.88	0.04	1.27	0.09*	1.93	0.08*	1.85	0.09**	2.37
Market frequency	0.01	0.10	0.08	0.75	0.10	1.06	0.19	1.61	0.23*	1.69	0.25**	2.23
Shop	−0.02	−0.23	0.01	0.01	0.08	0.50	0.03	0.43	0.08	0.57	0.14	1.12
Bicycle repair shop	−0.08*	−1.83	−0.06	−1.01	−0.04	−0.78	−0.04	−0.91	0.02	0.37	0.03	0.60
Pharmacy	0.08	0.99	0.04	0.32	−0.06	−0.31	0.14*	1.65	0.12	0.94	0.16	1.36
Restaurant	−0.03	−0.97	−0.01	−0.30	−0.01	−0.28	0.05	0.62	0.01	0.08	0.05	0.55
Services availability												
Women's hairdressing	−0.04	−0.70	−0.07	−0.72	−0.07	−0.72	0.14*	1.83	0.18**	2.19	0.20**	2.61
Men's barber	0.03	0.49	0.01	0.11	0.01	0.11	0.10	1.53	0.11	1.20	0.14**	2.15
Men and women's tailoring	0.12	1.60	0.11	1.42	0.10	1.26	0.09	1.19	0.10	1.12	0.12*	1.69
Employment: % households whose main occupation is:												
Farming	0.04	0.62	0.05	0.72	0.03	0.38	−1.99	−1.26	−2.04*	−1.67	−2.06**	−1.89
Trade	−0.05	−1.21	0.03	0.42	0.03	0.53	0.57	1.27	0.36	0.71	0.58	1.35
Services	−0.06	−0.14	−1.54	−1.15	−1.03	−0.95	1.01**	2.51	1.68**	2.43	1.72**	3.10
School enrollments												
Primary school completion (<15)	0.00	70.09	0.15**	2.58	0.25**	2.82	0.04	0.91	0.17**	2.48	0.30**	2.31
Secondary school enrollment	0.06	1.53	0.10	1.47	0.25	1.33	0.10**	2.88	0.05	1.41	0.07*	1.70

DD = difference in differences, PS = propensity score.

Notes: The sample consists of the 94 project and 95 non-project communes on common support as determined by propensity score matching. T-ratio of kernel matching is obtained from bootstrapping (100 repetitions). ** significant at 5% level or higher; * significant at 10% level. Standard errors of weighted DD estimations are robust to heteroskedasticity and serial correlation of communes within the same district.

Source: Mu and van de Walle (2011).

Case Study 4

Country : Indonesia
Source : Gertler, P., M. Gonzalez-Navarro, T. Gracner, and A. Rothenberg. 2015. Road Quality, Local Economic Activity and Welfare: Evidence from Indonesia's Highways. Preliminary draft. October 2015.

Brief Overview

The study examines the effects of road quality on economic activity in Indonesia. To do so, it exploits the centralized nature of the country's fiscal organization and the existence of a nationwide panel data set of road surface roughness to "predict road quality from temporal variation in budgets that are exogenously allocated to different road maintenance authorities" (Gertler et al. 2015, 1).

Results indicate that improving the quality of road networks positively affects the number of new manufacturing firms and jobs in the manufacturing sector, shifts jobs from agriculture to manufacturing, and increases profits for those that stay on in the agriculture sector. In turn, this reduces the income gap between the two sectors.

Intervention Evaluated

The study does not examine a specific intervention but examines the impact of road quality on economic activity more broadly. Treatment is thus not binary, but a continuous variable.

Road quality is measured using the international roughness index, a commonly accepted measure of road quality. Increasing levels of road roughness, the authors argue, caused for instance by gravel or potholes, increases travel time, fuel usage, maintenance needs, and the propensity for accidents. Road roughness is considered as directly related to transport costs and is a useful measure of road quality.

Outcome and Theory of Change Evaluated

The study considers that road quality affects not only transportation costs for farmers, firms, and workers, but also access to agricultural plots, equipment, and labor. It hypothesizes that improvements in road quality will lead to increased farm and firm productivity and profits, resulting in increased employment and eventual increases to in-migration.

The study thus evaluates outcomes at various levels:

(1) District-level outcomes including number of firms in the area, the number of newly opened firms, firm output, value added, investment, wage rates, and output per worker
(2) Firm-level outcomes, as above
(3) Individual-level outcomes including employment status and earnings in agriculture, manufacturing, sales/service, and others
(4) Household-level outcomes including per capita consumption, land value, and rent
(5) District-level outcomes on out-migration
(6) Community-level wages and prices

Methods Applied

The study authors face two main methodological concerns:

(1) The potential for bias arising from endogenous project placement, i.e., the possibility that the areas that receive improvements were selected by policy makers based on specific characteristics such as their potential for economic growth.
(2) The potential for attenuation bias, i.e., the possibility that high levels of economic activity may cause road quality to deteriorate more rapidly due to extensive use.

To address these concerns, the study employs an instrumental variables (IV) approach in combination with panel data. More specifically, it uses an IV approach in which provincial road maintenance budgets serve as instruments for road quality in a given district.

Maintenance budgets are proposed as valid instruments due to Indonesia's centralized fiscal organization. Because provincial and district funds are almost entirely dependent on national revenue, local government revenues are presented as characterized by a large degree of independence from local economic activity shocks.

Also of importance for the identification strategy is the fact that Indonesia has independent road authorities at the national, provincial, and district levels of government, and that "in any given district, the share of roads of each type is predetermined [which] induces temporal exogenous variation in district road quality arising from the differential shares of road authorities operating in each district" (Gertler et al. 2015, 2).

The equation of interest takes the following form:

$$Y_{dt} = \alpha_d + \alpha_t + \beta \log (\text{Road Quality})_{dt} + x'_{dt}0 + \varepsilon_{dt}$$

Impact is measured as the coefficient on the log of the road quality variable while maintenance budget is used as the IV for road quality.

Treatment and Comparison Groups

Treatment is a continuous variable characterizing road quality.

Data Analyzed

The study uses three sources of data:

(1) Data on road quality are obtained from a comprehensive road quality database collected by Indonesia's road authorities. The database tracks road-segment-level quality for Indonesia's highways over a 20-year period. The authors do not have direct data on road budgets but construct a measure of road investments from the available road roughness information.

(2) Data on manufacturing firms come from the Indonesia Annual Census of Manufacturing Establishments, which covers all firms with more than 20 employees and characterizes firm input use, costs, production, and employment.

(3) Data on individuals and households come from the Indonesian Family Life Survey which includes individual-level data on employment status and income, as well as household-level consumption expenditure data. The survey is a nationally representative longitudinal survey undertaken in 1993, 1997, 2000, and 2007, and covers more than 30,000 individuals over the 14-year period.

Sample Size

The Indonesian Family Life Survey has a sample of 30,000 individuals. The manufacturing firm census covers more than 278,000 firms.

Key Findings

The results show that improvements in the quality of road networks positively affect the number of manufacturing firms (Case Study Table 4.1). The results also indicate an increase in job creation in the manufacturing sector.

The study finds three sets of effects for households. Household consumption, land values, and rental prices are all found to rise significantly from road improvement (Case Study Table 4.2).

In terms of employment, the study finds an occupational shift from agriculture into manufacturing as well as improved profits for those who stay in agriculture (Case Study Table 4.3). The gap in average income between agriculture and manufacturing employment is also found to be reduced as road quality increases.

Case Study Table 4.1: Estimated Effects of Road Quality on District-Level Manufacturing Outcomes

	FELS	GMM	Statistics		
	(1)	(2)	N	Y	KBP
Any Firms (0 1)	0.007	0.273	3381	0.956	57.173
	(0.017)	(0.108)**			
Log Number of Opened Firms	0.035	1.582	3381	1.218	57.173
	(0.058)	(0.285)***			
Log Number of Closed Firms	−0.078	0.061	3184	1.171	65.882
	(0.069)	(0.293)			
Percent Δ Number of Firms	−0.003	0.356	3337	−0.032	59.892
	(0.020)	(0.124)***			
Log Output	0.296	3.860	3381	14.612	57.173
	(0.235)	(1.366)***			
Log Value Added	0.256	3.439	3381	13.510	57.173
	(0.216)	(1.262)***			
Log Investment	−0.394	3.350	2388	11.356	80.940
	(0.369)	(1.460)**			
Log Export Share	−0.018	0.018	3232	0.119	59.808
	(0.020)	(0.047)			
Log Average TFP	0.078	0.793	3043	8.250	69.181
	(0.075)	(0.336)**			
Log Number of Workers	−0.020	0.998	3381	4.379	57.173
	(0.099)	(0.436)**			
Log Wage Rate	0.040	−0.003	3198	7.687	59.113
	(0.036)	(0.158)			
Log Output per Worker	0.296	0.908	3232	10.458	59.808
	(0.086)***	(0.292)***			
Log Value Added per Worker	0.237	0.738	3232	9.305	59.808
	(0.091)***	(0.275)***			

FELS = fixed effects ordinary least squares, GMM = generalized method of moments, KBP = Kliebergen-Paap weak instruments F-statistic, TFP = total factor productivity.

Notes: The table reports the results of district-level panel regressions of the dependent variable on island market potential. Each cell reports results from a separate regression, with the dependent variable listed in the row heading. All regressions include district and year fixed effects, with controls that include logs of current population and non-oil regional gross domestic product. Robust standard errors, clustered at the district level, are reported in parentheses. *, **, and *** denote significant at the 10%, 5%, and 1% levels.

Source: Gertler et al. (2015).

Case Study Table 4.2: Estimated Effects of Road Quality on Household Outcomes

	FELS	GMM	Regression Stats		
	(1)	(2)	N	Y	KBP
Log of Per-Capita Consumption Expenditures	0.140	0.182	23129	11.064	39.372
	(0.040)***	(0.093)*			
Log of Land Value	0.283	0.969	7325	14.806	18.188
	(0.162)*	(0.322)***			
Log of Rent Per Room	0.199	0.726	19242	8.316	38.708
	(0.063)***	(0.135)***			
Household FE	Yes	Yes			
Year FE	Yes	Yes			

FELS = fixed effects ordinary least squares, FE = fixed effects, GMM = generalized method of moments, KBP = Kliebergen-Paap weak instruments F-statistic.

Notes: The table reports the results of household-level panel regressions with household and survey-wave fixed effects. Each cell reports estimates from a separate regression, with the dependent variable listed in the row heading. Controls include current district population, district gross domestic product, survey wave indicators, survey month indicators, and controls for household size. For the land value regressions, controls are included for the number of rooms, whether the house has electricity, piped water, its own toilet, indicators for types of floor (cement, dirt), walls (masonry), and a tiled roof. The log rent regression, uses the same additional controls but also add an indicator for whether the rent observation is actual rent, as opposed to being estimated. Robust standard errors in parentheses, clustered at the (initial) village level. *, **, and *** denote significant at the 10%, 5%, and 1% levels.

Source: Gertler et al. (2015).

Case Study Table 4.3: Estimated Effects of Road Quality on Employment Outcomes

	FELS	GMM	Regression Stats		
	(1)	(2)	N	Y	KBP
Any Employment (0 1)?	−0.022	0.000	36851	0.701	32
	(0.020)	(0.040)			
Log Total Hours Worked	−0.012	−0.038	23290	5.150	31.237
	(0.037)	(0.080)			
Log Total Earnings	0.467	0.913	17889	10.711	27.404
	(0.197)**	(0.399)**			
Agriculture ... Any Employment (0 1)?	−0.065	−0.085	23293	0.418	31.232
	(0.018)***	(0.043)**			
... Log Total Hours Worked	−1.398	4.070	23499	13.224	30.918
	(1.427)	(2.868)			
... Log Earnings	1.182	2.484	5308	7.824	13.431
	(0.778)	(1.473)*			
Manufacturing ... Any Employment (0 1)?	0.080	0.100	23293	0.290	31.232
	(0.023)***	(0.050)**			
... Log Total Hours Worked	4.083	9.817	23839	12.572	30.933
	(1.134)***	(2.455)***			
... Log Earnings	−0.101	0.507	4443	11.198	16.004
	(0.206)	(0.583)			
Sales and Services ... Any Employment (0 1)?	−0.043	−0.160	23293	0.313	31.232
	(0.021)**	(0.043)***			
... Log Total Hours Worked	−3.176	−7.239	23531	13.628	31.290
	(1.374)**	(2.458)***			
... Log Earnings	0.127	0.077	4174	11.047	22.725
	(0.251)	(0.525)			
Other (Formal) ... Any Employment (0 1)?	0.026	0.001	23293	0.190	31.232
	(0.015)*	(0.029)			
... Log Total Hours Worked	0.516	−1.113	23293	7.126	31.232
	(0.753)	(1.402)			
... Log Earnings	−0.928	−2.407	3275	4.584	23.136
	(0.562)*	(1.218)**			
Other (Informal) ... Any Employment (0 1)?	−0.048	−0.119	23293	0.225	31.232
	(0.018)***	(0.036)***			
... Log Total Hours Worked	−3.043	−7.202	23293	8.052	31.232
	(0.924)***	(1.739)***			
... Log Earnings	0.798	1.271	3757	8.643	26.553
	(0.618)	(1.049)			
Individual FE	Yes	Yes			
Year FE	Yes	Yes			

FELS = fixed effects ordinary least squares, FE = fixed effects, GMM = generalized method of moments, KBP = Kliebergen-Paap weak instruments F-statistic.

Notes: The table reports the results of individual-level panel regressions with individual and survey-wave fixed effects. Each cell reports estimates from a separate regression, with the dependent variable listed in the row heading. Controls include district gross domestic product, individual age, education, household size, and month of survey indicators. Total hours worked is defined only if the individual reported working. Earnings regressions also include hours worked (by sector) as a control. Robust standard errors in parentheses, clustered at the (initial) village level. *, **, and *** denote significant at the 10%, 5%, and 1% levels.

Source: Gertler et al. (2015).

APPENDIX 2:
OVERVIEW OF TRANSPORT SECTOR IMPACT EVALUATIONS

Appendix Table 2: Overview of Transport Sector Impact Evaluations

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
Completed ADB Studies						
1	Railway	Uzbekistan	Yoshino, N. and U. Abidhadjaev. 2015. An Impact Evaluation of Investment in Infrastructure: The Case of the Railway Connection in Uzbekistan. *ADBI Working Paper Series*. No. 548. Tokyo: Asian Development Bank (ADB) Institute.	Difference-in-differences (DiD)	Regional gross domestic product (GDP) growth rate	The study explores the effect of rail infrastructure provision on regional economic performance and employs a DiD approach to estimate the effect of a new railway in Uzbekistan on regional GDP. The study focuses on regional effects, spillover effects which include surrounding regions, and connectivity effects, which only include the effect in the hub region and regions at far ends of the railway. The study separately examines the effects of anticipation of the railway, the launch of the railway, and postponed effects of railway connection. It finds that railway connectivity increased regional GDP growth rates in affected regions by 2%, an effect driven primarily by increases in value-added of industry by 5% and services of approximately 7%. Agricultural value-added on the other hand increase by only 1%.
2	Almaty–Korday Road project	Kazakhstan	CAREC Institute Research Program. 2010. Final Report: Retrospective Impact Evaluation of the Almaty–Korday Road Project (Zhambyl Oblast).	DiD	Road accidents, injuries, and deaths; opening of new service facilities along the road	This study examines the impact of road rehabilitation on the number of road accidents, injuries, and deaths as well as the number of roadside service facilities. The project was a component of the ADB-financed Almaty–Bishkek Regional Road Rehabilitation project. The evaluation was designed and carried out ex post. Data on a number of outcomes were collected for 2003, before project implementation, and 2009, after completion. Data on road accidents came from existing records of the traffic committee, while data on facilities and other village statistics were gathered from district administrative offices. A village-level survey was also carried out in 2009. The study found that road rehabilitation led to an increase in roadside facilities, such as gas stations, hotels, and shops. It also however led to an increase in deaths in off-village segments. While a smaller decrease in deaths took place in village segments, there was an overall significant net increase in mortality.

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Appendix Table 2 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
3	Farm roads	Bhutan	Blöndal, N. 2015. ADB Impact Evaluation: Farm Roads to Support Poor Farmers' Livelihoods in Bhutan. Unpublished working paper.	Fixed effects (FE), matched DiD	Travel time, participation in training programs, time use, consumption, agricultural production	The evaluation analyzes the effects of the Farm Roads to Support Poor Farmers' Livelihoods project. It uses household panel data for 343 households collected at project baseline in 2011 and endline in 2013, respectively. FE and matched DiD estimators are used. Results show (i) a significant reduction in travel time to key services and locations and an increase in people using vehicle transportation following road implementation; (ii) a significant effect on the proportion of people who have received training and information on marketing, road maintenance, and access to financial services, though the latter remains relatively low; and (iii) an increased production of high-value crops, ginger, and oranges in the project areas.
4	Roads/transport corridors	People's Republic of China (PRC), Lao People's Democratic Republic (Lao PDR), Thailand	ADB. 2014. *Assessing Impact in the Greater Mekong Subregion: An Analysis of Regional Cooperation Projects*. Manila.	Propensity score matching (PSM)	Income and expenditure, indicators of health status, access to education and health facilities	The study examines the socioeconomic impacts of the Greater Mekong Subregion Northern Economic Corridor Project roads connecting Yunnan Province in the PRC, the Lao PDR, and Thailand. The study uses PSM to match project areas to non-project areas 3 years after project completion. The study explored a range of outcomes, such as income and expenditure, health status, and access to education and health facilities. The results reveal moderate impact, but the authors express concern that the PSM results might still suffer from selection bias on unobservables.
5	Rural roads	Multicountry	Cook, C., T. Duncan, S. Jitsuchon, A. Sharma, and W. Guobao. 2005. *Assessing the Impact of Transport and Energy Infrastructure on Poverty Reduction.* Manila: ADB.	DiD	Change in transport mode, travel time, and cost	The study covers three countries: the PRC, India, and Thailand, each of which are separate studies with different methodologies to examine the effect of rural roads on a range of socioeconomic outcomes. None of the 3 studies allowed for drawing robust conclusions on attribution. The Thailand study applies a DiD approach, although this appears to be based on recall questions included in an ex-post survey and the analysis is not econometrically convincing. The report contains a wide range of qualitative information as well.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
6	Access to rural feeder roads	Papua New Guinea	Wiegand, M., E. Koomen, M. Pradhan, and C. Edmonds. 2017. The Impact of Road Development on Household Welfare in Rural Papua New Guinea. Tinbergen Institute Discussion Papers 17-076/V. Tinbergen Institute.	Instrumental variables (IV)	Poverty	This paper evaluates the impact of road development on household welfare in rural Papua New Guinea over a 13-year period, using two cross-sectional household surveys and geographic data on the road system. A correlated random effects model is used to address the endogenous placement of road infrastructure programs and then a newly developed quantile regression method is used to investigate whether road improvements are beneficial for the poor. Results show that investments in sealing of roads leading to the nearest towns led to higher consumption levels and housing quality and less reliance on subsistence farming. The effects are more pronounced among households that are poor, less educated, and headed by women.
7	Development of roll-on roll-off ferry system	Philippines	Francisco, K. and M. Helble. 2017. The Impact of Improved Transport Connectivity on Income, Education, and Health: The Case of the Roll-On/ Roll-Off System in the Philippines. *ADBI Working Paper Series*. No. 792. Tokyo: ADB Institute.	DiD/FE	Income, education, health	This paper studies the impacts of the roll-on/roll-off (Ro-Ro) integrated mode of interisland transfer. It applies a set of fixed effects and DiD models to three rounds of panel data from the Family Income and Expenditure Survey to estimate effects on household income, school attendance rates, and alcohol consumption. It finds higher agricultural and nonagricultural income, higher school attendance with effects earlier for females than for males, and reduced household consumption of alcoholic beverages and tobacco.
8	High-speed rail	PRC	Zou, W., L. Chen, and J. Xiong. 2018. High-Speed Railway, Market Access, and Economic Growth. *ADBI Working Paper Series*. No. 852. Tokyo: ADB Institute.	FE	Economic growth	The study measures the effects of "market access," as proxied by the pairwise travel distances and railway speeds between 110 of the main prefecture-level cities of the PRC, on economic growth. Using a two-way fixed effects model, it finds that railway speed exerts significant positive effects on growth, especially of manufacturing. A series of robustness tests are conducted, which reinforce the results.

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Appendix Table 2 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
Completed Non-ADB Studies						
9	Urban street paving	Mexico	Gonzalez-Navarro, M. and C. Quintana-Domeque. 2016. Paving Streets for the Poor: Experimental Analysis of Infrastructure Effects. Review of Economics and Statistics. 98 (2). pp. 254 -267.	Randomized controlled trial (RCT)	Property prices, credit, and consumption	The article explores the effect of publicly financed infrastructure in the form of urban residential street pavement, on property values. Using a randomized experiment, the study finds positive effects on property values, alongside an increase in ownership of vehicles, household assets, as well as improved housing. Applying a cost–benefit analysis, the study finds that the increase in property values corresponds approximately with the cost of construction, which, they conclude, suggests efficiency in public goods provision.
10	Rural roads	Viet Nam	Mu, R. and D. van de Walle. 2011. Rural Roads and Local Market Development in Viet Nam. *The Journal of Development Studies*. 47 (5). pp. 709–734.	Matched DiD	Market development: presence of markets, availability of services	The study evaluates impacts of rural road rehabilitation on commune-level market development in rural Viet Nam. Using a nonexperimental approach combining DiD estimation with PSM, the study finds positive impacts on local market development with indications of stronger impact in poorer communes.
11	Status on and off highway, and distance from it	India	Datta, S. 2011. The Impact of Improved Highways on Indian Firms. *Journal of Development Economics.* 99 (2012). pp. 46–57.	DiD	Stocks of input inventories, change of supplier, transportation obstacles	This paper examines how firms along highways connecting the four largest cities in India were affected by improvements to road width and quality carried out between 2002 and 2005. It applies a DiD estimation strategy, with being located on an improved highway used as one treatment variable, and distance from the road used as another. Results show that highway improvements led to reductions in average stock of input inventories, more frequent changes of suppliers, and decreased transportation obstacles to production.
12	Access to rural roads	Papua New Guinea	Gibson, J. and S. Rozelle. 2003. Poverty and Access to Roads in Papua New Guinea. *Economic Development and Cultural Change*. 52 (1). pp. 159–85.	IV	Poverty (consumption-based measure using regional poverty lines)	The study explores to what extent rural roads affect poverty levels in Papua New Guinea. It uses a 1996 household consumption and living standards survey of 1,200 households in an IV approach where the year of national highway system penetration into each of the country's districts serves as an instrument for travel time to roads. The study finds a significant negative effect of distance (traveling time) to nearest road on consumption, which translates into a positive effect from access to roads.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
13	Access to rural roads	Ethiopia, sub-Saharan Africa	Dercon, S., D. Gilligan, J. Hoddinott, and T. Woldehanna. 2009. The Impact of Agricultural Extension and Roads on Poverty and Consumption Growth in Fifteen Ethiopian Villages. *American Journal of Agricultural Economics*. 91 (4). pp. 1007–1021.	IV, generalized method of moments (GMM)	Consumption, growth, and poverty rates	This paper examines the impacts of agricultural extension and rural roads on consumption growth and poverty in Ethiopia. Using data from a panel survey of households undertaken at four points in time between 1995 and 2004, the study estimates effects on poverty and household incomes as a function of extension services and access to roads. The authors employ a GMM IV estimator to do so, using lagged fertile land holdings, lagged number of adults, and lagged number of livestock as instruments. In addition to effects from extension, the study finds a significant positive effect of all-weather roads access on consumption, which also translates into a significant poverty reduction effect.
14	Bus ticket pricing	Africa, Malawi	Raballand, G., R. Thornton, D. Yang, J. Goldberg, N. Keleher, and A. Müller. 2001. Are Rural Road Investments Alone Sufficient to Generate Transport Flows? Lessons from a Randomized Experiment in Rural Malawi and Policy Implications. *World Bank Policy Research Working Paper*. 5535. Washington, DC: World Bank.	RCT	Bus use	This experiment quantifies the effects of ticket prices on bus use in rural Malawi. During the course of a 6-month period, a minibus service connecting five villages located within a distance of 20 kilometers was subsidized, allowing the study to provide randomly assigned discount vouchers ranging from zero to 500 Malawi kwacha or $3.57 to households residing within the five villages. Voucher take-up and bus usage were observed over the 6-month period and showed significant differences based on the price level assigned to a household. Having to pay at all leads to substantial declines in demand for ridership, even when subsidies lowered prices below marginal costs.
15	Rural road infrastructure	Georgia	Lokshin, M. and R. Yemtsov. 2003. Evaluating the Impact of Infrastructure Rehabilitation Projects on Household Welfare in Rural Georgia. *World Bank Policy Research Working Paper*. 3155. Washington, DC: World Bank.	DiD and PSM	Number of small and medium-sized enterprises, agricultural sales, access to health care, employment, travel time/costs	The study examines the impact of rural roads. Based on data from the Rural Community Infrastructure Survey and the Survey of Georgian Households, a DiD approach is used to find that road and bridge rehabilitation projects generate clear economic benefits at the community level. While the impact on labor markets is positive, it is insignificant. The study finds that the number of small and medium-sized enterprises increased while the importance of barter trade fell as a result of the road projects. At the household level, access to emergency medical assistance is found to clearly improve.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
16	Transportation network/railway, roads	PRC	Banerjee, A., E. Duflo, and N. Qian. 2012. On the Road: Access to Transportation Infrastructure and Economic Growth in China. *NBER Working Papers.* 17897.	IV	GDP growth	The paper explores the long-term impact of access to transportation infrastructure on economic performance in different regions in the PRC during a 20-year period of rapid growth. To overcome bias from endogenous placement of infrastructure the study uses distance to the nearest straight line connecting two historical cities (or ports) as an instrument for access to infrastructure. The variable correlates well with the location of major infrastructure networks, particularly with railroads constructed during the early 20th century, which affected the locations of other later networks. The study also controls for the potential confounding effects of distance to rivers and terminal cities. Results show that proximity to transportation networks has a moderate positive causal effect on per capita GDP levels across sectors, but no effect on per capita GDP growth.
17	Upgrade of the quality and width of the Golden Quadrilateral highway system	India	Ghani, E., A. Goswami, and W. Kerr. 2013. Highway to Success in India. The Impact of the Golden Quadrilateral Project for the Location and Performance of Manufacturing. *World Bank Policy Research Working Paper.* 6320. Washington, DC: World Bank.	DiD	Organization (establishment counts, employment, output levels) and performance (average labor productivity and total factor productivity) of the organized manufacturing sector	The study quantifies the effects of highway upgrades on economic performance of manufacturing establishments in India. Using several rounds of cross-sectional data, as well as data on distance to the upgraded highway, the study employs a DiD approach to examine how proximity to upgraded roads affects plant productivity and other outcomes. It finds several positive effects, such as higher entry rates and increases in plant productivity.
18	Rural road improvements	Zambia	Kingombe, C. and S. di Falco. 2012. The Impact of a Feeder Road Project on Cash Crop Production in Zambia's Eastern Province between 1997 and 2002. *Graduate Institute of International and Development Studies Working Paper.* No. 04/2012.	DiD, Tobit	Farm productivity and crop choices	The study examines the impact of a rural roads project implemented in five provinces of Eastern Zambia between 1996 and 2002 on cotton productivity. Using a combination of agricultural census data and post-harvest surveys, the study conducts a DiD analysis, which includes controls for other crop production and on the share of cash crops in farm production. Contrary to expectations, the results indicate a small unexplained negative effect of roads on cotton productivity.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
19	Combined effect of road paving and market-related investments	Bangladesh	Khandker, S., Z. Bakht, and G. Koolwal. 2009. The Poverty Impact of Rural Roads: Evidence from Bangladesh. *Economic Development and Cultural Change*. 57 (4). pp. 685–722.	FE	Transport costs, agricultural input and output prices, labor supply and earnings, school enrollment rates, and household per capita expenditure	This study measures the effects of rural road paving on a range of outcomes, including transport costs, agricultural prices, schooling, labor supply, and poverty. The study uses panel data of households and communities collected before and after implementation of two rural road projects, in FE estimations. The study also explores impact heterogeneity by income levels and sex. It finds poverty reduction effects through lower production prices, higher agricultural output, and higher market prices. Positive effects on secondary school enrollment are also found.
20	Road development	Indonesia	Gibson, J. and S. Olivia.2009. The Effect of Infrastructure Access and Quality on Non-Farm Enterprises in Rural Indonesia. *World Development*. 38 (5). pp. 717–26.	DiD	Nonfarm enterprises and employment	This paper investigates the effects of road and electricity infrastructure on employment and income on nonfarm enterprises using data from 3,951 households in rural villages in Indonesia. The results suggest that both lack of access to and poor quality of infrastructure constrain the nonfarm enterprises of rural households. Households living in a remote location with lower quality roads and access to electricity have lower income shares from nonfarm enterprises.
21	Rural roads	Peru	Escobal, J. and C. Ponce. 2002. The Benefits of Rural Roads: Enhancing Income Opportunities for the Rural Poor. *GRADE Working paper*. 40-I. Also as book chapter in *Economic Reform in Developing Countries: Reach, Range, Reason*, edited by J. M. Fanelli and L. Squire. GDN Series. Cheltenham, UK: Edward Elgar.	PSM	Income, employment, agricultural production	The study examines the impacts of rural road rehabilitation on household consumption and income. Using PSM on a cross-sectional data set to match households living near rehabilitated roads to similar households living near non-rehabilitated roads, the study finds positive effects on income but not on consumption. The authors suggest that increased income instead translates into increased savings and livestock ownership.
22	Labor-intensive rural roads	Nicaragua	COWI A/S.2008. *General Study of the Impact of Rural Roads in Nicaragua*. Kongens Lyngby, Denmark.	FE	Consumption, transport, agricultural production, health, literacy, employment	This analysis quantifies the effects of rural roads on socioeconomic outcomes in Nicaragua. Using a panel of 1,000 households surveyed in all three rounds of Nicaragua's living standard measurement survey, pooled ordinary least squares and fixed effects are applied. It finds positive impacts of rural roads on nonfarm employment, household consumption, and a small effect on health outcomes.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
23	Labor-intensive rural roads	Nicaragua	Rand, J. 2011. Evaluating the Employment-Generating Impact of Rural Roads in Nicaragua. *Journal of Development Effectiveness*. 3 (1). pp. 28–43.	Matched DiD	Employment growth	The study explores the effect of a rural (tertiary) roads project on employment generation in Nicaragua. It uses a small panel of 345 households constructed from the 2005 Nicaraguan household census and a project-specific follow-up survey. Via a matched DiD approach with three different empirical specifications, the study finds positive effects on employment. New jobs appear to be created in the agriculture sector, along with a shift into nonagricultural work for other households.
24	Road quality	Indonesia	Gertler, P., M. Gonzalez-Navarro, T. Gracner, and A. Rothenberg. 2015. Road Quality, Local Economic Activity, and Welfare: Evidence from Indonesia's Highways. Preliminary draft October.	IV	Household consumption and income, employment, wages	The analysis examines the effects of road quality on economic activity in Indonesia. To do so, it exploits the centralized nature of the country's fiscal organization and the existence of a nationwide panel data set of road surface roughness to "predict road quality from temporal variation in budgets that are exogenously allocated to different road maintenance authorities" (p. 1). The findings indicate that improving the quality of road networks positively affect the number of new manufacturing firms and jobs in the manufacturing sector, shifts jobs from agriculture to manufacturing, and increases profits for those that stay on in the agriculture sector, in turn reducing the income gap between the two sectors.
25	Rural roads	Palau	Akee, R. 2006. The Babeldaob Road: The Impact of Road Construction on Rural Labor Force Outcomes in the Republic of Palau. *The Institute for the Study of Labor (IZA) Discussion Paper*. 2452.	DiD	Wage sector employment, self-employment in agriculture, international migration, vehicle ownership, income	This evaluation estimates the impact of a new 87 kilometer road on the small pacific island of Babeldaob in Palau. The focus is on employment and wages, using census data from before and after road construction to carry out a DiD estimation, adjusted for households that move between states in response to road construction. The study finds a notable increase in wage sector employment, increased self-employment in agriculture, but no change in wages.
26	Private sector development, Private infrastructure	Latin America and the Caribbean	Calderon, C. and L. Serven. 2004. The Effects of Infrastructure Development on Growth and Income Distribution. *World Bank Policy Research Working Paper*. No. 3400. Washington, DC: World Bank.	GMM/IV	Economic growth	The study tests the effects of infrastructure development on growth and income inequality. It uses data on 121 countries between 1960 and 2000 to create indices of infrastructure quantity and quality and employs a range of IV estimators to account for endogeneity. Key results include a positive effect of infrastructure assets on growth and a positive effect of infrastructure quantity and quality on income equality.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
27	Driving restrictions program	Mexico	Davis, L. 2008. The Effect of Driving Restrictions on Air Quality in Mexico City. *Journal of Political Economy*. 116 (1). p. 38.	Regression discontinuity design (RDD)	Air quality	The analysis quantifies the effect of a driving restriction program on air quality in Mexico City. The program, which restricts driving to 4 days per week based on license plate number, was evaluated using high-frequency data on air pollution. The analysis employs a regression discontinuity design where air quality just before the program was introduced is compared to air quality just afterward, but across empirical specifications it finds no effects on air quality.
28	Driving restrictions program	Mexico	Salas, C. 2010. Evaluating Public Policies with High Frequency Data: Evidence for Driving Restrictions in Mexico City Revisited. *Instituto de Economia, Pontificia Universidad Catolica de Chile, Documento de Trabajo*. No. 374, May.	RDD	Air quality	Using the same data as Davis (2008), the study illustrates the potential implications that arise from minor changes to empirical strategy. The paper similarly uses a regression discontinuity design but changes a number of parameters in the estimating equations. With different specifications, the author finds a positive effect on air pollution with a 12% to 18% reduction during the first months of program implementation, followed by a gradual increase subsequently.
29	Highway	India	Sengupta, R., D. Coondo, and B. Rout. 2007. Impact of a Highway on the Socio-Economic Well-Being of Rural Households Living in Proximity. *Contemporary Issues and Ideas in Social Sciences*. 3 (3).	PSM	Poverty, income, employment, health, education, mobility	The study examines the impact of highway development on poverty and well-being in India. Using PSM, it finds positive effects on a range of household socioeconomic outcomes and that households' well-being declines as distance from the highway increases.
30	Public infrastructure (main roads)	Viet Nam	Larsen, T., H. Pham, and M. Rama. 2004. The Impact of Infrastructure Development on Rural Poverty Reduction in Viet Nam. Working Paper. No. 30790. Washington DC: World Bank.	IV	Poverty	The paper focuses on the effects of public investment (of which transport is the largest share) on poverty in Viet Nam. To do so, the study combines data on investment in large-scale infrastructure across provinces between 1996 and 2000 with poverty data. An IV approach is used, in which the proportion of donor financing in public investment serves as an instrument for public investment. Results show a positive effect of public investment on GDP.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
31	Rural road rehabilitation	Armenia	Millennium Challenge Corporation (MCC). 2015. Measuring Results of a Rural Road Rehabilitation Project in Armenia.	DiD	Travel times, employment, agricultural production, income, consumption	The study evaluates the impacts of a rural road rehabilitation project in Armenia. The evaluation piggybacked on the annual, nationally representative Integrated Living Conditions Survey and funded an increase in the sample size and a longer survey questionnaire from 2007 to 2011 to facilitate the evaluation. The study employs a DiD approach on 27 completed road segments as treatment and 28 planned but never completed road links as comparison. It finds positive effects on road quality, road usage, and access, whereas no effect was found on medium-term investment and production, income, consumption, or poverty.
32	Rural road rehabilitation	Georgia	NORC at the University of Chicago. 2013. Samtskhe–Javakheti Roads Activity Impact Evaluation. Millennium Challenge Corporation. Washington, DC.	DiD, matched DiD, economic modeling	(1) Traffic counts, vehicle speeds, travel times, availability of public transport; (2) investment, land use, and employment; (3) market prices; (4) household welfare: income, consumption, asset ownership; and (5) access to health and education	The study explores the impact of road rehabilitation in Georgia on a range of variables ranging from transportation usage and cost to longer-term welfare outcomes. The impact evaluation compares rehabilitated segments of the particular road in Georgia with road segments that were not rehabilitated using a DiD approach. It finds that road rehabilitation increased the number of vehicles using the roads and their speed. There is some indication of increases in employment and industrial activity, but no direct changes in household-level welfare were detected.
33	Public transit system (gondola, connected to urban rail)	Colombia	Cerda, M., J. D. Morenoff, B. Hansen, T. Hicks, L. Duque, A. Restrepo, and A. Diez-Roux. 2012. Reducing Violence by Transforming Neighborhoods: A Natural Experiment in Medellín, Colombia. *American Journal of Epidemiology*. 175 (10). pp. 1045–53.	Matching plus random effects (similar to FE)	Homicides, violence	This paper exploits a large-scale natural experiment resulting from a public works project in a subset of neighborhoods in the Colombian city of Medellín to examine the impact of connection to a public transit system on violence in otherwise isolated low-income neighborhoods. Treatment communities were matched to similar comparison communities, and neighborhood-level outcome measures of violence, and the local social/institutional climate constructed before and after the program. The study used the estimated change on the pooled sample in a matched DiD random effects model. It finds that the homicide rate decreased by two-thirds more in treatment neighborhoods, and violence decreased by 75% more.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
34	Communication campaign for safety	Kenya	Habyarimana, J. and W. Jack. 2011. Heckle and Chide: Results of a Randomized Road Safety Intervention in Kenya. *Journal of Public Economics*. 95(11). pp. 1438–1446.	RCT	Insurance claims, accidents	The analysis tests the impact of a campaign to empower passengers to speak up against reckless drivers. It consists of a randomized experiment with the participation of almost 2,300 long-distance minibuses serving 12 major cities. Half of participating buses were randomly assigned to have a set of stickers encouraging passengers to take action against dangerous driving. The other half of buses comprised the control group. Insurance claim information was used as a main outcome variable. It finds that the campaign reduced insurance claims by between 4.5 and 6.4 percentage points from a baseline rate of 10% annually, and claims that involved injury or death were halved.
35	Road safety interventions in the Kenyan minibus or *matatu* sector	Kenya	Habyarimana, J. and W. Jack. 2012. State vs Consumer Regulation: An Evaluation of Two Road Safety Interventions in Kenya. *NBER Working Paper*. No. 18378.	RCT	Accident rates	This study compares the effects of two minibus road safety interventions in Kenya. One is the passenger empowerment experiment described in Habyarimana and Jack (2011) above. Another was an experiment to test a top–down set of regulatory requirements. Detailed insurance claims are used to carry out DiD estimates in both experiments. Whereas positive effects are found for the empowerment campaign, the regulatory requirements has no effect on accident rates.
36	Rural road improvements	Brazil	Iimi, A. 2015. Social and Economic Impacts of Rural Road Improvements in the State of Tocantins Brazil. *World Bank Policy Research Working Paper*. 7249. Washington, DC: World Bank.	Matched DiD and DiD	Use of public and private transport, school attendance, employment, income	This analysis examines the impact of a rural road improvement project in Brazil. Because no comparison had been identified at baseline, the study uses comparison communities where planned roadwork had either not been completed or had been cancelled entirely. It then employs DiD estimation to find positive effects on public transport usage and on own vehicle use. It also finds an increase in school attendance, particularly for girls, over the longer term.
37	High-speed rail upgrade	PRC	Qin, Y. 2014. No County Left Behind? The Distributional Impact of High-Speed Rail Upgrade in China. Job Market Paper.	IV	County GDP and GDP per capita	The study evaluates the distributional impacts of high-speed rail upgrade in the PRC. Using a IV approach, the study compares economic outcomes of the counties located on the affected railway lines with the counties located on non-affected railway lines, before and after the upgrade. A pre-intervention parallel trend in the key outcome variable is illustrated, which increases chances that the approach is valid. Relative to non-affected counties, affected counties are found to suffer a 4%–6% reduction in GDP and GDP per capita following the upgrade, which can be explained largely by a concurrent drop in fixed asset investment.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
38	Railway	PRC	Wang, Y. and B. Wu. 2015. Railways and the Local Economy: Evidence from Qingzang Railway. *Economic Development and Cultural Change.* 63 (3). pp. 551–588.	Natural experiment, DiD	Local GDP per capita	The Qingzang railway is a high-altitude railway, which crosses the Qinghai Tibet Plateau. Its first phase was completed in 1984, with the second phase delayed until 2001, due to technical difficulties of building the railway in the given geographic setting. As such, the study can be seen as a natural experiment: the timing and exact location of the line for the second phase were determined by technicalities, and the construction was long planned and politically determined rather than driven by the local economy. The study exploits the nature of the setting to estimate railway impact using a DiD approach. It finds a substantial effect on local GDP per capita, which increased by one-third after the railway began operating.
39	Road network	Brazil	Bird, J. and S. Straub. 2014. The Brasília Experiment: Road Access and the Spatial Pattern of Long-Term Local Development in Brazil. *World Bank Policy Research Working Paper.* 6964. Washington, DC: World Bank.	IV	Population, GDP, GDP per capita	The evaluation estimates the impact of expansion of the Brazilian road network from the 1960s to the 2000s on the spatial allocation of population and economic activity. It considers the creation of Brasília in 1960 as a source of exogenous variation in road development, and uses distance to the direct corridor between Brasilia and other urban centers as an instrument. It finds that improved transport infrastructure increased concentration of economic activity and population.
40	PRC's national trunk highway	PRC	Faber, B. 2014. Trade Integration, Market Size and Industrialization: Evidence from China's National Trunk Highway System. *Review of Economic Studies.* 81. pp. 1046–1070.	Natural experiment, IV	GDP growth	The study explores the impact of highway construction on GDP growth using the construction of the national trunk highway system in the PRC. A nationwide least-cost tree network (which correlates with road but not with GDP) was used as an instrument for highway expansion. IV approaches find a negative effect of highway construction on GDP growth among smaller non-targeted counties, which appears to be driven by a significant reduction in industrial output growth.
41	Rural roads	Nigeria	Ali, R., A. Barra, C. Berg, R. Damania, J. Nash, and J. Russ. 2015. Transport Infrastructure and Welfare: An Application to Nigeria. *World Bank Policy Research Working Paper.* 7271. Washington, DC: World Bank.	IV	Crop revenue, livestock revenue, nonagricultural income, the probability of being multidimensionally poor, and local gross domestic product for Nigeria	This research quantifies the impact of road infrastructure on economic well-being in Nigeria. More specifically it analyzes the relationship between the transportation costs that households incur to access the nearest market (defined as cities with population of at least 100,000), and different measures of economic well-being. An IV approach is used to account for endogenous road placement using "the time it would take to walk along the most logical route connecting two points" as an instrument for roads. Results show a positive effect of lower transport costs on welfare outcomes such as crop revenue, wealth, nonfarm income, and local GDP.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
42	Combined effect of rural road quality and education	Indonesia	Yamauchi, F., M. Muto, S. Chowdhury, R. Dewina, and S. Sumaryanto. 2011. Are Schooling and Roads Complementary? Evidence from Income Dynamics in Rural Indonesia. *World Development*. 39 (12). pp. 2232–2244.	FE	Nonagricultural labor supply and income	The study examines the impacts of connectivity and improved local road quality on income growth and nonagricultural labor supply in rural Indonesia over a 12-year period. It uses fixed effects estimation on household survey panel and village data. Results suggest that impacts of improved local road quality on income growth and the transition to nonagricultural labor markets depend on household education and distance to economic centers.
43	Road infrastructure	Democratic Republic of Congo	Ali, R., A. Barra, C. Berg, R. Damania, J. Nash, and J. Russ. 2015. Infrastructure in Conflict-Prone and Fragile Environments: Evidence from the Democratic Republic of Congo. *World Bank Policy Research Working Paper*. 7273. Washington, DC: World Bank.	IV	Well-being: wealth, poverty, local GDP	The paper quantifies the effect of road infrastructure on welfare in the conflict-prone Democratic Republic of Congo. To do so, the authors make use of spatial road network data to develop a new data set of travel. To address endogenous road placement, the "walking time taken to reach markets using the natural path," is used as an instrumental variable. It finds that lower transport costs have a positive effect on wealth and lower the probability of being poor. The effect of conflict near the household is negative, and in high-conflict areas, households far from markets are likely to have higher welfare than those with easier access, reversing the wealth benefits.
44	Anti-drunk driving program	India	Banerjee, A., E. Duflo, D. Keniston, and N. Singh. 2014. The Efficient Deployment of Police Resources: Theory and New Evidence from a Randomized Drunk Driving Crackdown in India. Working Paper. July 2014.	RCT	Accidents, deaths, incidents of drunk driving	This experiment tested 12 different variations of an anti drunk-driving campaign. A randomized experiment combined with a structural model of perpetrator learning was used to test the effect of police roadblocks. During 2010 and 2011, police stations in 10 districts of Rajasthan were randomly assigned to either one of the treatment groups or a comparison group, which received no intervention. The study varied the frequency, location, and personnel deployed at checkpoints across a total of 12 overlapping treatment groups. It finds that drivers learn relatively quickly of the existence of checkpoints and responded strategically by changing routes, so that checkpoints set up in rotating, or "surprise," locations are significantly more effective in reducing accidents and deaths than fixed location checkpoints. The rotation approach reduced night accidents in the surrounding area by 17%, and night deaths by 25% over a 2-month campaign and for the subsequent 6 weeks.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
45	Rural roads	Viet Nam	Cuong, N. V. 2011. Estimation of the Impact of Rural Roads on Household Welfare in Viet Nam. *Asia-Pacific Development Journal*. 18 (2).	FE, DiD, PSM	Income, expenditure, working hours, education	The study evaluates the effect of rural roads on household welfare in Viet Nam. It employs a fixed effects estimation strategy and DiD combined with PSM on panel data from the Vietnam Household Living Standards Survey. Results indicate that roads increase mean income by 8.8%. The observed income gains, however, do not translate into increased consumption, which the author suggests is an indication that rural roads may have a positive effect on households' investment and savings.
46	Trunk roads	Tanzania	Gachassin, M. 2013. Should I Stay or Should I Go? The Role of Roads in Migration Decisions. *Journal of African Economies*. 22 (5). pp. 796–826.	DiD	Migration	This paper evaluates the effect of improved road infrastructure on out-migration. It employs a DiD approach, characterizing households living in proximity to a highway that was upgraded in the period between 1996 and 2002 as the treatment group and households living near a highway which was not upgraded in the same period, as the comparison group. The data used include household and community observations from a health and development survey, as well as data on road upgrade projects. Results reveal that road quality improvements have a negative effect on out-migration, with the strongest effect observed in well-connected communities.
47	Rural road project	Viet Nam	van de Walle, D. and R. Mu. 2007. Fungibility and the Flypaper Effect of Project Aid: Micro-Evidence for Viet Nam. *Journal of Development Economics*. 84.	DiD and DiD + PSM	Rural roads actually rehabilitated and built	The study explores the issue of aid fungibility in the context of financing for rural road projects, and focuses not on the outcomes of roads built or upgraded, but rather on whether aid funding for rural roads affects the kilometers of road actually rehabilitated and built. To explore this, the authors use a panel data set of communes and households within project and non-project areas collected for the purpose of this study. They find that, although impacts on rehabilitated road length were less than intended, more roads were built in project areas. The results suggest that there was fungibility within the sector, but that aid largely stuck to that sector, a so-called flypaper effect.
48	Interventions to reduce corruption in village road projects	Indonesia	Olken, B. 2007. Monitoring Corruption: Evidence from a Field Experiment in Indonesia. *Journal of Political Economy*. 115 (2).	RCT	Corruption (measured as discrepancy in officially reported project costs and independent estimates of same)	This experiment quantifies the effects of auditing mechanisms on proxies for corruption in road construction projects in rural Indonesia. A randomized design was used to examine the impact of three different interventions on "missing expenditures," defined as unexplained differences between independent cost-estimates and recorded costs: (i) increased use of external audits of village road projects and advance information of such audits at village meetings, (ii) use of written invitations for community members to

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
						participate in village accountability/monitoring meetings, and (iii) use of written invitations as above plus provision of an anonymous form to provide comments on the road project. Results indicate that substantially increasing the use of external audits from 4% of road projects to all road projects reduced expenditure discrepancies from almost 28% to just over 19%. Increased community involvement in meetings had an effect only on expenditures related to labor, but little overall effect. The combination of increased involvement and anonymous forms jointly had an effect only when village authorities had no role in distributing forms and invitations, suggesting that such campaigns are less likely to be effective where elite capture is present.
49	Rural road construction	Nepal	Charlery, L., M. Qaim, and C. Smith-Hall. 2016. Impact of Infrastructure on Rural Household Income and Inequality in Nepal. *Journal of Development Effectiveness*. 8 (2). pp. 266–288.	DiD	Household income, income inequality	This study analyzes the effects of rural road construction on household income and inequality in Nepal. A DiD approach is employed to analyze household data before and after road construction. Results show that road construction increased household annual income by 28% and contributed to reducing income inequality.
50	Transport subsidies	Ethiopia	Franklin, S. 2015. Location, Search Costs and Youth Unemployment: A Randomized Control Trial of Transport Subsidies in Ethiopia. *CSAE Working Paper Series*. 2015-11. Centre for the Study of African Economies, University of Oxford.	RCT	Employment outcomes	The paper examines effects of transport subsidies on labor market outcomes of unemployed youth living in spatially dislocated areas of Addis Ababa, Ethiopia, through a randomized controlled trial. Results show that lowering transport costs increases the likelihood of finding permanent employment by 6 percentage points in the short term. Analysis of weekly phone call data shows that job search activity declines over time but not among those who receive the subsidies. Subsidies were also found to reduce participation in temporary and informal work. These results highlight that the high cost of transport in large cities can lead to difficulty in matching job opportunities and workers and reinforce spatial inequality.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
51	Highway	El Salvador	Torero, M., M. Almanzar, and E. Nakasone. 2016. Impact Evaluation of the Construction of the Northern Transnational Highway of El Salvador. *Markets, Trade and Institutions*. Washington, DC: International Food Policy Research Institute.	RDD, continuous treatment	Market participation, volume sold in the market, agricultural production, availability of nonfarm employment, creation of nonfarm enterprises, use of public services including health and education	This analyzes the impacts of the Northern Transnational Highway (NTH) among households living within a 30-minute radius of it. Using regression discontinuity and continuous treatment methodologies finds that the NTH has moderate effects on household travel time and cost to nearest market and other services. However, there are no observed effects in harvest, agricultural sales, land value, income, or expenditure.
52	Driving restriction policy	PRC	Ye, J. 2017. Better Safe than Sorry? Evidence from Lanzhou's Driving Restriction Policy. *China Economic Review*. 45. pp. 1–21.	RDD	Air quality	This study evaluates the effects of a driving restriction policy in Lanzhou, which is presented as representative of several other cities in the PRC where the policy is being implemented. Using RDD, it finds a worsening of air quality in Lanzhou (the Air Quality Index became 33% worse, and hourly $PM_{2.5}$ and PM_{10} increased by 40%) because owners of private vehicles either worked around the restriction schedules, acquired alternative private transportation, or took alternate routes.
53	Lowering legal blood alcohol limit, increasing license suspensions for offenders	Chile	Otero, S. and T. Rau. 2017. The Effects of Drinking and Driving Laws on Car Crashes, Injuries, and Deaths: Evidence from Chile. *Journal of Accident Analysis & Prevention*. 106 (September 99). pp. 262–274.	RDD, general Poisson regression, linear logit models	Alcohol-related car accidents and injuries	Using RDD, general Poisson regression, and linear logit models, this paper assesses the effects of Chile's drinking and driving laws (lowering the legal alcohol level, increasing penalties) on car accidents. The study shows that the policy resulted in a significant decrease in alcohol-related accidents leading to injuries but had no significant effects on accidents that resulted in deaths.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
54	Removal of high-occupancy vehicle travel rules	Indonesia	Hanna, R., G. Kreindler, and B. A. Olken. 2017. Citywide Effects of High-Occupancy Vehicle Restrictions: Evidence from "Three-in-One" in Jakarta. *Jinan University Science Journal*. 357 (6346). pp. 89–93.	RDD/ interrupted time series	Traffic conditions	The study evaluates whether Jakarta's "three-in-one" high-occupancy vehicle policy, which the government suspended, was an effective policy for reducing traffic. It utilizes data from before the policy was suspended and real-time android-phone traffic-speed data collected through Google Maps for data from 2 days after the first suspension announcement in an RDD design. It finds that (i) suspension of the policy led to longer travel time even on roads that were not previously congested, and (ii) traffic congestion also increased at times not previously covered by the policy.
55	Highway toll	PRC	Fu, S. and Y. Gu. 2016. Highway Toll and Air Pollution: Evidence from Chinese Cities. *Journal of Environmental Economics and Management*. 83 (May). pp. 32–49.	RDD, DiD	Air pollution, visibility	The authors used an 8-day National Holiday in 2012, when highway tolls were waived nationwide for passenger vehicles, to identify the effects of highway tolls on air pollution. Daily pollution and weather data for 98 cities in the PRC in 2011 and 2012 are employed in RDD with the National Day holiday as controls. The authors find that eliminating tolls increases pollution by 20% and decreases visibility by 1 kilometer. The authors also estimate that the toll elasticity of air pollution is −0.15.
56	Driving restriction	Colombia	Zhang, W. and V. Umanskaya. 2017. The Effects of License Plate-Based Driving Restrictions on Air Quality: Theory and Empirical Evidence. *Journal of Environmental Economics and Management*. 82 (March). pp. 181–220.	RDD	Air quality	The study develops a theoretical model that includes behavioral channels which earlier studies had identified as conditioning the effectiveness of driving restriction policies. This model, and a list of hypotheses, were examined using empirical evidence from Bogota, Colombia (hourly pollution records from 1997 to 2009 for seven air pollutants from observations of seven stations). Observations were ordered according to time as the assignment variable and the date the restriction was implemented as the threshold in RDD. The results show that through the identified channels, driving restriction policies led to significant increases in hourly O_3 and NO_2 but no significant effects on hourly CO, PM_{10}, NO, NO_X, or SO_2.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
57	Driving restriction	Mexico	Davis, L. W. 2017. Saturday Driving Restrictions Fail to Improve Air Quality in Mexico City. *Scientific Reports*. 7 (41652).	RDD	Air quality	A 2-decade-long (weekday) driving restriction policy in Mexico City was expanded to Saturdays. This paper evaluates whether the expansion positively affected air quality in Mexico City, utilizing data on air pollution, public transport ridership, gasoline consumption, and registered vehicles, from a wide variety of sources. RDD was employed on hourly pollution-monitoring station data to measure the effects of the expansion via a before-and-after (expansion) comparison of pollution levels, including airborne particulates. The results indicate that the program expansion did not have any significant effect on the city's pollution levels and did not increase ridership of alternative mass transportation systems.
58	Driving restrictions	PRC	Viard, V. B. and S. Fu. 2015. The Effect of Beijing's Driving Restrictions on Pollution and Economic Activity. *Journal of Public Economics*. 125 (May). pp. 98–115.	RDD, DiD	Pollution, employment	The study evaluates the effects of Beijing's driving restrictions on pollution reduction and economic activity (work time). It uses daily air pollution data at both aggregate and monitoring station levels, as well as data on time spent watching television among different worker categories. A DiD approach combining time-series and spatial variations of monitoring station locations is employed to eliminate other explanation for reductions in air pollution. A reduction of particulate matter by 18% for every-other-day restrictions and by 21% for a once-a-week restriction is found. TV viewership is found to have increased by 8.9%–16.9% for the self-employed, while hourly workers were relatively unaffected.
59	Driving restriction	PRC	Sun, C., S. Zheng, and R. Wang. 2014. Restricting Driving for Better Traffic and Clearer Skies: Did It Work in Beijing? *Transport Policy*. 32 (March). pp. 34–41.	DiD	Traffic speed, air quality/ particulate matter	The paper examines the effect on air pollution and traffic of Beijing's 1 day per week driving restriction policy. It compares the days when plate numbers ending in 4/9 were restricted with the other workdays, as there is cultural aversion to those numbers, so that fewer vehicles are restricted on those days. Data used include the Transportation Performance Index for measuring traffic speed and the daily average PM_{10} concentration for each of the eight monitoring stations in Beijing through the daily Air Pollution Index. It finds a positive effect on traffic flow, but no effects on air quality.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
60	Ethanol content in blended gasoline fuel	Brazil	Salvo, A. and Y. Wang. 2017. Ethanol-Blended Gasoline Policy and Ozone Pollution in Sao Paulo. *Journal of the Association of Environmental and Resource Economists*. 4 (3). pp. 731–794.	RDD	Ozone concentrations	Drawing on four discontinuities in ethanol content in blended gasoline, the authors investigate if ethanol use affects ozone concentrations in ambient air. Results show that ozone concentrations increase as gasoline blend progressed toward higher ethanol proportions. In contrast, no significant relationship was observed between ethanol blending and $PM_{2.5}$ levels.
61	Urban rail transit	Taipei,China	Chen, Y. and A. Whalley. 2012. Green Infrastructure: The Effects of Urban Rail Transit on Air Quality. American *Economic Journal Economic Policy*. 4 (1). pp. 58–97.	RDD (sharp)	Air quality (e.g., carbon monoxide, ozone)	Using hourly air quality data, the study investigates the impacts of rail transit infrastructure on air quality. Results show that the opening of a rail transit led to a reduction in carbon monoxide, a key tailpipe pollutant. However, it does not find an effect on ground-level ozone pollution, or that drivers adjust their traveling time or route in response to the rail schedule.
62	License plate restrictions	PRC	Gu, Y., E. Deakin, and Y. Long. 2017. The Effects of Driving Restrictions on Travel Behavior Evidence from Beijing. *Journal of Urban Economics*. 102. pp. 106–122.	Natural experiment, cross-sectional regression	Travel behavior (e.g., trip frequency, miles traveled)	The authors analyze the 2010 Beijing Household Travel Survey data to investigate the effects of a license-plate-based driving restriction on individual travel behavior. The study finds that driving restrictions have reduced trip frequency and miles traveled, but that effects may be offset by adaptation mechanisms including substitution toward unrestricted hours/days, having access to unrestricted vehicles, and nonobservance of the restriction.
63	Temporary emissions restrictions	PRC	Wichmann, B. and M. Yang. 2017. Blue Beijing: Estimating the Effects of Temporary Emissions Restrictions on Air Quality. *Applied Economics Letters*. 24 (10). pp. 1–7.	RDD	Air quality (e.g., particulate matter)	This study investigates whether temporary emissions restrictions—a practice which has been used in the PRC to improve air quality during international exposure events—actually improve air quality. It finds that temporary emissions restrictions lead to the unintended consequence of having extremely high post-restriction peak levels of fine particulate matter.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
64	Public transport	PRC	Yang, J., S. Chen, P. Qin, F. Lu, and A. A. Liu. 2018. The Effect of Subway Expansions on Vehicle Congestion: Evidence from Beijing. *Journal of Environmental Economics and Management*. 88. pp. 14–133.	RDD	Vehicle congestion, vehicle speed	This paper quantifies the impacts of opening six subway stations on short-run congestion in Beijing. Analyzing daily data on subway ridership, bus ridership, and traffic congestion (2009–2015), it finds that (a) subway opening leads to a sharp drop in vehicle congestion (average of 15% across the six subway openings) during the morning rush periods, and that (b) subway opening leads to an increase in road speeds.
65	License plate restrictions	Ecuador	Carrillo, P., A. Lopez-Luzuriaga, and A. Malik. 2018. Pollution or Crime: The Effect of Driving Restrictions on Criminal Activity. *Journal of Public Economics*. 164. pp. 50–69.	RDD, DiD	Crime rates	Applying DiD and spatial RDD, the authors evaluate the effects of Pico y Placa, a license plate-based driving restriction program, on crime levels in Ecuador. Analysis shows that the introduction of the program led to a 5% to 10% increase in crime rates and that the increase was more apparent at the boundary of the driving restriction zone.
66	Public transit fares (increase)	PRC	Yang, Z. and M. Tang. 2018. Does the Increase of Public Transit Fares Deteriorate Air Quality in Beijing? *Transportation Research Part D: Transport and Environment*. 63 (August). pp. 49–57.	Synthetic controls	Air quality index (PM_{10}, $PM_{2.5}$), nitrogen dioxide, sulfur dioxide, carbon monoxide, and ozone	The effects of increasing public transit fares on air quality in Beijing were investigated in this study. Using daily data on air pollution and controlling for weather conditions and holidays, it finds that fare increases led to a 16.3% increase in air pollution in the short run, as people shifted to more polluting modes of transportation. However, there is no significant long-term effect.
67	Nonlocal license plate restrictions	PRC	Li, J., X. B. Li, B. Li, and Z. R. Peng. 2018. The Effect of Nonlocal Vehicle Restriction Policy on Air Quality in Shanghai. *Atmosphere*. 9 (299).	RDD	Air quality (NO_2, CO, NO_x, NO, and $PM_{2.5}$)	The authors use data on CO concentration and the Air Quality Index to measure the effects of nonlocal license plate restrictions on air quality in Shanghai. Results show that restriction days lead to higher ground-level CO concentration vis-à-vis non-restriction days. The study also finds that extending the restriction policy period exposes commuters to high pollution for a longer time, unless it is during the evening rush period, in which case it improves air quality.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
68	Urban rail transit	PRC	Lin, B. and Z. Du. 2017. Can Urban Rail Transit Curb Automobile Energy Consumption? *Energy Policy*. 105. pp. 120–127.	Matched DiD	Automobile energy consumption, automobile energy consumption per capita, modal shifts	The impact of rail transit infrastructure on automobile energy consumption in the PRC from 2003 to 2013 is investigated in this paper. Binary modeling is conducted to identify key factors for constructing rail transit in the PRC which include urban population, GDP, and automobile density. Populations in proximity to and far from rail were then matched on these characteristics. The results indicate that rail transit infrastructure leads to a significant 5.5% reduction in automobile energy consumption and 6.6% reduction in automobile energy consumption per capita with continuous impact in the second year.
69	Rural road quality improvement	Sierra Leone	Casaburi, L., R. Glennerster, and T. Suri. 2013. Rural Roads and Intermediated Trade: Regression Discontinuity Evidence from Sierra Leone.	RDD	Rural market prices of agricultural commodities (cassava and rice)	Utilizing data from various sources (EU Feeder Roads Rehabilitation Program as primary source), the effects of rural road infrastructure on crop prices in rural markets are measured in this study. It finds that market prices of local crops drop with the improvement of road conditions and that the effect was stronger in markets farther from major urban centers and/or located in less productive areas. However, better cell phone penetration reverses the observed price effects.
70	Vehicle driving restriction program	Mexico and Chile	Gallego, F., J. P. Montero, and C. Salas. 2013. The Effect of Transport Policies on Car Use: Evidence from Latin American Cities. *Journal of Public Economics*. 107. pp. 47–62.	RDD/DiD	Carbon monoxide (CO) concentration levels as proxy for vehicle use	The authors measure the effects of driving restriction programs implemented in Mexico (Hoy-no-Circula or HNC) and Chile (Transantiago or TS) on vehicle use (using CO concentration levels as proxy variable). The results of the two interventions are evaluated separately. The HNC is found to have led to a reduction in morning peak-house concentration of CO by 5%–13% during the first month of program execution. However, 12 months later, CO concentration increased by 11% vis-à-vis baseline levels. The TS analysis shows virtually no impact in CO concentration immediately after implementation, but there was a 27% city-level increase 7 months later.
71	Vehicle driving restriction program	PRC	Yang, J., F. Lu, and P. Qin. 2016. How Does a Driving Restriction Affect Transportation Patterns? Evidence from Beijing. Environment for Development Discussion Paper Series 16-10. March.	IV	Traffic performance index, bus and taxi ridership, rail ridership	The short- and medium-run effects of a license plate-based driving restriction program on transportation patterns in the PRC are evaluated using data from 2009 to 2014. The study finds that (i) the intervention significantly improves traffic conditions during the restriction period without aggravating traffic conditions outside the intervention hours, (ii) there was an increase in bus and taxi ridership but not in rail ridership, and (iii) improvement in evening traffic conditions become more apparent over time, especially with the introduction in 2011 of a car purchase quota and tougher penalties for noncompliance.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
72	Urban rail transit	PRC	Guo, S. and L. Chen. 2018. Can Urban Rails Transit Systems Alleviate Air Pollution? Empirical Evidence from Beijing. *Growth and Change.* October 2018. DOI: 10.1111/grow.12266.	RDD	Air pollutant concentrations ($PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO) and ozone pollution	This study evaluates the effects of the Beijing Metro on air pollution levels in the city. It finds that rail transit led to a significant reduction in $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO concentrations, but has negligible effects on ozone pollution. The observed effects are robust across different specifications.
73	Driving restrictions	PRC	Liu, Z., R. Li, X. Wang, and P. Shang. 2018. Effects of Vehicle Restriction Policies: Analysis Using License Plate Recognition Data in Langfang, China. *Transportation Research Part A: Policy and Practice*. 118. pp. 89–103.	RDD	Traffic volume, congestion	The effects of shifting from one-day-per-week driving restriction policy to odd-and-even on traffic conditions (speed) and travel demand (including travel intensity/frequency and illegal travel or use of restricted vehicle) are analyzed in this paper. In terms of traffic conditions, it finds that odd-even restrictions lead to significant improvement in travel speed during both peak and non-peak hours. As for travel demand, it finds that odd-even leads to a decline in traffic volume. However, the decrease is lower than expected because of the increase in policy offenders and travel intensity.
74	Driving restrictions	PRC	Zhong, N., J. Cao., and Y. Wang. 2017. Traffic Congestion, Ambient Air Pollution and Health: Evidence from Driving Restrictions in Beijing. *Journal of the Association of Environmental and Resource Economists*. 4 (3). pp. 821–856.	IV	Ambulance call rates as proxy for health, air pollution	This study investigates the effects of driving restrictions on air pollution and health. The identification strategy is based on the local cultural resentment toward the number 4, which allows more vehicles on days when the number is restricted. By analyzing ambulance call data and air quality indicators, the study finds that on days when 4 is restricted, traffic congestion is higher by 22%. In addition, 24-hour average concentration of NO_2 is raised by 12%, thereby increasing ambulance calls by 12% due to fever and 3% due to other health-related problems.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
75	Rural road development	India	Banerjee, R. and A. Sachdeva. 2015. Pathways to Preventive Health, Evidence from India's Rural Road Program. *USC Dornsife Institute for New Economic Thinking Working Paper.* No. 15–19.	Fuzzy RDD	Use of preventative health care, awareness of health care, and social group membership	This paper evaluates effects of a large nationwide road construction program on preventive health care utilization. The paper uses the eligibility criterion of a village population of at least 500 inhabitants as the basis of an assignment variable, under a fuzzy RDD approach appropriate to incomplete assignment. The paper matches household survey data with the program placement data at the village by combining data sets. The study finds that year-round roads increase use of preventive health care by women and households, due to increased awareness, increase health care supply, and increased social interactions.
76	Urban metro development	India	Goel, D. and S. Gupta. 2015. The Effect of Metro Expansions on Air Pollution in Delhi. *Centre for Development Economics Working Paper*. No. 229. Department of Economics, Delhi School of Economics.	RDD/ Interrupted time series (ITS)	Air pollution	To estimate the effects of mass transit on air pollution, the analysis applies a regression discontinuity design, in which the discontinuity is the point in time at which a new metro line opened in Delhi (interrupted time series approach). The study finds that one of the longer rail extensions led to a 34% reduction in localized carbon monoxide at a major traffic intersection, and that nitrous oxide results are suggestive of a decline, although effects on fine particulate matter are inconclusive, in part due to data limitations.
77	Rural road development	India	Shamdasaniy, Y. 2016. Rural Road Infrastructure & Agricultural Production: Evidence from India. Job Market Paper. Columbia University.	DiD	Agricultural production practices, employment	This study estimates the effects of rural road improvement on production decisions in agriculture. It draws on the eligibility criteria used by the Government of India (minimum village population of 500) to provide all-weather, all-season roads to characterize villages as treated or untreated. Using this distinction, household-level panel data are used in a DiD framework to estimate effects. It finds that households gaining access to improved roads diversify their crop portfolio into higher return, non-cereal hybrid crops, increase take up of complementary productive inputs, intensify labor hiring, and increase sales of agricultural output.
78	Rural road development	Bangladesh	Ali, R. 2011. Impact of Rural Road Improvement on High Yield Variety Technology Adoption: Evidence from Bangladesh. Paper. University of Maryland.	DiD	Agricultural production practices	The paper evaluates the effects of road access on rice production practices. It employs DiD techniques on a household panel survey data conducted in 1995/1996 and 2000 (pre- and post-road improvement) in Bangladesh. The analysis finds that road improvement leads to increased aggregate rice area and area of high yield variety rice, while there is no statistically significant effect on local variety rice area.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
79	Rural road development	India	Aggarwal, S. 2014. Do Rural Roads Create Pathways out of Poverty? Evidence from India. *Journal of Development Economics*. 133. pp. 375–395.	DiD	Agricultural production practices, time use, employment, education	This study combines household level survey with district level data on road access to evaluate outcomes of rural road development. It employs a fixed effects (DiD) model in which treatment is characterized by the share of the district population with road access. It finds that treatment areas report (a) lower prices, (b) increased availability of non-local goods, (c) increased use of agricultural technologies, (d) greater school enrollment for younger children, and (d) reduced school enrollment of older children.
80	Road improvement	Peru	Volpe Martincus, C., Carballo, J., Cusolito, A., 2017. Roads, Exports and Employment: Evidence from a Developing Country. *Journal of Development Economics*. 125. pp. 21–39.	IV, DiD	Firm exports and employment	The study estimates the effects of road development on firm outcomes, including exports and employment. It utilizes detailed geo-referenced data on firm-level trade for the period 2003–2010 as well as on recent and historical road infrastructure. Two identification strategies are utilized—first a set of DiD estimates that include extensive sets of fixed effects, then IV estimations are performed that instrument changes in the road network with distance to the pre-Colombian Inca road network. The study finds significant positive impacts on firms' exports and employment.
81	Roads	Chile	Volpe Martincus, C. and J. Blyde. 2013. Shaky Roads and Trembling Exports: Assessing the Trade Effects of Domestic Infrastructure Using a Natural Experiment. *Journal of International Economics*. 90 (1).	DiD	Firm exports	This paper investigates effects of road infrastructure on firm export performance. It exploits the 2010 earthquake as an exogenous source of variation in available transport infrastructure. It combines firm-level export data with detailed geo-referenced information on damages in a DiD framework. The results indicate that diminished transportation infrastructure had a significant negative impact on firms' exports.
82	Railroads	Africa	Jedwab, R. and A. Moradi. 2013. Transportation Technology and Economic Change: The Impact of Colonial Railroads on City Growth in Africa. *CSAE Working Paper*. WPS/ 2013–17.	DiD	Agricultural production, urbanization	This study estimates the effects of rail construction in colonial Africa on urbanization, cacao production, and contemporary development patterns. It employs DiD methods to estimate effects, and finds large permanent effects on agriculture and urbanization before independence, as well as a persistent set of effects on modern development patterns.

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	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
83	Rural road development	India	Asher, S. and P. Novosad. 2018. Rural Roads and Local Economic Development. *World Bank Policy Research Working Paper*. No. 8466. Washington, DC: World Bank.	Fuzzy RDD	Employment, income, firm performance, time use	This analysis estimates effects of rural road development using village-level estimates derived from data covering every individual and firm. The paper uses the eligibility criterion of a village population of at least 500 inhabitants as the basis of an assignment variable, under a fuzzy RDD approach appropriate to incomplete assignment. It finds that the main effect of new feeder roads is to allow workers to obtain nonfarm work (mostly outside of the village), and that there are no major changes in consumption, assets, or agricultural outcomes.
84	Rural road development	India	Mukherjee, M. 2012. Do Better Roads Increase School Enrollment? Evidence from a Unique Road Policy in India. Working paper.	Fuzzy RDD	Education	This analysis estimates effects of rural road development using village-level estimates derived from school administrative information systems. The paper uses the eligibility criterion of a village population of at least 500 inhabitants as the basis of an assignment variable, under a fuzzy RDD approach appropriate to incomplete assignment. The most conservative estimates show a 22% increase in enrollment due to year-round road access.
85	Rural road development	India	Adukia, A., S. Asher, and P. Novosad. 2017. Educational Investment Responses to Economic Opportunity: Evidence from Indian Road Construction. Working paper.	DiD	Education	To estimate effects of rural road development on educational outcomes, this study focuses on villages that received roads between 2003 and 2015 under a national road development program. The study uses data from an annual census of schools in a DiD model to estimate effects on enrollment and middle school educational performance. It finds that children stay in school longer and perform better on standardized exams due to road access.
86	Rural road development	Nepal	Bucheli, J. R., A. K. Bohara, and K. Villa. 2016. The Impact of a Rural Road Development Project on Multidimensional Poverty in Nepal. Paper presented at the 2016 Agricultural & Applied Economics Association Annual Meeting. Boston, Massachusetts.	DiD, PSM	Multidimensional poverty index, health, education	This study examines the effect of rural roads in Nepal on health, education, and living standards. It uses data from the 2001 and 2011 rounds of the Nepal Demographic and Health Survey in a DiD model to estimate effects on a multidimensional poverty index. It finds improvements in asset ownership and dwelling infrastructure, but not in the health and education indicators. Propensity score matching and inverse-probability weighting methods are used as robustness checks with similar results.

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Appendix Table 2 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
87	Rural road development	Peru	Valdivia, M. 2011. Contracting the Road to Development: Early Impacts of a Rural Roads Program. *PEP Working Paper Series*. No. 2010–18.	DiD	Road quality, income, employment, education, health	The focus of the impact evaluation is a program involving contracting of private local firms for the rehabilitation and maintenance of rural roads with supervision by community leaders. It applies a DiD design to two rounds of household surveys designed for the impact evaluation. The results suggest that this institutional arrangement improved road quality, increased income, changed employment, and increased investments in education and health. It also finds that income effects accrue in less-connected households, and employment effects are greater for women, but that educational effects do not favor girls.
88	Road construction	Nepal	Shrestha, S. A. 2017. Roads, Participation in Markets, and Benefits to Agricultural Households: Evidence from the Topography-based Highway Network in Nepal. Working paper.	IV	Agricultural production and land prices	An IV approach is applied in this paper to identify the effects of roads on agricultural livelihoods and market mechanisms. The study instruments road development based on rugged terrain that influences the design and costs of constructing roads in Nepal. It finds a positive impact of road on farmland values, increased participation by households in agricultural markets, increased fertilizer use, and improved farm production and incomes.
89	Railroads	India	Donaldson, D. 2018. Railroads of the Raj: Estimating the Impact of Transportation Infrastructure. *American Economic Review*. 108 (4-5). pp. 899–934.	FE	Agricultural income, domestic trade	This study uses archival data from colonial India to estimate the historical effects of railroad development. It develops predictions from a general equilibrium trade model, which are then tested via a two-way fixed effects model that relates railroad development to agricultural production value per land area. The study also performs an additional set of regression to confirm that the estimated effects are achieved via the channel of domestic trade, as well as placebo tests to confirm the validity of the parallel trends assumption. Its results validate that railroads significantly raised agricultural production value per area (considered as real income) via elevated domestic trade.
90	Urban rail (metro)	Brazil	Moreno-Monroya, A. I. and F. R. Ramos 2015. The Impact of Public Transport Expansions on Informality: The Case of the São Paulo Metropolitan Region.	Endogenous treatment effects regression (IV)	Formal employment	The study estimates the effects of development of the São Paulo metro rail on formal employment rates. It uses an endogenous treatment regression approach in which metro development is instrumented by historical urban development plans and other characteristics. Data are from census sampling units. The study finds that informality decreased on average 16% faster as an effect of metro development.

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Appendix Table 2 continued

	Intervention	Country	Study	Study Design	Outcomes	Summary Findings
91	Road construction	Bangladesh	Mahmud, M. and Y. Sawada. 2015. Infrastructure and Well-Being: Employment Effects of Jamuna Bridge in Bangladesh. CIRJE-F-986 Discussion Paper. Tokyo.	DiD	Employment	This study evaluates the impact of the Jamuna multipurpose bridge, on employment. It employs a multinomial logit DiD model to estimate job transition patterns based on household survey data covering locations nearer to and further from the bridge. The study finds a significant decrease in household unemployment, and a farm-to-nonfarm shift of occupation.
Selected Ongoing Impact Evaluations from ADB						
92	Rural road improvement project	PRC	Nishimura, M., N. Seiber, and S. Wang. 2018. Impact Evaluation of Road Improvements and Rural Poverty—Baseline Survey in the Ningxia Liupanshan Area of the People's Republic of China. *ADB East Asia Working Paper Series.* Manila: ADB.	PSM	Employment, income, migration, travel time	This working paper describes the methodology and results of baseline study conducted in 2016. It also provides technical background on transport investments and rural poverty, and selected results of the baseline study.
93	Rural road	India	Impact Evaluation Study for Rural Road Investment Program in the States of Chhattisgarh and Madhya Pradesh	RDD	Farmers' participation in agricultural value chain, income, labor force participation	This study will look into the effects of rural roads upgrade and how improved road conditions will affect the development of agricultural value chains, participation in labor force and what pre-cautious behaviors are changed due to the reduced impact of disasters, what are the implied benefits, and whether improved rural roads affect the quality of consumption among households.
94	Bus rapid transit	Pakistan	Impact Evaluation of Transport for Employment in Lahore, Pakistan	RCT	Employment (access to jobs and labor)	The research will establish quantitative evidence based on the importance of urban transport for employment. In particular, it will help inform similar projects in (1) establishing quantitative effects of high-quality transport on job seekers' access to jobs and employers' access to skilled labor; (2) informing potential policies for the vehicles themselves, such as whether to include physical partitions for women's sections; (3) informing potential features of feeder routes to the main BRT arteries; and (4) informing optimal fare policies.

Source: Authors' compilation from listed studies. Descriptions draw in part on study abstracts.

APPENDIX 3:
SUMMARY DESCRIPTIONS OF MAJOR IMPACT EVALUATION METHODS

Note: This section draws on White and Raitzer (2017), which provides a more detailed explanation of the methods described.

Difference-in-Differences and Fixed Effects

The difference-in-differences (DiD) technique is based on the difference in the changes in the outcome between treatment and comparison groups over time. The method takes the trajectory of the comparison group as the counterfactual trajectory for the treatment group with the intervention of interest. That is, the change in the outcome that takes place in the comparison group is taken as what would have happened to the treatment group in the absence of the intervention. Therefore, subtracting the change in the outcome observed in the comparison group from that observed in the treatment group gives the measure of impact. The effects of all factors that do not change over time or that do not affect changes over time are thereby eliminated from the impact estimate. Many determinants of program placement or participation can be expected to be rather time invariant, hence the attractiveness of this approach. DiD provides an unbiased estimate of program impact if the "parallel trends" assumption holds, which is the assumption that the outcome variable follows the same trajectory over time in treatment and comparison groups without the intervention. Fixed effects models in two-way panel form (with individual and time period dummies) function similarly to DiD, but can incorporate additional control variables to reduce reliance on the parallel trends assumption, and can be applied to continuous intervention variables (for which the comparison is regarding amounts of the intervention, rather than presence versus absence of the intervention).

Synthetic Controls

Synthetic controls build on the concepts of difference-in-differences approaches, in that the difference in trends between the outcome and comparison group observations provides the estimate of impact. However, synthetic controls relax the parallel trends assumption and build the control by weighting the comparison group observations such that trends in covariates and outcomes of the synthetic control match those of treatment before the intervention. Under this method, a panel regression of outcomes on covariates (excluding treatment) is conducted, and a binary variable indicating the treatment status of individual observations is specified. An optimization procedure is conducted to identify weights for individual comparison group observations, such that the weighted synthetic control trends in covariates and outcomes match those of the treated units before treatment as closely as possible. Application of these weights to the comparison group observations during the treatment period allows for a synthetic control, or counterfactual that can be compared with the actual trend of treated groups. The technique requires a time series of observations before and after the intervention of interest for those with and without the intervention.

Propensity Score Matching and Weighting

The propensity score is the estimated probability of being in the treatment group given the observable characteristics from a regression model of participation. Estimated propensity scores can be used to underpin a range of impact evaluation methods, including propensity score matching (PSM), the most common technique; weighting estimators; and weighted regressions. PSM creates a comparison group from untreated observations by matching treatment observations to one or more observations from the untreated sample, based on observable characteristics. Treated units are matched to untreated units with a similar propensity score before making comparisons. Weighting techniques apply weights to balance observable characteristics between treated and untreated groups. Propensity score approaches cannot address selection on unobservables (or variables without measured values that can be incorporated into the regression model of participation), so they may give biased estimates if these are important. DiD can be combined with PSM to eliminate confounding by both time invariant and observable factors.

Regression Discontinuity Design and Interrupted Time Series

Regression discontinuity design (RDD) can be used when there is a threshold rule for program eligibility, such as the poverty line; villages either side of an administrative boundary; or a score used to rank potential subprojects according to an assignment variable with a cutoff value. The underlying assumption, which is tested as part of the procedure, is that units in proximity to either side of the boundary are sufficiently similar for those excluded from the program to be a valid comparison group. The difference in outcomes between those near either side of the cutoff boundary, as measured by the discontinuity in the regression line at that point, is attributable to the program, and so is the measure of impact. The validity of the technique is contingent upon the cutoff value of the assignment variable conditioning eligibility only for the intervention of interest and not other interventions.

Interrupted time series is a specific application of RDD in which the threshold is the point in time at which the program came into effect. This can be a particularly relevant method where intervention effectiveness is sudden, rather than gradual, such as the completion of a bridge or major power transmission connection.

Instrumental Variables and Endogenous Treatment Approaches

The instrumental variable (IV) technique is used to obtain consistent estimates by using one or more variables that affect exposure to the intervention, but not outcomes, as a proxy for the intervention. Natural experiments are the ideal conditions for the application of IV methods, as the exogenous condition determining access to the intervention becomes the instrument. IV is often implemented as two-stage least squares: (i) stage one regresses the endogenous variable (that measuring program participation) on the instruments and calculates the fitted value; and (ii) stage two, estimates the outcome equation, replacing the endogenous variable with the fitted values from the first stage. The impact estimate is the coefficient on the fitted values. Other variants of IV techniques include endogenous selection or switching regressions. The limitation of IV-based approaches is that appropriate instruments are difficult to find.

Impact Evaluation of Transport Interventions

A Review of the Evidence

This publication aims to support impact evaluation in the transport sector by assessing what has been produced against what might be possible. It reviews 91 impact evaluations of transport interventions in developing countries, summarizes findings on outcomes, identifies evidence gaps, and proposes ways forward. Most of the studies reviewed find significant effects on at least one of the outcomes investigated. However, impact evaluation has given relatively little coverage to major areas of investment, such as urban and sustainable transportation, transport corridors, and efficiency enhancing measures. New methods and increasing openness of geospatial data provide scope to generate more innovative impact studies.

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ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org