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ABSTRACT

This paper estimates the local welfare impacts of road maintenance investments. We instrument road quality exploiting Indonesia's two-step budgeting process for allocating funding to local road authorities. Using comprehensive data on road quality from 1990-2007, we find that better roads help manufacturers create new jobs, enabling worker transitions out of informal employment, and increasing wages. In terms of cost of living, road quality reduces perishable food prices but also raises housing prices. We estimate the elasticity of household welfare with respect to road quality to be 0.16 and the benefit/cost ratio for road maintenance investments to be 2.8.

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1 Introduction

Road maintenance, which includes repaving and resurfacing existing roads, is often justified as a public good investment to stimulate economic activity and create jobs. In fact, a common response to macroeconomic shocks such as the great recession and the COVID-19 pandemic has been to increase spending on infrastructure, a large part of which is dedicated to road maintenance. Although most public expenditures on roads are allocated to rehabilitation instead of new construction, we lack credible evidence on how maintenance investments impact local economic development outcomes and welfare.[1] Our lack of understanding is particularly acute for developing countries, where the effects of smoother pavement surfaces, and the faster speeds they allow, could be particularly transformative.

In this paper, we study how changes in road quality impact local economic development in Indonesia. Our empirical analysis relies on a long and comprehensive administrative database on road quality. From 1990 to 2007, Indonesia's highway authority measured the roughness of each segment of all national and provincial roads on three of the country's most populous islands: Java, Sumatra, and Sulawesi. We combine these spatio-temporal measures of road roughness with economic outcomes from several high-quality datasets: (1) the Indonesia Family Life Survey (IFLS), a nationally representative panel of households; (2) the Industrial Survey (SI), an annual census of large manufacturing firms; and (3) population census data.

Causal estimates of the effects of road improvements are difficult to obtain because maintenance investment decisions are not exogenously determined. If planners target road improvements based on economic trajectories or political characteristics, this generates selection bias (Blimpo et al., 2013; Burgess et al., 2015; Asher and Novosad, 2020). We overcome this challenge with a novel instrumental variables strategy that takes advantage of Indonesia's multi-stage budgeting process for road financing.

In Indonesia, independent road authorities corresponding to sub-national (provincial) units make investment decisions based on a two-stage budgeting process. In the first stage, the central government sets an annual total budget for maintenance and this common pool is subsequently allocated to provincial units based on strict formulas that depend on observable characteristics. Then, in the second stage, different provincial road authorities use the funds allocated to them to upgrade their choice of roads. This implies that endogeneity of road investments is limited to second stage decision making. The federal transfers received by provincial road authorities provide the bulk of financing for road investments, because provincial governments have very limited abilities to raise their own revenue, and they seldom save budgets for future infrastructure investments. This implies that in Indonesia, budgets for road investments in any given year depend on two factors: (1) annual national road infrastructure funding from the central government allocated to provinces based on strict distribution formulas; and (2) discretionary allocation of those funds by provincial road authorities to districts within their jurisdiction.

We measure road quality using the World Bank's International Roughness Index, a widely used measure in the civil engineering and transportation literature. To construct instruments for district road quality based on this two-step budgeting process, we use the total provincial budget for road investments interacted with the sum of characteristics of other districts in the province. These characteristics

[1] Engineering models from the World Bank (1994) estimate that the returns to road maintenance are twice as high as those for network expansions. Foster et al. (2022) find that across developing countries from 2010-2018, infrastructure spending was low and declined over time.

proxy for relevant dimensions considered in discretionary maintenance allocation decisions. Since district budgets sum to the provincial budget, the characteristics of other districts in the province influence a district's budget allocation through the provincial budget constraint. Other district characteristics interacted with the total provincial budget for roads then directly affect a given district's budget for road improvements, and we find a strong first stage relationship. However, because the characteristics of other districts in the province do not directly affect any outcomes of interest for that particular district, they are also likely to satisfy the exclusion restriction. We use lasso techniques to choose instruments that give us the best first stage fit, following Belloni et al. (2012), given the large vector of characteristics available for this purpose.

To guide our empirical analysis, we begin by providing a simple framework that allows us to decompose the different channels through which road quality affects household welfare. These channels include: (1) wage income; (2) firm profits; and (3) living costs (prices). We causally estimate the effect of road quality on these different outcomes using our instrumental variable approach, and then we combine those estimates with our framework to estimate overall household welfare effects.

To confirm the validity of our instrumental variables approach, we first verify that improvements in instrumented district-level road quality predict travel times to nearby provincial and district capitals according to IFLS household survey data. We estimate these effects from panel regressions with two-way fixed effects at the community and survey-wave levels. Reassuringly, travel time reductions are observed not only in IFLS survey responses but also in measures of travel times derived from the roughness data itself.

Using household and individual-level outcome measures from the IFLS, our main results show that when road quality improves, nominal income and consumption expenditures increase. The elasticity of per capita consumption to road quality is about 0.2, implying a large and significant effect. We neither observe extensive margin effects on employment nor intensive margin effects on hours worked, and we show that the observed increase in consumption expenditures is mainly driven by an occupational shift out of informal employment and into higher-wage manufacturing and other formal jobs.

Given the importance of this formal manufacturing sector employment result, we verify that it also holds using SI data on large manufacturing firms. District-level panel specifications confirm that better road quality is indeed reflected in higher total value added, output, and employment of manufacturing firms. Because the output response is larger than the impact on employment, output per worker also increases. Next, using firm-level panel regressions where we control for firm fixed effects, we demonstrate that increases in the performance of manufacturing firms appear to be driven by newly created firms, and not by changes in output or output per worker of incumbent firms.

When evaluating the impact of road quality on the cost of living, we find that road quality improvements reduce the price of perishable food products, but it has no discernible impact on non-perishable goods prices. Road improvements also generate higher land values and rents, consistent with road quality being a productive amenity. Finally, we examine the extent to which road improvements impact migration, as this could play an important role in our welfare analysis. Using cross sectional district level census data, we provide suggestive evidence that better roads lead to increases in internal migration, but these statistically significant effects are not economically large. For this reason, as a first approximation, we ignore the potential for road quality to induce migratory responses when calculating household welfare.

Our main estimates are robust to a number of different specifications, including different ways to construct instruments, controls for other simultaneous changes in infrastructure, and different cuts of the sample. We also show that the increase in the number of firms and employment is not driven by footloose, foreign-owned manufacturing firms, nor is it simply due to displacement of other firms from nearby districts. This suggests that our results represent genuine development effects instead of a reshuffling of economic activity. In an important robustness check, we add controls for market access outside the province and find that the effects of road improvements operate independently of trade-related channels emphasized in the extant literature. This result shows that road improvements not only affect market access but also have additional effects on the productivity of the local economy.

Next, we combine these separate reduced form effects of road quality to estimate how road improvements impact overall household welfare. We find that a 10 percent increase in road quality increases household welfare by 1.6 percent on average. Most of these welfare effects owe to increases in labor income that are driven by the growth of formal factory employment opportunities.

Finally, we conduct a benefit-cost analysis using counterfactual simulations in which we upgrade each district's national and provincial roads by bringing them up to the roughness of paved roads in the data. For the median district, positive stimulus benefits would be enjoyed for 6 years before deterioration erodes road quality back to its initial levels. These upgrades would confer a discounted stream of income equal to 22.8 percent of district GDP. Accounting for the costs of road upgrades, this yields a net benefit of 10.5 percent of district GDP. However, these calculations ignore general equilibrium effects (Egger et al., forthcoming). Once we include fluctuations in the cost of living and goods prices that are induced by the stimulus, we find that upgrades for the median district would generate a net present value (NPV) of roughly 6.2 percent of district GDP. Expressed in terms of a cost-benefit ratio, we find that the median upgrading program is quite cost effective even after considering general equilibrium price effects, with the stream of benefits equal to 2.8 times the costs.

This paper contributes to a sizeable literature evaluating the impact of transport infrastructure improvements in developing countries. A large body of work studies the effects of newly created surface links that expand transportation networks, including China's new national trunk roads (Banerjee et al., 2012; Faber, 2014), India's Golden Quadrilateral Project (GQ) (Ghani et al., 2016), new railways in colonial India (Donaldson, 2018), or new highways in Brazil (Morten and Oliveria, 2018; Bird and Straub, 2020). Our work instead focuses on quality improvements to existing roads, which are relatively understudied (Cosar et al., 2021). Such projects may be be more politically feasible and result in a larger cost-benefit ratio.

Our work is also related to a large body of evidence on the impacts of transport improvements in rural areas, which often involve upgrades to existing unpaved roads (e.g. Aggarwal, 2018; Gollin and Rogerson, 2014; Khandker et al., 2009; Valdivia, 2011; Khandker and Koolwal, 2011; Casaburi et al., 2013). Asher and Novosad (2020) find that new rural roads built by the Village Road Program in India lead to a transition of workers out of agriculture, but there were no impacts on income, unlike in our work. One possible reason for this difference in results is that our paper studies highways instead of rural roads, which may be far more important for moving local goods and people. Another advantage of our work is that it benefits from a continuous road quality measure, instead of binary treatment indicators that are often used in the literature.

This paper's results also relate to the structural transformation literature and the shift from agricultural to manufacturing employment (Lewis, 1954). Our results show that road quality can reduce informal employment and expand formal employment opportunities, increasing wages. The potential for formal factory employment to provide a source of wage and income gains for workers outside of urban areas has also been identified in other contexts, such as India (Foster and Rosenzweig, 2004).

A large body of work also studies how transport infrastructure improvements can shape economic geography using the lens of trade theory. For example, Donaldson and Hornbeck (2016), Asturias et al. (2019), and Storeygard (2016) find large, positive effects of transportation infrastructure on aggregate welfare and income, but for these studies, the impacts largely came about due to a reduction in transport costs and an increase in trade volumes. We complement that work by interpreting local transport infrastructure improvements as having a productive amenity effect and show that Indonesia's road improvements led to the development of new firms, leading to a transition of labor out of informal employment. Our setting also complements work in urban economics on highway improvements that has mostly focused on the U.S. interstate highway system. For example, Duranton and Turner (2012) investigate city growth effects, Michaels (2008) analyzes skill premia changes, while Baum-Snow (2007) documents suburbanization effects.

Finally, this paper is related to the macroeconomic literature on the benefits of infrastructure spending as fiscal stimulus (Gramlich, 1994; Chandra and Thompson, 2000; Leeper et al., 2010; Leduc and Wilson, 2013). Unlike new highway construction, which takes much longer to plan and develop, the road resurfacing and upgrading projects we study are "shovel ready" and better suited for fiscal stimulus. Few estimates of the transport stimulus effects exist in the literature, and the vast majority of evidence is from developed countries (see Leduc and Wilson, 2014, for a review). Recent transport spending in developing countries has largely been pro-cyclical (Foster et al., 2022), which is unfortunate given that the economic boost provided by government spending tends to be largest during recessions (Auerbach and Gorodnichenko, 2012). It is important to assess the stimulus effects of infrastructure spending in a lower-middle income country, where the benefits and transmission mechanisms could be quite different, and our paper fills this gap.

The rest of the paper proceeds as follows. Section 2 discusses how improvements to existing roads may affect local economic development outcomes, and it provides a framework evaluating the welfare effects of road improvements. Section 3 describes the data we use, and Section 4 describes the historical and institutional background behind the evolution of road quality in Indonesia. Section 5 describes our identification strategy, and Section 6 presents our reduced form results. Section 7 shows that our main results are robust to different specifications and investigates some of the mechanisms behind our findings. Section 8 presents our estimates of how road quality impacts welfare and conducts counterfactual simulations, and Section 9 concludes.

2 Welfare Framework

In this section, we present a simple framework to establish the channels through which marginal improvements in road quality impact household welfare. Let i index households, and let U_i =

$U(\mathbf{c}_i, H_i)$ denote household i's utility function, which is defined over a vector of consumer goods, $\mathbf{c}_i = (c_{i1}, c_{i2}, ..., c_{iK})'$, and housing, H_i. For clarity, we specialize to a Cobb-Douglas functional form:

$$\max_{\mathbf{c}_i, H_i} \theta \left(\prod_{k=1}^{K} c_{ik}^{\alpha_k} \right) H_i^{1-\alpha} \quad \text{s.t.} \quad Y_i = \sum_{k=1}^{K} p_k c_{ik} + p_H H_i \ ,$$

where $k = 1, ..., K$ indexes the different types of consumable goods available to households, θ, $\{\alpha_k\}_{k=1}^{K}$, and α are constants, and where we assume that $\sum_{k=1}^{K} \alpha_k + \alpha = 1$.

Households earn income primarily through labor sources, Y_L, but they may also derive income from a farm or non-farm business, earning profits given by π. Total income, Y, is therefore given by the sum of wage income and business profits: $Y = Y_L + \pi$. Given this setup, the household's indirect utility function is given by:

$$V(p, Y) = c \cdot Y \cdot \left(\prod_{k=1}^{K} p_k^{-\alpha_k} \right) \cdot p_H^{-(1-\alpha)} \quad , \tag{1}$$

where c is a constant. Taking logs of (1), and totally differentiating with respect to log road quality, $\log A$, we obtain:

$$\mathcal{E}_{V,A} = \underbrace{\theta_{Y_L} \mathcal{E}_{Y_L,A} + \theta_\pi \mathcal{E}_{\pi,A}}_{\text{(I)}} - \underbrace{\sum_{j=1}^{J} \alpha_j \mathcal{E}_{p_j,A}}_{\text{(II)}} - \underbrace{(1-\alpha)\, \mathcal{E}_{p_H,A}}_{\text{(III)}} \ , \tag{2}$$

where we use $\mathcal{E}_{y,x}$ to denote the elasticity of y with respect to x, and we use $\theta_x \equiv x/Y$ to denote the share of x in total household income.[2]

Equation (2) shows that the elasticity of household welfare with respect to road quality is the sum of three components. The first component, (I), is the effect of changing road quality on household labor income and household-owned business profits. Business profits can be decomposed further into farm and non-farm business profits, as better road quality may reduce input costs and increase profits, as in Jacoby (2000).

On the labor income side, we account for the fact that many developing economies are characterized by the dual-economy nature of their labor markets, where there is a high wage, productive formal sector, and a low-wage, unproductive informal sector (Lewis, 1954; Temple, 2005; La Porta and Shleifer, 2014). If a local labor market faces poor road quality, formal sector employment opportunities may be limited or nonexistent, and this forces workers to instead supply their labor to the informal sector. Agriculture represents a large source of informal sector employment (e.g. Singh et al., 1986; Benjamin, 1992; Bardhan and Udry, 1999).

However, when road quality improves, manufacturing firms may now be able to operate in locations that were previously infeasible for production. When those firms are created, they provide new, higher wage, formal sector jobs that were not available before. These new formal employment opportunities can enable workers to transition out of informal employment (Foster and Rosenzweig, 2004). This increased availability of higher wage employment opportunities is expected to increase workers' total earnings and consumption. In the empirical analysis, we will thus analyze the margin of informality in labor

[2] The constant in equation (1) is given by the following: $c \equiv \theta \left(\prod_{k=1}^{K} \alpha_k^{\alpha_k} \right) (1-\alpha)^{1-\alpha}$. Appendix C provides a derivation of equation (2).

income.

The second term of equation (2), (II), is a weighted sum of the elasticities of prices with respect to road quality across different goods, where the weights are baseline expenditure shares. As road quality improves, transport costs may fall, and this could directly impact the prices of goods consumed by households. We expect that the prices of perishable goods may be more sensitive to road roughness than non-perishable goods, which are less sensitive to transit times.

The third term of equation (2), (III), is the elasticity of housing prices with respect to road quality, multiplied by $(1-\alpha)$, the share of the consumer's income spent on housing. If a district becomes more attractive for firms, this bids up the price of land. The rise in the price of land can also occur if households migrate towards districts with better roads. If road quality is a productive amenity, valued by both producers and consumers, firms and workers may sort across locations in response to road improvements, bidding up the price of land, as in standard spatial equilibrium models (e.g. Rosen, 1979; Roback, 1982). In the absence of migration costs, road improvements would lead to population growth and increased housing prices, hurting renters and benefiting homeowners. However, if internal migration is costly (e.g. Bryan and Morten, 2019), these migratory responses to road quality improvements could be dampened. New manufacturing firms may be able to bring jobs to a community, raise wages, and increase incomes, leading to positive welfare benefits for affected communities that are not completely bid-away through housing price effects.

In our empirical work, we separately test each of the different aspects of this theoretical framework, to determine whether road quality improvements: (1) lead to new manufacturing jobs; (2) encourage workers to switch sectors; (3) increase total earnings and consumption; (4) increase housing prices and land values; and (5) change prices of perishables and non-perishables.

3 Data

In this section, we describe the main data sources used in our analysis. These include the road quality data, household survey data, manufacturing data, population census data, and geospatial datasets. We briefly describe each of these data sources here, leaving additional details for Appendix B.

Road Quality Data. Our road quality data are from Indonesia's Ministry of Public Works and Housing (*Kementerian Pekerjaan Umum dan Perumahan Rakyat* or Kemen PUPR), which conducts an annual high resolution data collection effort to monitor pavement quality. Surveyors collect information on every segment of national and provincial highways, with measures of surface type, width, and road roughness. Our data includes this information for all provincial and national roads in Indonesia from 1990-2007, and contains more than 1.2 million kilometer-post-interval-year observations. The road survey data were merged to maps of road networks to construct an annual spatial panel of road quality.

Road quality is measured using the International Roughness Index (IRI), a widely accepted indicator from civil engineering developed by the World Bank in the 1980s. The IRI is defined as the ratio of a vehicle's accumulated suspension motion (in meters), divided by the distance traveled by that vehicle (in kilometers) during measurement.[3] All else equal, when driving on rougher roads marked by potholes or ragged pavement, drivers decrease speeds and increase their travel time. Rough surfaces may also

[3]See Appendix Section B.1.2 for more details on the IRI.

cause accidents, increase maintenance costs, and lead to greater fuel consumption. Consequently, road roughness directly reduces local productive and consumer amenities through effects on travel times, vehicle maintenance costs, and safety (Bock et al., 2021).[4]

Let $\mathcal{R}_d$ denote the set of national and provincial road segments in district d, and let d_r denote the length of road segment r. We measure the average road quality in district d by taking the negative of a distance-weighted average of roughness for all road segments in that district:

$$\text{Road Quality}_{dt} = (-1) \times \frac{\sum_{r \in \mathcal{R}_d} d_r \text{IRI}_{rdt}}{\sum_{r \in \mathcal{R}_d} d_r} \quad , \tag{3}$$

where IRI_{rdt} denotes the roughness of road section r in district d at time t. The average in equation (3) is taken over all national and provincial roads located in the district, and different districts have different shares of these types of roads.

Figure 1 shows the distribution of road quality in two years of our sample (1990 and 2000). The graph displays large variation in road quality over space and over time, the latter observed as a significant leftward shift in the distribution of road roughness across districts between the two years. Similarly, Figure 2 documents substantial spatial variation in road improvements over time on Sumatra, Indonesia's 2nd most populous island. Nearly 84 percent of Sumatra's network of national and provincial highways was unpaved in 1990, but this figure fell to 46 percent only a decade later. Similar trends can be seen for the highway networks on Java and Sulawesi.[5] Finally, Figure 3 shows that the distribution of roughness substantially narrowed between 1990 and 2007, suggesting that maintenance and upgrading projects were targeted at improving quality at the low end of the distribution.

Indonesia Family Life Survey (IFLS). Our main source of data for individual employment and household-level consumption outcomes is the Indonesia Family Life Survey (IFLS). The IFLS is a national longitudinal survey, representative of 83 percent of Indonesia's population, and it tracks more than 30,000 individuals in 5 waves over a 22 year period (1993-2015). These individuals are observed in more than 300 communities (*desa* or *kelurahan*), which are the lowest administrative unit in Indonesia and comprise one of our main spatial units of analysis.[6] IFLS communities are spread across 13 of Indonesia's 27 provinces and are located in over 200 districts (*kabupaten*). We use data from the first four waves of the IFLS (1993, 1997, 2000, and 2007), matching the timing of our data on road quality. The IFLS is notable for its low attrition rate, as more than 87 percent of the original households were tracked through the first four survey waves. These panel data allow us to track the same households and individuals facing different road infrastructure conditions over 14 years. Appendix Figure A.3 shows the locations of IFLS villages used in our analysis.

Census of Manufacturing Firms. Our primary data source of firm-level outcomes is the Annual Census of Manufacturing Establishments (*Survei Tahunan Perusahaan Industri Pengolahan*, or SI), collected by Indonesia's Central Statistical Agency, (*Badan Pusat Statistik* or BPS). The SI covers manufacturing plants with more than 20 employees and contains detailed information on plants' cost variables, employment

[4] During our period of study, fuel consumption and labor costs accounted for more than 50 percent of vehicle operating costs in Indonesia (Asia Foundation, 2008).

[5] Appendix Figure A.1 shows the evolution of road quality in Java, and Appendix Figure A.2 shows the evolution of road quality in Sulawesi.

[6] According to Census data, the communities in our sample had an average population of 3,100 in 2000 and 3,145 in 2010.

sizes, and measures of value added. SI data also contain firm-level identifiers, enabling us to track changes in firm-level outcomes over time. The data also record information on plants' starting dates, locations at the district level, as well as firm-level outcomes, such as employment and wage rates, value added, and output.[7]

Population Census. To study migration responses to changes in road quality, we combine the above datasets with data from the 2000 Population Census. These data collect individuals' birth districts and other socio-demographic characteristics. We also supplement the 2000 Population Census data with data from the 1971, 1980, and 1990 censuses from the Integrated Public Use Microdata Series (IPUMS).

Geospatial Data on Administrative Boundaries and Topography. Our analysis relies on administrative boundary shapefiles that identify district borders from BPS. Because district boundaries have changed substantially over time (Booth, 2011), we assign all observations to their districts in 1990. We also use these boundaries in combination with data from the *Harmonized World Soil Database (HWSD)* to construct several basic topographic characteristics (e.g., area, ruggedness, slope, and elevation).

4 Background on Road Maintenance

During their rule, Dutch colonists built and maintained much of Indonesia's current road network.[8] After independence in 1945, roads were left to deteriorate until 1967, when President Suharto assumed power. Road rehabilitation then became a top priority, and quantitative targets for improvement were included in many national five-year development plans (*Rencana Pembangunan Lima Tahun*, or Repelita). Spending on roads increased rapidly until the late 1970s, but it slowed in response to the collapse of state oil revenues and remained stagnant during the 1980s.

However, in the early 1990s, road upgrading again became a priority. During Repelita IV (1984-1989), the total budget for road improvements was \$2.1 billion, but in Repelita V (1989-1994), this budget was increased by 84 percent, to a sum of \$3.9 billion.[9] Transportation investments were the single largest item of the development budget during Repelita V, forming nearly 18 percent of total planned development expenditures. Almost all resources were allocated to improving the existing road network, especially upgrading dirt roads to asphalt. Although policymakers planned to maintain a high level of transport investments during Repelita VI (1994-1999), the Asian financial crisis and its concurrent political upheaval resulted in less spending than originally intended. Road expenditures have experienced a slow recovery ever since (World Bank, 2012).

In this section, we explain how road maintenance in Indonesia is financed through a two-stage budgeting process. This budgeting process forms the basis of our identification strategy. Central transfers

[7]New firms are counted when they appear in the dataset having never appeared before. For the purpose of our analysis, we dropped all firms coded as state-owned enterprises (less than 3 percent of all firm-year observations). Throughout this article, we use plants and firms interchangeably since less than 5% of plants in the dataset are operated by multi-plant firms (Blalock and Gertler, 2008).

[8]Especially on Java, transport networks constructed by the Dutch were considered high quality by regional standards. By 1900, Java already had "a sophisticated agro-industrial economy integrated by overlapping networks of telegraphs, telephones, railways, and narrow-gauge tramways and good roads. Nowhere in Southeast Asia could boast better infrastructure. Elsewhere in East Asia, only Japan could compare" (Dick, 2000).

[9]These numbers, expressed in constant 2000 U.S. dollars, were taken from various planning documents describing Indonesia's five year development plans.

to local (provincial level) road maintenance authorities are made to finance both national and provincial road improvements, and these transfers follow pre-determined allocation formulas. We also discuss how local governments in Indonesia consistently rely on the central government for transfers to finance infrastructure spending. Local governments seldom borrow or save to finance infrastructure investment, and most improvements are organized through single-year contracts.

The Two Stage Budgeting Process for National and Provincial Roads. In 1990, at the beginning of our sample, Indonesia was divided into 26 provinces and 290 districts. Our empirical analysis focuses on road quality for two types of roads: (i) arterial roads maintained by the national government, and (ii) provincial roads that maintained by provincial public works agencies. While the processes are separate, in both cases the central government allocates an annual budget to local agencies who are then responsible for using that budget to upgrade road segments of their choice. The annual budgets are assigned to provincial authorities based on predetermined allocation formulas, and individual road improvement projects are executed on a project-by-project basis.

Maintenance and upgrading of national roads is primarily the responsibility of the Directorate General of Highway Development at the Ministry of Public Works and Housing, who allocates funding to its local branch offices (*Kantor Wilayah*, or *Kanwil*) (Leigland, 1993). Provincial public works agencies (*Dinas Pekerajaan Umum*, or *Dinas*) are responsible for maintaining and upgrading provincial highways, and they use national funds to invest in roads under their jurisdiction (Leigland, 1993; Lewis, 2017). Hence, road investment decisions can be thought of as following a two-stage budgeting procedure (Deaton and Muellbauer, 1980), where the central government sets the budget for each provincial unit, and provincial units make independent spending decisions. As a result, while the second stage is clearly endogenous, the first stage is not.

Prior to decentralization in 1998, provincial budgets for provincial road improvements were primarily funded through the *INPRES Jalan Propinsi* program.[10] *INPRES Jalan Propinsi* was a central-to-provincial grant program, which began in FY 1979/1980, to fund the development and maintenance of provincial roads. Provinces were given *INPRES Jalan Propinsi* grants for improving roads based on strict quantitative formulas, where allocation criteria included road condition, road length, density of roads, and per-unit construction prices (Shah et al., 1994). During Repelita V, funding for *INPRES Jalan Propinsi* increased substantially, from Rp 70 billion in FY 1989/1990 to Rp 348 billion by FY 1992/1993, a nearly 4 fold increase (Booth, 2003). The fund allocation process was top-down, with decisions made at the national level regarding total grant allocations (Crane, 1995). After being awarded funding, sub-national budgets were allocated independently by provincial *Dinas* for spending.

In 1998, the INPRES system of central to regional transfers was replaced by general allocation fund grants (*Dana Alokasi Umum*, or DAU) and special allocation fund grants (*Dana Alokasi Khusus*, or DAK) (Lewis, 2001). More than 85 percent of local road expenditures were financed through DAU grants, while the remainder came through DAK grants. Importantly, both types of grants were also allocated to provincial units based on national formulas, and the criteria and weights behind those formulas changed every few years. The criteria and weights for the DAK are in Appendix Figure A.5 and for the DAU in

[10]Appendix Figure A.4 presents a schematic for the institutional and funding arrangements behind road maintenance in Indonesia.

Appendix Figure A.6.[11] Most changes in the weights were driven by new decentralization laws and with the objective of equalizing economic development throughout the regions, in accordance with national priorities (Bank, 2007). An additional source of variation in provincial road budgets came from changes to allocation criteria—for instance, the human development index and GDP replaced the poverty index in 2006 (World Bank, 2012).

Pre-determined Allocation Formulas. Importantly, both before and after decentralization, the central to local grants to both national and provincial road authorities were based on allocation formulas that were publicly available. For instance, INPRES grant allocation rules were based largely on interregional and intersectoral allocation formulas devised by the Ministry of National Development Planning (*Bappenas*), in consultation with the Ministry of Home Affairs and the Ministry of Finance (Crane, 1995). The formulas were set in Jakarta with no local inputs, nor were there annual negotiations with local governments over the allocations. More recently, formulas for DAU were designed to help to equalize fiscal capacities of sub-national governments, to subsidize poorer or more remote areas, and are aligned with national priorities stated in Repelita documents (Bird and Smart, 2002).

Reliance of Local Governments on Central Transfers. Under Suharto, sub-national governments were heavily reliant on the central government for tax revenue to finance local infrastructure spending, and this situation has not changed much as a consequence of decentralization. Before decentralization, local tax rates were equalized everywhere, and local governments had limited autonomy in their revenue raising policies (Hill, 1998). The central government maintained control of all major tax bases, even after decentralization, and the bulk of local government revenues came from central transfers.[12] For instance, Fane (2003) uses Ministry of Finance data to show that in FY 2002, local governments generated just under 5 percent of their total revenue from own-tax and non-tax sources, on average, with the central government accounting for the remaining 95 percent. By the end of 2007, sub-national governments accounted for 38 percent of total public sector expenditure but only about 8 percent of total public revenue (Lewis and Oosterman, 2009; Lewis, 2010). To the extent that local spending on roads was responsive to local economic activity, it probably only occurred in provinces that were large oil and gas producers, and we explore this possibility in robustness checks.

Lack of Borrowing to Finance Road Maintenance. Even before decentralization, regional infrastructure spending was conducted through annual budget allocations, with little borrowing to finance investments and few projects that spanned multiple years (Crane, 1995). Local governments tended to finance capital spending entirely out of operating balances (cash and reserves), instead of through borrowing (Lewis and Oosterman, 2011). Consequently, most infrastructure spending in Indonesia was funded through single-year contracts. Even as late as 2015, single-year contracts accounted for 93% of contracts signed by the Ministry of Public Works and Housing (Ray and Ing, 2016). Due to the short contract horizon, after procurement and mobilization, there is often little time left for implementation.

Fixed Road Administration Status. Importantly, over the period we study, road administration

[11] Appendix Figure A.7 provides more information on how revenue sources and local expenditures for road maintenance changed over time.

[12] Appendix Figure A.8 shows the growth in revenues and expenditures for road maintenance at a national and regional level over time. Until 2000, almost all of the financing came from the center, after which the regional public budget share rose modestly (Green, 2005; World Bank, 2012).

status remains fairly constant. Appendix Figure A.9 uses BPS data to plot the total length of roads administered by national, provincial, and district governments. Panel A shows total road length for all roads in Indonesia, while Panel B reports the shares of national and provincial roads in total road length. While road length increased nationally from 1990-1996, provincial roads accounted for 64 percent of total national and provincial road length, on average, from 1990-2003. Panels C and D show that in our sample of roads, provincial roads accounted for 52 percent of total national and provincial road length, a figure that remained relatively stable over time.

Summary. In this section, we have described a two-stage budgeting process for financing the maintenance of Indonesia's national and provincial roads. In the first stage, central transfers to local authorities, which include both the *Kanwil* of the Ministry of Public Works but also provincial public works *Dinas*, were made using pre-determined allocation formulas. Local governments were heavily reliant on central transfers to conduct infrastructure spending. They seldom borrowed to finance road maintenance, and many road improvement contracts were single year. Direct central spending on local infrastructure improvements was also very infrequent.[13] As a result, road investment decisions in a district can be thought of as following a two-stage budgeting procedure (Deaton and Muellbauer, 1980), where the central government sets the budget for each provincial unit, and those budgets are later allocated in a discretionary manner for spending across districts within a province. In the next section, we explain how this hierarchical budgeting process can be used to construct instrumental variables to study the effects of road quality.

5 Empirical Strategy

Using Indonesia's two-stage budgeting process, we construct instruments that enable us to identify the causal effect of a marginal improvement in road quality on local economic development outcomes. We first describe our basic regression model without instrumentation:

$$y_{dt} = \alpha_d + \alpha_t + \beta \log \text{Road Quality}_{dt} + \mathbf{x}'_{dt}\theta + \varepsilon_{dt} \ , \tag{4}$$

where y_{dt} is an outcome for district (or community) d at time t, and $\log \text{Road Quality}_{dt}$ is the distance weighed average road quality in a district, defined in equation (3). We include district fixed effects, denoted by α_d, to control for time-invariant unobservables that may be correlated with road quality and outcomes. Year fixed effects, denoted by α_t, control for year-specific national factors that affect outcomes in all districts. In some specifications, we estimate a regression model similar to equation (4) at the individual (household) level; in those cases, we include corresponding control variables and individual (household) fixed effects. The vector $\mathbf{x}_{dt}$ represents a set of time-varying controls, including household size and controls for other infrastructure projects. When y_{dt} is measured in logs, the key parameter of interest, β, measures the elasticity of y with respect to road quality.

Causal estimates of the effects of road improvements are challenging to obtain because maintenance decisions are endogenous, and the sign of the selection bias is difficult to ascertain a-priori. For example,

[13] Lewis and Chakeri (2004) explain that such spending was declared to be illegal according to Law 25/1999 on the Financial Balance between the Center and Regional Governments. Crucial for our identification strategy, this implies independence between the first and the second stage in road upgrade decision-making.

areas that receive greater maintenance investments may be selected by policymakers, either to target rapid economic growth, to stimulate growth in lagging regions, or because of previous deterioration. On the other hand, if better roads increase local economic activity, this feedback may generate attenuation bias if roads deteriorate faster due to their more extensive use.

These endogeneity concerns are unlikely to be solved with time and location fixed effects. To obtain unbiased estimates of the effects of road quality on local economic development outcomes, we use a novel instrumental variables strategy that takes advantage of Indonesia's centralized fiscal organization and budgeting process. As described in Section 4, Indonesia uses a two-stage budgeting process where road maintenance budgets are first allocated to provincial authorities, and local policymakers then decide how to spend those budgets on specific road segments. While the second stage is clearly endogenous, we now show that the first stage, i.e. the budget allocations to local road authorities, is plausibly exogenous and can generate useful instruments for road quality.

5.1 Using Multistage Budgeting to Generate Road Quality Instruments

Let $p = 1, ..., P$ denote different provinces in Indonesia, and let $i = 1, ..., N_p$ index the districts that comprise province p. Each year, the national government allocates a total budget for national and provincial roads to province p, given by $\overline{B}_{pt} \equiv \overline{B}_t$. These allocations follow national formulas for road spending, as described in Section 4. After the provincial budget is determined, provincial public works officials, including both the provincial branch offices of the Ministry of Public Works (*Kanwil*) and also the provincial public works agencies (*Dinas Pekerjaan Umum*), make road investments in districts under their jurisdiction based on observed and unobserved district characteristics.

Let B_{it} denote the total budget for road investments assigned to district i in year t. This can be written as follows:

$$B_{it} = \alpha_{it}\overline{B}_t \ , \tag{5}$$

where α_{it} is the budget share of district i in year t out of the total provincial budget B_t. α_{it} is itself a function of the district's own characteristics, as follows:

$$\alpha_{it} = \alpha_{0t} + \mathbf{w}'_{it}\theta_t + \varepsilon_{it} \ . \tag{6}$$

Here, α_{0t} represents a year-specific intercept, and $\mathbf{w}_{it}$ denotes a $(K \times 1)$ vector of observable characteristics of district i at time t that are used to determine budget allocations. These observables may include fixed factors, such as geographic characteristics, the area of the district, or historical population measures. They could also include time-varying factors, such as road quality in lagged periods, natural resource revenues in year t, or other tax revenues in year t. The term ε_{it} represents unobservable factors that shift the budget share for district i at time t. Importantly, α_{it} will vary over time, owing both to changes in allocation decisions and to changes in observed and unobserved district characteristics.

Each year, because these budget shares sum to 1, we have the following:

$$\alpha_{it} = 1 - \sum_{j \neq i} \alpha_{jt}$$

$$\implies \alpha_{it} = 1 - (N-1)\,\alpha_{0t} - \sum_{j\neq i} \mathbf{w}'_{jt}\theta_t - \sum_{j\neq i} \varepsilon_{jt} \ .$$

Define $\mathbf{s}_{it} = \left[\sum_{j\neq i} w^{(1)}_{jt}, \sum_{j\neq i} w^{(2)}_{jt}, ..., \sum_{j\neq i} w^{(K)}_{jt}\right]'$ to be a $(K \times 1)$ vector of the sums of other districts' observable characteristics that influence budget shares. Using this definition, we can write district i's budget for roads at time t as follows:

$$B_{it} = \left(1 - (N-1)\,\alpha_{0t} - \mathbf{s}'_{it}\theta_t - \sum_{j\neq i} \varepsilon_{jt}\right) \overline{B}_t \ . \tag{7}$$

Equation (7) makes explicit that district i's road budget at time t depends on the total budget for road improvements in the province, $\overline{B}_t$, interacted with the characteristics of the sum of all other districts in the province, $\mathbf{s}_{it}$. These other district characteristics interacted with $\overline{B}_t$ directly affect district i's budget for road improvements at time t. However, because the characteristics of other districts in the province do not directly affect any outcomes of interest for district i, they are likely to satisfy the exclusion restriction.

In robustness checks, we show that our results are robust to several different permutations for how to construct instruments. These include dropping adjacent districts from constructing the sums in $\mathbf{s}_{it}$, dropping time-varying characteristics in proxying for the budget shares, and using a district's own-characteristics ($\mathbf{w}_{jt}$) interacted with $\overline{B}_t$ as instruments.[14]

5.2 Implementation

To make use of equation (7) to develop instruments, we need to specify two sets of features: (1) a province's total budget for roads in year t, $\overline{B}_t$, and (2) the sums of characteristics for other districts in the province. We describe each of these features in detail.

Measuring Road Budgets. To measure $\overline{B}_t$, we approximate the total budget for national and provincial roads in the province using road roughness data. Note that we do not use direct data on total financial amounts allocated to roads to measure $\overline{B}_t$. Such figures may not be so informative about actual road improvements, given corruption and monitoring issues common to developing countries (Olken, 2007), so that our $\overline{B}_t$ measure should be thought of as effective road budgets net of corruption and administration inefficiencies.

Let $L \in \{N_p, P\}$ index road maintenance authorities (e.g. National, N_p, or Provincial, P), and let t index years. Let r index road segments, and let $\mathcal{R}^L_p$ denote the set of road segments in province p under maintenance authority L. We classify a road r as upgraded between $t-1$ and t if its roughness improves, i.e.: $U_{rt} = \mathbf{1}\{\text{IRI}_{r,t} < \text{IRI}_{r,t-1}\}$. Using these upgrading indicators, we measure the total roads upgraded in province p under different maintenance authorities as follows:

$$\widetilde{B}^L_{p,t} = \sum_{r\in\mathcal{R}^L_p} d_r U_{rt} \times (\text{IRI}_{r,t-1} - \text{IRI}_{r,t}) \ , \tag{8}$$

[14] Using a district's own-characteristics ($\mathbf{w}_{jt}$) interacted with $\overline{B}_t$ as instruments relies more heavily on the exogeneity of $\overline{B}_t$, but if crucial variables for the budget shares are not observed, this own-characteristics approach may perform better than the other-characteristics IVs.

where d_r denotes the length of segment r. In words, the budget for road improvements for administrative authority L in province p and year t, $\widetilde{B}^L_{p,t}$, equals the total kilometers of roads upgraded in year t and province p that are administered by that authority, weighted by the change in roughness for each road segment r between $t-1$ and t. This implies that larger improvements in road quality represent a larger financial budget spent improving the road.

In addition to using $\widetilde{B}^L_{p,t}$, we also calculate unweighted proxies for national and provincial road budgets. Further, we construct proxies that normalize $\widetilde{B}^L_{p,t}$ by the total kilometers of roads under that authority in the province. Appendix Table A.1 presents summary statistics on the four different proxies for the provincial budget for national roads and the four different proxies for the provincial budget for provincial roads that we use in our analysis.

Measuring Own and Other-District Characteristics. To measure $\mathbf{w}_{it}$ and $\mathbf{s}_{it}$, we work with several fixed, district-specific characteristics, many of which are mentioned in the allocation formulas described above. Summarized in Appendix Table A.2, these measures can be grouped into four categories: (1) *physical characteristics* (e.g. area, elevation, slope, ruggedness, distance to major cities); (2) *land cover* (cultivated, forest, grass, water coverage, built-up land); (3) *historical population data*; and (4) *road characteristics* (length of different types of roads, changes in elevation along different types of roads, and slopes of different types of roads). We also work with time-varying measures summarized in Appendix Table A.3. These include district-level measures of total fiscal transfers (DAK, DAU, and DBH SDA), as well as the share of households with access to safe sanitation, safe water, and electricity, all measured from the Indonesia Database for Policy and Economic Research (INDO-DAPOER), maintained by the World Bank.

Because we work with multiple proxies for $\overline{B}_t$ and multiple measures of $\mathbf{s}_{it}$, our set of instruments is potentially large, and many of these instruments may be weak on their own. As a result, we use post-double-selection Lasso techniques to select instruments, following Belloni et al. (2012). This approach obtains the efficiency gains from optimal instruments while reducing problems associated with many weak ones.

6 Results

This section presents reduced-form estimates of the impact of road quality on local economic development outcomes and provides evidence on possible causal pathways behind these effects. As a preamble to these results, we first show that changes in our our main measure of district road quality are correlated to perceived changes in travel times between IFLS communities and nearby cities according to survey respondents. Next, we present our main estimates of the impact of local road quality improvements on individual and household-level consumption, income, and employment outcomes. We then examine how road quality affects large manufacturing firms. Finally, we estimate how road quality improvements affect prices.

Road Quality and Perceived Travel Times. To verify that changes in district-level road quality affect survey-based perceptions of travel times from IFLS villages to nearby provincial capital cities, we employ the following regression specification:

$$\log y_{ct} = \alpha_c + \alpha_t + \beta \log \text{Road Quality}_{ct} + \mathbf{x}'_{ct}\theta + \varepsilon_{ct} \ , \tag{9}$$

where α_c denotes a fixed effect for community c, α_t is a year (survey wave) fixed effect, Road Quality$_{ct}$ is our road quality measure for community c's district at time t, $\mathbf{x}_{ct}$ is a vector of time-varying controls, and ε_{ct} is the error term. The dependent variable, y_{ct} measures log travel times derived from IFLS survey data. In the community module of the IFLS, survey enumerators asked community informants questions about typical travel times between their village and the nearest district or provincial capital, and we use their survey responses (in logs) as the outcome variable.[15] Because equation (9) is a log-log specification, the parameter of interest, β, can be interpreted as the elasticity of travel times with respect to road quality.

In Table 1, we report estimates of β from equation (9) for an expanded set of outcomes. In row 1 of Panel A, we report results on travel times to the nearest provincial capital, while in row 2, we consider travel times to the nearest district capital. Column 1 reports fixed effects least squares (FELS) estimates of β, while column 2 reports IV-lasso results using the other-district IVs. The corresponding Kleibergen-Paap Wald Rank F statistic is listed next to column 2. Finally, the last two columns report means of the dependent variables and sample sizes.[16] Robust standard errors, clustered at the community level, are reported in parentheses.

Row 1 of Table 1 shows a least squares elasticity that implies that a 1 percent increase in road quality reduces travel times by 0.18 percent. This elasticity increases to 0.37 in the IV-lasso specification (column 2). The three selected instruments in the IV-lasso specification, reported in Appendix Table A.4, are (1) the provincial road budget interacted with the sum of other districts' populations as measured in the 1971 census; (2) the provincial road budget interacted with the sum of other districts' populations as measured in the 1980 census; and (3) the national road budget interacted with the sum of other districts' shares of national roads with very steep slopes ($> 45°$). In row 2 of Table 1, we show that the estimated effects of road quality on stated travel times to district capitals are negative and of a similar magnitude, but not statistically significant.

In Panel B of Table 1, we run the same regressions but we instead use travel times derived from the road roughness data. To construct these variables, we first selected the provincial (or district) capital that was closest to each IFLS community, based on crow-flies distance. We then calculated travel times between location pairs based on the continuous roughness data, assuming that trips take place using the network of national and provincial roads.[17] We again find that road quality improvements reduce travel times, but the magnitudes of the coefficients are larger. One interpretation is that travel times in the IFLS are noisy and subject to recall bias, attenuating estimates with measurement error.[18]

[15]In the early waves of the IFLS, community informants were mostly village heads. In later waves, local leaders also served as community informants if village heads were not available. These included school principals, health professionals, religious leaders, or local community organizers.

[16]The IVs that were selected in the IV-lasso specifications for all outcomes are reported in Appendix Table A.4.

[17]See Appendix B for more details on the mapping between road roughness and travel speeds.

[18]Another reason for measurement error is that the locations of provincial and district capitals have been changing over time. Until the late 1990s, district boundaries were relatively stable (Booth, 2011). However, because of the decentralization process, many subdistricts split off from their original districts, forming new districts. The number of districts increased from 302 in 1999 to 514 in 2014, through a process known as *pemekaran* or blossoming (Bazzi and Gudgeon, 2021). This may have created new district capitals in our sample and altered travel times. In our main travel time results presented in Table 1, we focus on IFLS villages in districts where provincial capitals did not change, but we find similar results for the full sample of IFLS

Table 1 shows that across specifications, the Kleibergen and Paap (2006) Wald Rank F statistic, a generalization of the first-stage F-statistic for multiple instrumental variables, is large. In Appendix Table A.5, we report more diagnostics tests for these regressions. Both the Kleibergen-Paap LM tests and the Anderson-Rubin (AR) tests strongly reject the null of weak instruments of the endogenous road quality variable. Finally, the Sargan-Hansen J test statistics for overidentifying restrictions are generally small, and we cannot reject the null that the instruments are correctly excluded from the estimation equation. Overall, the results in Appendix Table A.5 point to well-specified IV models.

Because our analysis studies the effects of local road quality improvements on a large set of outcomes, we need to account for multiple hypothesis testing. In all tables, after reporting conventional clustered standard errors, we also report two-stage false-discovery rate (FDR) sharpened q-values in brackets (Benjamini et al., 2006; Anderson, 2008). These q-values represent adjustments to p-values that account for the multiple hypothesis tests we run in each table. The results in Table 1 confirm that the significance of our estimates is robust to multiple testing concerns.

Road Quality and Consumption, Income, and Employment. To study how changes in road quality impacted individual and household outcomes, including consumption, earnings, and employment, we use detailed panel data from the IFLS over 4 survey waves. We estimate household (or individual) fixed effects regressions of the following form:

$$y_{idt} = \alpha_i + \alpha_t + \beta \log \text{Road Quality}_{dt} + \mathbf{x}'_{idt}\theta + \varepsilon_{dt} \ , \tag{10}$$

where α_i denotes a household (or individual) fixed effect and α_t denotes a survey wave fixed effect, as before. Included in $\mathbf{x}_{idt}$ are survey month indicators and controls for household size. In the individual-level regression specifications, we also add time-varying controls for individual age and years of schooling.

In the first row of Table 2, Panel A, we present our estimate of the effect of road quality on log per-capita household consumption expenditures.[19] Column 2 shows that the elasticity of expenditures to road quality is 0.22 and is significant at the 1 percent level. In the next two rows, we examine how road quality impacts household businesses distinguishing between farm and non-farm profits. We report effects on both farm and non-farm profits that are positive and of similar magnitude but not statistically significant. These two results suggest that road quality improves expenditures but the effects are not coming from improvements in own business ventures (either farm or non-farm).

In Panel B, we examine whether increased expenditures are due to changes in labor income. Individual-level fixed effects regressions show that the elasticity of labor earnings with respect to road quality is 0.19, which closely tracks the increase in per capita expenditures from Panel A. In the next set of rows for Panel B, we examine the impact of road quality improvements on hours worked and employment outcomes. We first show that road quality improvements do not have any impact on the probability of being employed (row 5), nor do they affect the total number of hours worked (row 6). However, in the final rows of Table 2, we find significant impacts of road quality on the composition of employment.

villages in Appendix Table A.6.

[19] Appendix Table A.7 reports the selected instrumental variables from the other-district IV-lasso specifications shown in Table 2.

Using the IFLS employment module, we first assign every employed worker into one of three different employment sectors: (1) formal agricultural employment, which includes wage-earning agricultural labor; (2) other formal employment, which includes manufacturing; and (3) informal employment, which includes both informal agricultural employment and also other informal jobs. Rows 7-9 in Table 2 show that improving road quality does not affect agricultural employment (row 7), but we also find that the elasticity of *formal* employment to road quality is 0.10 (row 8). Mirroring this increase in formal employment, we find a similarly-sized reduction in the probability of working in the informal sector (row 9).

Taken together, the findings from Table 2 suggest that the positive consumption benefits and positive total earnings effects of road quality are due to workers moving out of low wage jobs in the informal sector and into higher wage formal-sector employment. Indeed, we find that improved road quality does not affect hours worked (row 3) but it increases total earnings (row 2). These results on sector switching in Indonesia explain one mechanism through which the growth of non-farm factory employment can be a source of wage gains for workers in rural areas, as emphasized by Foster and Rosenzweig (2004) for the case of India. They are also consistent with road quality playing a crucial role in local economic development and structural transformation (Lewis, 1954).

Road Quality and District-Level Manufacturing Outcomes. To what extent are the employment effects of road quality driven by the increased presence of large manufacturing firms? To investigate this, we begin by creating district-year aggregates of the individual firm-level data from the SI. We then use these district-year variables in the following panel regression specification:

$$y_{dt} = \alpha_d + \alpha_t + \beta \log \text{Road Quality}_{dt} + \mathbf{x}'_{dt}\theta + \varepsilon_{dt} \ , \tag{11}$$

where α_d and α_t represent district and year fixed effects respectively, $\log \text{Road Quality}_{dt}$ is the log of district d's average road quality measure in year t, $\mathbf{x}_{dt}$ are time-varying controls, and ε_{dt} is the error term. In estimating equation (11), we report robust standard errors, clustered at the district level.

Columns 1 and 2 of Table 3 show the results of estimating an overall β for an average district. The Kleibergen-Paap Wald Rank F statistics for the overall effects in column 2 are large for all outcomes, suggesting that our IV models are well specified.[20] In Panel A, we focus on how road quality impacts the quantity of large manufacturing firms in the district. From the IV specifications in row 1, we find that the elasticity of firm openings to road quality is 0.6. We also find larger IV estimates of β than FELS estimates. This suggests that naive estimates of treatment effects of the impact of road quality may suffer either from negative targeting bias (e.g. policymakers upgraded roads in less developed areas) or from negative feedback (e.g. faster growing areas had greater road deterioration).

In row 2, we find no evidence that road improvements are associated with changes in firm closures. Finally, in row 3, we show that the elasticity of the number of firms to road quality is 0.13. In summary, the results from Table 3, Panel A show that road quality improvements lead to increases in the number of firms in the district, and this effect is driven by new firms instead of by firm closures.[21]

[20] The IVs that were selected in these other-district IV-lasso specifications are reported in Appendix Table A.9.

[21] Appendix Table A.10 shows estimates of the number of new firms by 2-digit product code. We find that road quality improvements seem to be associated with increases across most industries, but only the effects on food and beverage processors, wood products firms, and ceramic and glass producers are positive and significant.

In Panel B, we study the effect of road improvements on district-level production outcomes. In row 5, the IV specifications show that a 1 percent increase in road quality leads to a 0.5 percent increase in district-level value added. In row 6, we find that a 1 percent increase in road quality leads to a 0.4 percent increase in value added. We also find positive, but somewhat smaller effects of road improvements on the total number of manufacturing workers in large firms in the district. A 1 percent increase in road quality only leads to a 0.2 percent increase in the number of manufacturing workers in the district, closely matching the survey based result. Given this, it is not surprising that we see positive effects on output per worker; a 1 percent increase in road quality leads to a 0.3 percent increase in output per worker at the district level.

Road Quality and Firm-Level Manufacturing Outcomes. One potential explanation for the manufacturing results from Table 3 is that they reflect intensive-margin improvements of existing firms, instead of new firm creation. To investigate this further, we exploit the firm-level identifiers in the SI data that allow us to track how input and production outcomes for existing firms change in response to road improvements. In Table 4, we use our IV strategy to estimate the following firm-level panel regression specification:

$$y_{idt} = \alpha_i + \alpha_t + \beta \log \text{Road Quality}_{dt} + \mathbf{x}'_{dt}\theta + \varepsilon_{dt} \ , \tag{12}$$

where i indexes firms, α_i is a firm fixed effect, and α_t is a year fixed effect. Because we do not observe firms that move in our sample, the firm fixed effect also controls for any time-invariant, district-specific characteristics. We estimate equation (12) using more than 275,000 firm-year observations over the 1990-2007 period. Standard errors are clustered at the district level, as before.

Table 4 shows results on firm-level output (row 1), value added (row 2), total employment (row 3), and output per worker (row 4), mirroring the outcomes listed in Table 3, Panel B.[22] Despite large Kleibergen-Paap Wald Rank F statistics, we find that overall, road improvements had no significant impact on any of the outcomes for existing firms. Taken together with evidence from Table 3, our results suggest that road quality improvements had modest impacts on the extensive margin of firm creation, but they had no significant effects on production or employment outcomes for preexisting firms. This suggests that the sector switching effects of road improvements are most likely due to newly created manufacturing firms.

Road Quality and Prices. To study how road quality improvements affected prices, we use community-level price data derived from the IFLS in the following regression specification:

$$y_{cdt} = \alpha_c + \alpha_t + \beta \log \text{Road Quality}_{dt} + \mathbf{x}'_{cdt}\theta + \varepsilon_{cdt} \ , \tag{13}$$

where c indexes IFLS communities, α_c is a community fixed effect, and α_t is a year fixed effect. Table 5 shows our results. In row 1, we show that local road improvements are associated with positive increases in factory wages, but this effect is not statistically significant. Row 2 shows that the impact on farm wages is slightly negative, but is also not significant.[23]

In rows 3 and 4, we study the effect of local road quality on food prices, an important component of consumer welfare, particularly for lower-income households. The food price measures we use are

[22]The selected instrumental variables used in the specifications of Table 4 are reported in Appendix Table A.11.
[23]The selected instrumental variables used in the specifications of Table 5 are reported in Appendix Table A.12.

Laspeyres price indices composed of perishable goods (including meat and fish) and non-perishable traded foods (including rice, oil, sugar, and salt). We use initial consumption values for expenditure weights. In row 3, we show a significant negative relationship between road quality and perishable prices. A 1 percent increase in road quality leads to a 0.6 percent reduction in perishable food prices. Row 4 shows that road quality has a positive but insignificant impact on the prices of non-perishable goods.

Finally, in the last two rows of the table, we study the relationship between road quality and housing prices, using estimates of log land values and log rents from hedonic specifications. In the first step, we estimate a hedonic price regression of log rents or log land values on a large vector of household and plot characteristics, in addition to controlling for fixed effects at the community-by-wave level.[24] In the second step, we use the estimated community-by-wave fixed effects from the first-step regressions as the dependent variable in rows 5 and 6. We find an elasticity of land value to road quality of 0.79 (significant at the 1 percent level) and an elasticity of rents to road quality of 0.2 (significant at the 10 percent level).[25] This result is as expected for a policy that makes an area more attractive to firms, which bids up the cost of land and housing. In Section 8 below, we take this higher cost of living effect into account when calculating overall welfare effects.

7 Robustness and Mechanisms

In this section, we first demonstrate that our results on the reduced form relationships between road quality and different economic outcomes are robust to different ways to construct instruments. Next, we show that our results are robust to including different controls and to different sample splits. Finally, we investigate several mechanisms that could explain our findings.

Instrument Robustness. Appendix Table A.15 shows that our main results are robust to different ways of constructing instruments. Columns 1 and 2 repeat our baseline FELS and other district IV-lasso estimates. In column 3, to form candidate instruments, we drop the time-varying sums of district characteristics from the set of variables we interact with the national and provincial budgets. This column just uses fixed sums of other district characteristics interacted with the national or provincial budget proxies to form instruments. Results are robust to this change. In column 4, when constructing instruments, we form sums of other district characteristics after dropping the district with the largest population in the province. This deals with the concern that results are being driven by the most important district in the province. The results are practically unchanged. In column 5, we drop adjacent districts from the set of other districts in the province when forming sums. This addresses the concern that nearby district characteristics may be directly influencing a district's outcomes, as opposed to solely through the road budget as our analysis requires. Again, this change leaves estimates unaffected. In column 6, instead of

[24]The hedonic regression we use includes the following controls: (1) indicators for dwelling type; (2) separate indicators for whether the house is surrounded by human or animal waste, piles of trash, or stagnant water; (3) an indicator for whether the house is owned or rented; (4) the number of rooms in the house; (5) indicators for the types of floor, outer walls, and roof; and (6) indicators for electricity access, piped water, type of water used for cooking. Estimates of the hedonic relationships between these variables and rents and land values can be found in in Appendix Table A.13.

[25]We also tried specifications using the community's median land value and median log rent, instead of relying on the hedonic approach. Overall, these specifications produced similar results, which can be found in Appendix Table A.14.

using the sums of other districts' characteristics, we interact the district's own-characteristics with national and provincial budget proxies. This latter approach relies more heavily on the exogeneity of our budget proxies, but it also allows for omitted district characteristics to more directly influence budget shares. Overall, Appendix Table A.15 shows that our main results are unchanged when using any of these different instrumental variables strategies.

Controls and Sample Splits. Next, Appendix Table A.16 shows that our main results are robust to different sample splits, as well as to several different time-varying controls. Columns 1 and 2 report our baseline FELS and IV-lasso estimates of the effects of road quality on our main outcomes. To address concerns that districts' own revenues may be used to finance road maintenance investments, in column 3, we drop districts engaged in any oil and gas production, and in column 4, we drop districts where the share of GDP in the mining sector exceeds 5 percent. Overall, the effects are largely unchanged.

If Indonesia's road improvements were driven by the presence of multinational firms, who might negotiate with local governments to obtain better roads or maintain key roads themselves, then controlling for the presence of FDI should attenuate our effect sizes. In column 5, we return to the full sample of districts, but we add a control for the share of output in the district produced by large foreign-owned manufacturing firms. Introducing this control does little to change significance or effect sizes, suggesting that footloose multinational firms are not responsible for explaining our results.

Next, in column 6-9, we include other time-varying controls, constructed from multiple waves of *Podes* data, to proxy for changes in other infrastructure that may be correlated with road maintenance investments. Column 6 includes a time-varying control for the share of households connected to the national electricity grid (*Perusahaan Listrik Negara*, or PLN). In column 7, we control for the time-varying share of households with access to a national TV signal. Column 8 includes separate, time-varying controls for the number kindergarten, primary, junior secondary, and senior-secondary schools in the district. Column 9 includes time-varying controls for the number of hospitals, the number of community health clinics (*Puskesmas*), and the number of community based preventive and promotive care facilities (*Posyandu*). Finally, to deal with concerns about different allocation rules or formulas after Suharto, in Column 10, we only estimate effects using data from the post-decentralization period (1999-2007). Overall, our results are largely robust to each of these different controls and sample splits.

Mechanisms: Reallocation. One alternative explanation for our findings is that instead of creating new jobs, road improvements could simply reshuffle activity from one district to another. If that were the case, our estimates of the welfare effects of road quality improvements would not be true welfare improvements, but would instead reflect welfare gains in one district coming at the expense of welfare losses elsewhere. To investigate the potential for reallocation to explain our findings, in Appendix Table A.17, we estimate how road quality improvements in district d affect manufacturing outcomes in nearby districts. Column 1 reproduces the baseline IV-lasso estimates of the effects of road quality from Table 3. In panel A, column 2, we regress the number of new firms (row 1), the number of closed firms (row 2), and the percent change in firms (row 3) in districts within 100 km of district d on road quality in that district. Panel B is structured similarly. Overall, we find no evidence for regional reallocation effects. Importantly, we see no evidence that road quality in district d is positively associated with increased firm closures in nearby districts. Although the effects on output, value added, and employment are negative, the point estimates are small and not statistically different from zero. This suggests that the manufacturing results reported in Table 3 reflect new firm creation and not reallocation of existing activities between nearby districts.

Mechanisms: Road Quality or Market Potential? Local road improvements could improve economic outcomes by making a district more productive, but road quality improvements can also increase market access and internal trade. To investigate which of these forces is driving our results, we estimate regressions of the following form:

$$y_{dt} = \alpha_d + \alpha_t + \beta \log \text{Road Quality}_{dt} + \gamma \log \text{OMP}_{dt} + \mathbf{x}'_{dt}\theta + \varepsilon_{dt} \quad , \tag{14}$$

where d indexes a district (or individual) fixed effect, $\log \text{Road Quality}_{dt}$ is defined as above, and $\log \text{OMP}_{dt}$ is the log of outside of province market potential for district d. To construct this, let $\mathcal{I}_d$ denote the set of other districts in district d's island that are outside of district d's province. We define outside-province market potential as follows:

$$\text{OMP}_{dt} = \sum_{j \in \mathcal{I}_d} \frac{Y_{jt}}{\tau_{jdt}} \quad , \tag{15}$$

where τ_{jdt} is the roughness-based travel time between district j and district d in year t and Y_{jt} is district j's real GDRP. As district d grows closer to larger markets on the same island, OMP_{dt} increases.[26]

In Table 6, we produce estimates of β and γ from equation (14) for our key outcome variables. Column 1 reproduces our main IV-lasso estimates of β ignoring the effect of off-province market potential and setting $\gamma = 0$ in equation (14). In Column 2, we report IV-lasso estimates of the effect of off-province island market potential on outcomes, ignoring the impact of local road quality (i.e. setting $\beta = 0$). To estimate these effects, we created a new set of instruments for off-province market potential. These use the budget shares from districts in other provinces on the same island, interacted with own district location characteristics. To weight locations in constructing the instruments, we use (fixed) market potential weights (e.g. GDP in 1990 / physical distance), mirroring how the market potential variable is constructed in equation (15).

Overall, we find similar relationships between instrumented off-province market potential and outcomes as we do for road quality. Market potential increases log total earnings, induces sector switching away from the informal sector and into manufacturing, and stimulates new firm entry and productivity improvements. The Kleibergen-Paap Wald Rank F statistics from the specifications column 2 are also large, suggesting that the IV models for market potential are well specified.

In column 3, we include both local road quality and off-province island market potential in the same regression, allowing both β and γ from equation (14) to be non-zero. Instrumenting both variables reduces the Kleibergen-Paap Wald Rank F statistics substantially, but they are still above 10, suggesting that the model is well specified. Across specifications, we tend to find that local road quality coefficients fall by about a third compared to column 1, but they are still significantly predictive of outcomes conditional on off-province market potential. This suggests that local road quality has independent impacts on local productive amenities and does not operate entirely through trade-related channels.

[26]Note that we only sum over districts outside of district d's province in equation (15) because of collinearity between instruments for own-province market potential and local road quality instruments.

Mechanisms: Migration. In this paper, we have argued that local road quality represents a productive amenity. A simple spatial equilibrium model would suggest that if migration costs are small, firms and workers would move to upgraded locations in response to increases in road quality. Greater in-migration should unambiguously increase land and housing prices, but the impacts on wages depend on the relative shifts of labor demand and labor supply (Rosen, 1979; Roback, 1982).

To assess the extent to which local road quality improvements impacted internal migration, we use census data from 1990 and 2000 to examine how the number of recent migrants at the district-level (i.e. those arriving within the last 5 years) was impacted by changes in road roughness. Our empirical specification is the following:

$$y_d = \alpha_{p(d)} + \beta \Delta \log \text{Road Quality}_d + \mathbf{x}_d' \theta + \varepsilon_d \; , \qquad (16)$$

where y_d is a cross-sectional migration outcome, $\alpha_{p(d)}$ represents a fixed effect for district d's province, $\Delta \log \text{Road Quality}_d$ is the log difference in road quality between 1995 and 2000, and $\mathbf{x}_d$ is a vector of additional controls, including logs of population and GDP in 1990. In this specification, instead of instrumenting road quality in levels, we instrument the change in road quality between 1995 and 2000 with the same IV-lasso strategy as above, but we also incorporate lags of the provincial budget shifters, because we do not observe precisely when people migrate over the previous 5 year period.

The first row of Table 7 shows that districts with improved road quality are associated with a positive rate of population growth, but the effect is not statistically significant.[27] In the next two rows, we regress a district's log total number of recent migrants from different districts and different provinces (in 2000) on the change in road quality between 1995 and 2000. We find that a 1 percent increase in road quality growth leads to a 0.8 percent increase in the number of district migrants and a 0.4 percent increase in the number of province migrants, although the latter effect is not significant.

Despite the positive and statistically significant estimates of the effect of road quality on migration, the effect sizes are quite modest. At the average number of district migrants, a 10 percent increase in road quality would lead to roughly an additional 3,400 district migrants. The average district has a population of roughly 730,000 in 2000, so this increase would represent less than one half of 1 percent of the population. Although these cross-sectional long-difference estimates are less well identified than the panel specifications used in the rest of the paper, they nevertheless provide evidence that road quality improvements lead to positive, statistically significant increases in migration. The fact that the migratory response is small reinforces our choice to focus on non-migrant households when approximating the welfare effects of road improvements in the next section.

In summary, using our IV strategy, we find that the effects of road quality are robust to a number of specification concerns, including using different instruments, different treatment measures, controls for other changes in infrastructure, and different cuts of the sample. We also find that reallocation cannot explain our results, and that the effects of road quality improvements operate not just through trade-related channels, but also due to productive amenity effects. Migratory responses to road quality are positive, as expected, but small in relation to district population.

[27] In Appendix Table A.18, we report the selected IVs for the other-district IV-lasso specifications used in Table 7.

8 Welfare Analysis and Counterfactuals

In this section, we combine the reduced form estimates presented in Section 6 with our welfare decomposition formula, given by equation (2), to provide an overall welfare estimate. In addition, this exercise sheds light on the relative importance of different channels through which road quality affects household welfare. Finally, we use this framework to conduct counterfactual policy exercises.

We begin this section by describing how we calibrate key components of the welfare formula: (1) the share of food, non-food, and housing in the budgets of consumers; and (2) the share of labor income and profits in total household income. We then present our welfare decomposition results. Finally, we discuss our counterfactual simulations.

Expenditure Shares. We use data from the first wave of the IFLS to measure households' expenditure shares on four separate categories of products: (1) housing; (2) perishable foods; (3) non-perishable foods; and (4) non-food consumption goods. Appendix Table A.19 shows estimates of per-capita expenditure shares by quartile of total household expenditure. This table reports relatively low housing expenditure shares, with the lowest quartile of the income distribution (Q1) devoting approximately 11 percent of their total expenditures to housing. As expected, this share falls as households grow wealthier.

Note that 20 percent of households in IFLS-1 did not report owning their home. For those households, we interpret the increase in housing prices associated with road improvements as costly, to the extent that it increases rental payments. However, for homeowners who constitute 80 percent of the sample, a similar increase in housing prices could actually increase welfare, as it could lead to greater borrowing and consumption through housing wealth effects (e.g. Gonzalez-Navarro and Quintana-Domeque, 2016; Paiella and Pistaferri, 2017). In order to provide conservative estimates, in our benchmark calculation we ignore home ownership effects and assume that the increase in housing prices associated with road improvements does not impact welfare for home owners.[28] Because we ignore the potential for housing price increases to positively improve welfare, our estimates are probably a lower bound on the true welfare impact of road quality.

Appendix Table A.20 reports the share of non-housing expenditures on perishable foods, non-perishable goods, and non-food products. The lowest quartile of households in IFLS-1 spent about 10 percent of their non-housing expenditures on perishable goods, 58 percent on non-perishable goods, and about 32 percent on non-food goods. As households grow wealthier, they spend less of their total expenditures on food, and they increase their non-food consumption.

To bring these expenditure shares to the welfare decomposition, equation (2), we set the values of α and $\{\alpha_k\}_{k=1}^{K}$ for each household equal to their expenditure shares, taking values from Appendix Table A.19 and Appendix Table A.20 corresponding to their total expenditure quartile.

Income Shares and Road Quality Elasticities. To further calibrate equation (2), we use initial values of Y equal to the household's total earnings from labor income and self-owned farm and non-farm business profits. These initial values are taken from the IFLS-1 survey in 1993.

Recall from the results described in Table 3 that we found that road quality improvements lead to a small increase in the number of new large manufacturing firms. If those large manufacturing firms

[28] In emerging economies, this sort of housing wealth effect may be attenuated by imperfect access to credit markets, particularly for lower and middle-income earners.

were locally owned, their profits should show up in household income through profits. If not, we ignore their effects on welfare, and this again could cause us to understate the welfare gain from better road quality.[29]

To complete our calibration of equation (2), we use constant average road quality elasticities to measure $\mathcal{E}_{Y_L,A}$, $\mathcal{E}_{\pi,A}$, $\mathcal{E}_{p_H,A}$, and $\mathcal{E}_{p_j,A}$ for $j = 1, ..., J$. In doing so, we assume that the elasticity of road quality with respect to non-perishable food goods is the same as the elasticity of road quality with respect to non-food goods.

Before calculating the welfare elasticity, we need to confront the fact that our estimates of these elasticities are subject to sampling error. To construct confidence intervals that take this sampling error into account, we use a parametric bootstrap procedure, following Horowitz (2001) and Atkin et al. (2018). In each bootstrap, we take a random sample (with replacement) from the 6,567 households in IFLS-1. We redraw each road quality elasticity parameter from a normal distribution, with a mean equal to that elasticity's point estimate and the standard deviation equal to that elasticity's standard error. We repeat this bootstrapping exercise for 1,000 replications.

Results. Table 8 shows the results of calculating equation (2) for the 6,567 households in IFLS-1. Row 1 of the table shows that the elasticity of household welfare with respect to road quality is 0.16 on average. In the decomposition of the different channels in the rows below, we see that the positive average effects on welfare come both through impacts of road quality on wage labor income and on business profits, but there are also small positive effects that owe to lower perishable food prices. Greater housing costs associated with road quality also slightly reduce average welfare, but only for the 20 percent of households that are not home owners. Non-perishables and non-food prices contribute to a rise in the cost of living, but not by enough to swamp the positive effects on labor and business incomes.

Figure 4 plots estimates of the distribution of the welfare effects of road quality for each quartile of the baseline income distribution. We find similar effects across the welfare distribution, although there is some suggestive evidence that road quality improvements benefit higher income households more than lower income households. This is because lower income households have a larger share of housing in their budget, and road quality moderately increases housing costs.

Policy Simulations: Stimulus Effects of Road Upgrades. Finally, we investigate the extent to which road upgrades can act as a cost-effective local stimulus program. We conduct counterfactual simulations for each district, where we suppose that all roads in the district are improved to a minimum IRI of 5.35, which is the median IRI for asphalt roads in the road quality data. We suppose that upgrades take place in period $t = 0$, which is equivalent to the year 1990 in our data.

For each period $t = 0, 1, ..., T$, we calculate the benefit of road upgrades as follows:

$$B_{dt} = 0.158 \times GDP_d \times \%\Delta RQ_{dt}^{CF},$$

where 0.158 is the elasticity of welfare with respect to road quality, from Table 8, GDP_d is district d's GDP in 1990 (converted to 2000 USD), and $\%\Delta RQ_{dt}^{CF}$ is the counterfactual percent change in road quality in

[29] Given that these are large firms, it is probable that they are owned by residents who live elsewhere.

simulation period t:

$$\%\Delta RQ_{dt}^{CF} = \left(\frac{RQ_{dt} - RQ_{d,0}}{RQ_{d,0}} \right) .$$

In the first year ($t = 0$), $\%\Delta RQ_{dt}^{CF}$ is driven purely by upgrading roads in the district. However, in subsequent years, those upgraded roads deteriorate. We estimate road deterioration using a regression of log road roughness on years since upgrading at the kilometer-post-interval level:

$$\log \text{IRI}_{it} = \alpha_i + \alpha_t + \beta \text{Years Since Upgrade}_{it} + \varepsilon_{it} .$$

We estimate this relationship separately for paved and unpaved roads. Results are shown in Appendix Table A.21. We find that each additional year since upgrading increases road roughness for paved roads by 6.3 percent and unpaved road roughness by 12 percent. The log-linear relationship also seems to fit the data well, as shown in the residual-on-residual plots from Appendix Figure A.10. For $t = 1, ..., T$, we simulated the counterfactual change in road quality at the kilometer-post level assuming: (1) no upgrades occur and; (2) roads deteriorate at the fixed rates estimated in Appendix Table A.21. We construct counterfactual average district road quality measures using distance weighted averages of the simulated road quality measures at each kilometer-post interval.

We also assume that it would cost $93,350 per kilometer in 2000 USD to upgrade roads in this way. This cost estimate is taken from the World Bank's Road Costs Knowledge System (ROCKS), used by Collier et al. (2016).[30] It is equal to the average cost of a 60-79 mm asphalt overlay across contracts listed in the ROCKS database for Indonesia.[31]

Using these measures of benefits and costs, we can calculate the net present value of the upgrade as follows:

$$NPV_d = \sum_{t=0}^{s_d} \left(\frac{B_{dt} - C_{dt}}{(1+\beta)^t} \right) ,$$

where B_{dt} is defined above, C_{dt} measures the cost of road upgrades, and β is the discount rate, set at 0.05, and s_d is defined as the largest period for district d where road quality improvements are still positive (i.e. $\%\Delta RQ_{d,s_d}^{CF} > 0$). We assume that the costs of road maintenance are borne entirely in the first period, $t = 0$, so that $C_{dt} = 0$ for $t > 0$. This is consistent with the pervasive use of single-year contracts by Indonesia's Ministry of Public Works and Housing (Ray and Ing, 2016).

Appendix Figure A.11 shows a plot of discounted $B_{dt} - C_{dt}$ against time for district Labuhan Batu in North Sumatra. In the first period, all of the upgrading costs are incurred, and these large costs do not outweigh the one year benefits of the upgrade. However, after one year elapses, the net present value becomes large and positive, increasing to nearly $20 million USD. The cumulative net present value remains positive for 9 years, until road deterioration completely erodes away the benefits of the upgrade.

Figure 5 presents scatterplots of NPV_d across districts in our sample against district road length

[30]The World Bank's Road Costs Knowledge System (ROCKS) is a database of road-related projects completed by the World Bank Group. It is designed as a repository that can be used to calculate the average and range of unit costs based on historical data that could improve the reliability of new cost estimates and reduce the risks generated by cost overruns. The World Bank's Transport Unit last updated the data in 2008.

[31]Note that we are assuming that the upgrading cost is constant for all roads, but in practice, it would vary considerably by geometry and initial surface type.

(Panel A) and district GDP per capita (Panel B). In both plots, we calculate NPV_d is expressed as a percentage of district GDP. The median district upgrading project generates a positive NPV of roughly 6.2 percent of district GDP, and 80 percent of districts had positive NPV projects. Moreover, relative to the cost of upgrades, the median upgrading program would confer benefits equal to 2.8 times their costs. Some districts enjoyed considerably large NPVs relative to their GDPs, particularly urban districts with relatively smaller road lengths and larger values of output per capita. However, 20 percent of districts had negative NPVs; such districts tended to be poorer and have longer road lengths. The median district would also enjoy 6 years of positive stimulus benefits before deterioration erodes road quality back to its initial level, and the interquartile range of benefit length was between 3.5 and 11 years.[32]

9 Conclusion

Even though road maintenance investments typically account for a significant proportion of countries' budgets, little is known about their effects in developing countries, where roads deteriorate rapidly and spatial disparities are particularly pronounced. This paper aims to understand the role that road maintenance investments can play in such countries, not only through looking at welfare effects, but also by investigating the different possible mechanisms through which these effects materialize. While much of the previous literature on this topic has focused on the construction of new roads, we add to the literature by evaluating the effects of substantial changes in road quality due to maintenance and upgrading of existing roads, using data from all national and provincial highways in Indonesia.

Using a novel dataset that documents substantial variation in road quality from 1990 to 2007, and combining this with high quality panel data on households and firms, we provide reduced form evidence that road improvements significantly increase nominal consumption and income. We do not see substantial changes in the extensive or intensive margin of labor supply, but instead observe occupational shifts from informal employment (including agriculture) into higher paying, newly available manufacturing jobs. These employment results are consistent with our analysis of outcomes using data on manufacturing firms, which shows that improved roads generate the entry of new firms in the formal manufacturing sector.

When we combine the reduced form estimates of the effects of road quality on labor income, firm profits, and prices with a simple model to estimate the welfare effects of road improvements, we find that a 10 percent increase in road quality would lead to an increase in welfare of 1.6 percent. This elasticity is about 35 percent lower than what we would have obtained had we ignored general equilibrium cost of living effects.

Under reasonable assumptions about the costs of road upgrades and the speed of deterioration, we use policy simulations to find that for the median district, upgrading national and provincial roads to the average roughness of paved roads would generate a positive NPV of roughly 6.2 percent of district GDP. For the median district, the benefit of improving roads to this standard is 2.8 times the cost.

The methodological contribution of this paper is in addressing the common concerns of targeting bias and reverse causality by proposing a new instrument, replicable in many instances. We take advantage of Indonesia's institutional two-step budgeting framework for road funding, where sub-national author-

[32] A histogram of the number of years of postive NPV across districts is reported in Appendix Figure A.12.

ities are in charge of maintaining roads and funding different parts of the road network. This allows us to construct a time varying instrument for road quality based on allocation formulas. Our instrumental variables strategy identifies effects from the set of roads that get maintained when road budgets allow for it, but which get less maintenance when road budgets are tight or scaled back.

The evidence presented in this paper shows that improving major national and provincial highways can improve local economic development through increasing formal labor market opportunities. Conversely, deterioration of these roads may have adverse effects in the opposite direction. Our analysis suggests that governments should be aware of the impacts of road maintenance investments on household welfare when setting priorities for transportation budgets as well as considering counter-cyclical policy.

References

AGGARWAL, S. (2018): "Do Rural Roads Create Pathways out of Poverty? Evidence from India," *Journal of Development Economics*, 133, 375–395.

AHMAD, E. AND A. M. MANSOOR (2002): *Indonesia: managing decentralization*, International Monetary Fund.

ANDERSON, M. L. (2008): "Multiple inference and gender differences in the effects of early intervention: A reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects," *Journal of the American statistical Association*, 103, 1481–1495.

ASHER, S. AND P. NOVOSAD (2020): "Rural roads and local economic development," *American Economic Review*, 110, 797–823.

ASIA FOUNDATION (2008): "The Cost of Moving Goods: Road Transportation, Regulations and Charges in Indonesia," Survey report.

ASTURIAS, J., M. GARCÍA-SANTANA, AND R. RAMOS (2019): "Competition and the welfare gains from transportation infrastructure: Evidence from the Golden Quadrilateral of India," *Journal of the European Economic Association*, 17, 1881–1940.

ATKIN, D., B. FABER, AND M. GONZALEZ-NAVARRO (2018): "Retail Globalization and Household Welfare: Evidence from Mexico," *Journal of Political Economy*, 126, 1–73.

AUERBACH, A. J. AND Y. GORODNICHENKO (2012): "Measuring the output responses to fiscal policy," *American Economic Journal: Economic Policy*, 4, 1–27.

BANERJEE, A., E. DUFLO, AND N. QIAN (2012): "On the Road: Access to Transportation Infrastructure and Economic Growth in China," Working Paper.

BANK, W. (2007): "Spending for Development: Making the Most of Indonesia's New Opportunities," Tech. rep.

BARDHAN, P. AND C. UDRY (1999): *Development Microeconomics*, Oxford: Oxford University Press.

BAUM-SNOW, N. (2007): "Did Highways Cause Suburbanization?" *Quarterly Journal of Economics*, 122, 775–805.

BAZZI, S. AND M. GUDGEON (2021): "The political boundaries of ethnic divisions," *American Economic Journal: Applied Economics*, 13, 235–66.

BELLONI, A., D. CHEN, V. CHERNOZHUKOV, AND C. HANSEN (2012): "Sparse Models and Methods for Optimal Instruments With an Application to Eminent Domain," *Econometrica*, 80, 2369–2429.

BENJAMIN, D. (1992): "Household Composition, Labor markets, and Labor demand: Testing for Separation in Agricultural Household Models," *Econometrica*, 60, 287–322.

BENJAMINI, Y., A. M. KRIEGER, AND D. YEKUTIELI (2006): "Adaptive linear step-up procedures that control the false discovery rate," *Biometrika*, 93, 491–507.

BENNETT, C. R., A. CHAMORRO, C. CHEN, H. DE SOLMINIHAC, AND G. W. FLINTSCH (2007): "Data Collection Technologies for Road Management," Technical report, East Asia Pacific Transport Unit, World Bank.

BIRD, J. AND S. STRAUB (2020): "The Brasilia experiment: the heterogeneous impact of road access on spatial development in Brazil," *World Development*, 127, 104739.

BIRD, R. M. AND M. SMART (2002): "Intergovernmental fiscal transfers: International lessons for developing countries," *World Development*, 30, 899–912.

BLALOCK, G. AND P. J. GERTLER (2008): "Welfare Gains from Foreign Direct Investment Through Technology Transfer to Local Suppliers," *Journal of International Economics*, 74, 402–421.

BLIMPO, M. P., R. HARDING, AND L. WANTCHEKON (2013): "Public investment in rural infrastructure: Some political economy considerations," *Journal of African Economies*, 22, ii57–ii83.

Bock, M., A. Cardazzi, and B. R. Humphreys (2021): "Where the Rubber Meets the Road: Pavement Damage Reduces Traffic Safety and Speed," NBER Working Paper 29176.

Booth, A. (2003): "Decentralisation and Poverty Alleviation in Indonesia," *Environment and Planning C: Government and Policy*, 21, 181–202.

——— (2011): "Splitting, splitting and splitting again: A brief history of the development of regional government in Indonesia since independence," *Bijdragen tot de taal-, land-en volkenkunde/Journal of the Humanities and Social Sciences of Southeast Asia*, 167, 31–59.

Bryan, G. and M. Morten (2019): "The Aggregate Productivity Effects of Internal Migration: Evidence from Indonesia," *Journal of Political Economy*, 127, 2229–2268.

Burgess, R., R. Jedwab, E. Miguel, A. Morjaria, and G. Padró i Miquel (2015): "The Value of Democracy: Evidence from Road Building in Kenya," *American Economic Review*, 105, 1817–51.

Casaburi, L., R. Glennerster, and T. Suri (2013): "Rural roads and intermediated trade: Regression discontinuity evidence from Sierra Leone," *Available at SSRN 2161643*.

Chandra, A. and E. Thompson (2000): "Does public infrastructure affect economic activity?: Evidence from the rural interstate highway system," *Regional science and urban economics*, 30, 457–490.

Collier, P., M. Kirchberger, and M. Söderbom (2016): "The cost of road infrastructure in low-and middle-income countries," *The World bank economic review*, 30, 522–548.

Cosar, A. K., B. Demir, D. Ghose, and N. Young (2021): "Road Capacity, Domestic Trade and Regional Outcomes," Nber working paper.

Crane, R. (1995): "The practice of regional development in Indonesia: Resolving central-local coordination issues in planning and finance," *Public Administration and Development*, 15, 139–149.

Deaton, A. and J. Muellbauer (1980): "An almost ideal demand system," *The American economic review*, 312–326.

Dick, H. (2000): "Representations of development in 19th and 20th century Indonesia: a transport history perspective," *Bulletin of Indonesian Economic Studies*, 36, 185–207.

Donaldson, D. (2018): "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review*, 108, 899–934.

Donaldson, D. and R. Hornbeck (2016): "Railroads and American Economic Growth: A 'Market Access Approach," *Quarterly Journal of Economics*, 131, 799–858.

Duranton, G. and M. A. Turner (2012): "Urban Growth and Transportation," *The Review of Economic Studies*, 79, 1407–1440.

Egger, D., J. Haushofer, E. Miguel, P. Niehaus, and M. Walker (forthcoming): "General Equilibrium Effects of Cash Transfers: Experimental Evidence from Kenya," *Econometrica*.

Faber, B. (2014): "Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System," *Review of Economic Studies*, 81, 1046–1070.

Fane, G. (2003): "Change and Continuity in Indonesia's New Fiscal Decentralisation Arrangements," *Bulletin of Indonesian Economic Studies*, 39, 159–176.

Foster, A. D. and M. R. Rosenzweig (2004): "Agricultural Productivity Growth, Rural Economic Diversity, and Economic Reforms: India, 1970–2000," *Economic Development and Cultural Change*, 52, 509–542.

Foster, V., A. Rana, and N. Gorgulu (2022): "Understanding Public Spending Trends for Infrastructure in Developing Countries," World Bank Policy Research Working Paper 9903.

GHANI, E., A. G. GOSWAMI, AND W. R. KERR (2016): "Highway to success: The impact of the Golden Quadrilateral project for the location and performance of Indian manufacturing," *The Economic Journal*, 126, 317–357.

GOLLIN, D. AND R. ROGERSON (2014): "Productivity, transport costs and subsistence agriculture," *Journal of Development Economics*, 107, 38–48.

GONZALEZ-NAVARRO, M. AND C. QUINTANA-DOMEQUE (2016): "Paving Streets for the Poor: Experimental Analysis of Infrastructure Effects," *The Review of Economics and Statistics*, 98, 254–267.

GRAMLICH, E. M. (1994): "Infrastructure Investment: A Review Essay," *Journal of Economic Literature*, 32, 1176–1196.

GREEN, K. (2005): "Decentralization and good governance: The case of Indonesia," Working Paper.

HILL, H. (1998): "The challenge of regional development in Indonesia," *Australian Journal of International Affairs*, 52, 19–34.

HOROWITZ, J. L. (2001): "The bootstrap," in *Handbook of econometrics*, Elsevier, vol. 5, 3159–3228.

JACOBY, H. G. (2000): "Access to Markets and the Benefits of Rural Roads," *The Economic Journal*, 110, 713–737.

KHANDKER, S. R., Z. BAKHT, AND G. B. KOOLWAL (2009): "The Poverty Impact of Rural Roads: Evidence from Bangladesh," *Economic Development and Cultural Change*, 57, 685–722.

KHANDKER, S. R. AND G. B. KOOLWAL (2011): "Estimating the long-term impacts of rural roads: a dynamic panel approach," World Bank Policy Research Working Paper 5867.

KLEIBERGEN, F. AND R. PAAP (2006): "Generalized reduced rank tests using the singular value decomposition," *Journal of Econometrics*, 133, 97–126.

LA PORTA, R. AND A. SHLEIFER (2014): "Informality and Development," *Journal of Economic Perspectives*, 28, 109–26.

LEDUC, S. AND D. WILSON (2013): "Roads to prosperity or bridges to nowhere? Theory and evidence on the impact of public infrastructure investment," *NBER Macroeconomics Annual*, 27, 89–142.

——— (2014): "Infrastructure Spending as Fiscal Stimulus: Assessing the Evidence," *Review of Economics and Institutions*, 5, 24.

LEEPER, E. M., T. B. WALKER, AND S.-C. S. YANG (2010): "Government investment and fiscal stimulus," *Journal of monetary Economics*, 57, 1000–1012.

LEIGLAND, J. (1993): "Decentralizing the Development Budget Process in Indonesia: Progress and Prospects," *Public Budgeting & Finance*, 13, 85–101.

LEWIS, B. D. (2001): "The new Indonesian equalisation transfer," *Bulletin of Indonesian Economic Studies*, 37, 325–343.

——— (2010): "Indonesian decentralization: Accountability deferred," *International Journal of Public Administration*, 33, 648–657.

——— (2017): "Does local government proliferation improve public service delivery? Evidence from Indonesia," *Journal of Urban Affairs*, 39, 1047–1065.

LEWIS, B. D. AND J. CHAKERI (2004): "Central Development Spending in the Regions Post-Decentralisation," *Bulletin of Indonesian Economic Studies*, 40, 379–394.

LEWIS, B. D. AND A. OOSTERMAN (2009): "The Impact of Decentralization on Subnational Government Fiscal Slack in Indonesia," *Public Budgeting & Finance*, 29, 27–47.

——— (2011): "Sub-National Government Capital Spending in Indonesia: Level, Structure, and Financing," *Public administration and development*, 31, 149–158.

LEWIS, W. A. (1954): "Economic Development with Unlimited Supplies of Labour," *The Manchester School*, 22, 139–191.

MICHAELS, G. (2008): "The Effect of Trade on the Demand for Skill: Evidence from the Interstate Highway System," *The Review of Economics and Statistics*, 90, 683–701.

MORTEN, M. AND J. OLIVERIA (2018): "The Effects of Roads on Trade and Migration: Evidence from a Planned Capital City," NBER Working Paper 22158.

OLKEN, B. A. (2007): "Monitoring Corruption: Evidence from a Field Experiment in Indonesia," *Journal of Political Economy*, 115, 200–249.

PAIELLA, M. AND L. PISTAFERRI (2017): "Decomposing the wealth effect on consumption," *Review of Economics and Statistics*, 99, 710–721.

RAY, D. AND L. Y. ING (2016): "Survey of Recent Developments: Addressing Indonesia's Infrastructure Deficit," *Bulletin of Indonesian Economic Studies*, 52, 1–25.

ROBACK, J. (1982): "Wages, Rents, and the Quality of Life," *Journal of Political Economy*, 90, 1257–1278.

ROSEN, S. (1979): "Wage-Based Indexes of Urban Quality of Life," in *Current Issues in Urban Economics*, ed. by P. Mieszkowski and M. Straszheim, Johns Hopkins University Press.

SAYERS, M. W. AND S. M. KARAMIHAS (1998): "The Little Book of Profiling: Basic Information about Measuring and Interpreting Road Profiles," Tech. rep., University of Michigan, Ann Arbor, Transportation Research Institute.

SHAH, A., Z. QURESHI, B. BINDER, AND H.-F. ZOU (1994): "Intergovernmental fiscal relations in Indonesia," World bank discussion paper.

SINGH, I., L. SQUIRE, AND J. STRAUSS (1986): *Agricultural Household Models: Extensions, Applications, and Policy*, Baltimore: Johns Hopkins University Press.

STOREYGARD, A. (2016): "Farther on Down the Road: Transport Costs, Trade and Urban Growth in sub-Saharan Africa," *The Review of Economic Studies*, 83, 1263–1295.

TEMPLE, J. (2005): "Dual economy models: A primer for growth economists," *The Manchester School*, 73, 435–478.

VALDIVIA, M. (2011): "Contracting the road to development: early impacts of a rural roads program," *Poverty and Economic Policy Network PMMA Working Paper*.

WORLD BANK (1994): *World development report 1994: Infrastructure for development*, The World Bank.

——— (2008): *Spending for Development: Making the Most of Indonesia's New Opportunities*, World Bank.

——— (2012): *Investing in Indonesia's roads: improving efficiency and closing the financing gap*.

YU, J., E. CHOU, AND J. YAU (2006): "Development of Speed-Related Ride Quality Thresholds using International Roughness Index," *Transportation Research Record*, 1974, 47–53.

Table 1: Road Quality and Travel Times

	FELS	Other District IV-Lasso		Stats	
Panel A: IFLS Travel Times	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log Travel Time to Nearest Provincial Capital	-0.178** (0.073)	-0.371*** (0.128) [0.03]	82.966	169.363	856
Log Travel Time to Nearest District Capital	-0.106 (0.143)	-0.440 (0.293) [0.06]	79.564	46.664	834
Panel B: Roughness-Based Travel Times					
Log Travel Time to Nearest Provincial Capital	-0.464*** (0.030)	-0.962*** (0.084) [0.00]	126.425	73.002	888
Log Travel Time to Nearest District Capital	-0.465*** (0.043)	-0.792*** (0.106) [0.00]	126.425	21.305	888
Year FE	Yes	Yes			
Village FE	Yes	Yes			

Notes: We report the results of community-level panel regressions of the dependent variable on road quality (both in logs). Each cell reports β from a separate regression, with the dependent variable listed in the row heading. Panel A uses measures of travel times derived from the IFLS survey responses, while Panel B uses measures of travel times derived from the road roughness network data. To construct these roughness-based travel times, we use the mapping between roughness and speed reported in Appendix B. All regressions include community and year fixed effects. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. Dependent variable means are reported in levels. Robust standard errors, clustered at the community level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 2: Effects of Road Quality on Consumption, Income, and Employment

	FELS	Other District IV-Lasso		Stats	
Panel A: Household-Level Outcomes	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log HH Per-Capita Consumption Expenditures	0.127*** (0.041)	0.217*** (0.082) [0.04]	107.391	11.498	22036
Log Farm Enterprise Profits	-0.912 (0.687)	0.091 (1.019) [0.78]	160.033	11.139	6793
Log Non-Farm Profits	-0.181 (0.540)	0.903 (0.945) [0.39]	98.423	12.205	4381
Panel B: Individual-Level Outcomes					
Log Total Earnings	0.074** (0.032)	0.192*** (0.050) [0.01]	84.406	1.438	17619
Any Employment (0 1)?	-0.025 (0.021)	-0.032 (0.037) [0.39]	141.783	0.701	36257
Log Total Hours Worked	-0.006 (0.037)	-0.092 (0.074) [0.30]	89.103	199.077	22931
Agriculture ... Working (0 1)?	-0.059*** (0.018)	-0.001 (0.045) [0.78]	89.388	0.418	22934
Manu / Other Formal ... Working (0 1)?	0.086*** (0.022)	0.097** (0.048) [0.10]	89.388	0.563	22934
Other, Informal ... Working (0 1)?	-0.091*** (0.022)	-0.151*** (0.046) [0.02]	89.388	0.465	22934
Year FE	Yes	Yes			
Individual FE	Yes	Yes			

Notes: In Panel A, we report the results of household-level panel regressions with household and year fixed effects, while in Panel B, we report the results of individual-level panel regressions with individual and year fixed effects. Each cell reports estimates of β from a separate regression, with the dependent variable listed in the row heading. For Panel A, controls include household size and month of survey indicators. The farm and non-farm profit variables are only defined for households that reported profits, and we first winsorize these variables to account for outliers. In Panel B, we additionally control for individual age and years of schooling. Total hours worked and the working-by-sector indicators are defined only if the individual reported working. The log total earnings regression also includes total hours worked as a control. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. Robust standard errors, clustered at the village level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 3: Road Quality and District-Level Manufacturing Outcomes

	FELS	Other District IV-Lasso		Stats	
Panel A: Firm Counts	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log Number of Opened Firms	0.067 (0.061)	0.606*** (0.130) [0.00]	74.541	6.074	3383
Log Number of Closed Firms	-0.022 (0.072)	-0.070 (0.187) [0.11]	76.260	6.113	3184
Percent Δ Number of Firms	0.008 (0.021)	0.125*** (0.043) [0.03]	75.064	-0.032	3339
Panel B: Production					
Log Output	0.189 (0.147)	0.544** (0.237) [0.05]	74.541	1590.341	3383
Log Value Added	0.138 (0.141)	0.451* (0.237) [0.07]	74.541	575.124	3383
Log Total Employment	-0.147* (0.081)	0.239** (0.118) [0.06]	74.541	13725.216	3383
Log Output per Worker	0.311*** (0.087)	0.320** (0.134) [0.05]	71.842	0.081	3234
Year FE	Yes	Yes			
District FE	Yes	Yes			

Notes: We report the results of district-level panel regressions of the dependent variable on road quality. Each cell reports β from a separate regression, with the dependent variable listed in the row heading. All regressions include district and year fixed effects. Robust standard errors, clustered at the district level, are reported in parentheses. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 4: Road Quality and Firm-Level Manufacturing Outcomes

	FELS	Other District IV-Lasso		Stats	
Panel A: Firm Counts	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log Output	-0.043 (0.044)	0.018 (0.076) [1.00]	36.232	19.936	278475
Log Value Added	-0.068 (0.051)	0.051 (0.080) [1.00]	36.201	7.371	278409
Log Total Labor	-0.008 (0.012)	-0.016 (0.022) [1.00]	36.220	164.244	278580
Log Output per Worker	-0.034 (0.042)	0.002 (0.077) [1.00]	36.225	0.073	278325
Year FE	Yes	Yes			
District FE	Yes	Yes			
Firm FE	Yes	Yes			

Notes: We report the results of firm-level panel regressions of the dependent variable on road quality. Each cell reports β from a separate regression, with the dependent variable listed in the row heading. All regressions include firm and year fixed effects (and implicitly also district fixed effects). Robust standard errors, clustered at the district level, are reported in parentheses. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 5: Road Quality and Community Prices

	FELS	Other District IV-Lasso		Stats	
	(1)	**(2)**	**KBP**	$\overline{Y}$	N
Log Factory Wage	-0.041 (0.177)	0.407 (0.386) [0.30]	25.724	3842.123	226
Log Farm Wage	0.052 (0.113)	-0.063 (0.171) [0.58]	128.085	3766.165	339
Log Perishables Price	-0.321*** (0.078)	-0.580*** (0.133) [0.05]	70.020	76.494	914
Log Non-Perishables Price	0.049 (0.075)	0.164 (0.126) [0.30]	96.970	135.355	923
Log Land Value (Hedonic FE)	0.393*** (0.133)	0.786*** (0.270) [0.09]	149.001	3790.753	579
Log Rent (Hedonic FE)	0.140** (0.061)	0.200* (0.105) [0.18]	140.148	3838.634	901
Year FE	Yes	Yes			
Village FE	Yes	Yes			

Notes: We report the results of community-level panel regressions of the dependent variable on road quality (both in logs). Each cell reports β from a separate regression, with the dependent variable listed in the row heading. Log Farm Wage is not available in 1993. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. Robust standard errors, clustered at the community level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 6: Effects of Local Road Quality and Market Potential

	IV-Lasso		
Panel A: Log Total Earnings	**(1)**	**(2)**	**(3)**
Log Road Quality	0.192		0.117
	(0.050)***		(0.059)**
Log Island Market Potential (Off Province)		0.504	0.080
		(0.138)***	(0.110)
N	17619	17619	17619
Kleibergen-Paap Wald Rank *F* Stat	84.41	203.87	29.38
Panel B: Working in Agriculture (0 1)			
Log Road Quality	-0.001		-0.019
	(0.045)		(0.051)
Log Island Market Potential (Off Province)		-0.023	0.004
		(0.087)	(0.101)
N	22934	22934	22934
Kleibergen-Paap Wald Rank *F* Stat	89.39	96.82	22.81
Panel C: Working in Manu / Other Formal (0 1)			
Log Road Quality	0.097		0.070
	(0.048)**		(0.046)
Log Island Market Potential (Off Province)		0.473	0.166
		(0.113)***	(0.094)*
N	22934	22934	22934
Kleibergen-Paap Wald Rank *F* Stat	89.39	96.82	22.81
Panel D: Working in Other Informal (0 1)			
Log Road Quality	-0.151		-0.105
	(0.046)***		(0.044)**
Log Island Market Potential (Off Province)		-0.363	-0.100
		(0.113)***	(0.087)
N	22934	22934	22934
Kleibergen-Paap Wald Rank *F* Stat	89.39	96.82	22.81
Panel E: Log Number of New Firms			
Log Road Quality	0.606		0.492
	(0.130)***		(0.198)**
Log Island Market Potential (Off Province)		1.640	0.458
		(0.389)***	(0.570)
N	3383	3349	3349
Kleibergen-Paap Wald Rank *F* Stat	74.54	104.07	20.56
Panel F: Log Output Per Worker			
Log Road Quality	0.320		0.774
	(0.134)**		(0.365)**
Log Island Market Potential (Off Province)		1.372	-1.833
		(0.597)**	(1.385)
N	3234	3200	3200
Kleibergen-Paap Wald Rank *F* Stat	71.84	109.00	12.55
Year FE	Yes	Yes	Yes
Cross-Section FE	Yes	Yes	Yes
Instrumenting Road Quality	Yes	Yes	Yes
Instrumenting Market Potential	Yes	Yes	Yes

Notes: We report the results of community-level panel regressions of the dependent variable on road quality and off province island market potential (both in logs). All regressions include year fixed effects and cross-sectional fixed effects (household FE in Panel A; individual FE in panel B, C, and D; and district FE in panels E and F). Cluster robust standard errors are reported in parentheses, with community-level clustering in Panels A-D and district-level clustering in Panels E and F. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table 7: Road Quality and District-Level Migration Outcomes

	FELS	Other District IV-Lasso		Stats	
	(1)	(2)	KBP	$\overline{Y}$	N
Percent Δ Population (2000-1990)	0.054 (0.037)	0.270 (0.177) [0.17]	38.981	0.137	198
Log Total Recent Migrants (Kabu)	0.427** (0.167)	0.792** (0.332) [0.09]	32.503	43514.102	198
Log Total Recent Migrants (Prov)	0.208 (0.281)	0.414 (0.392) [0.25]	32.503	20453.100	198
Province FE	Yes	Yes			

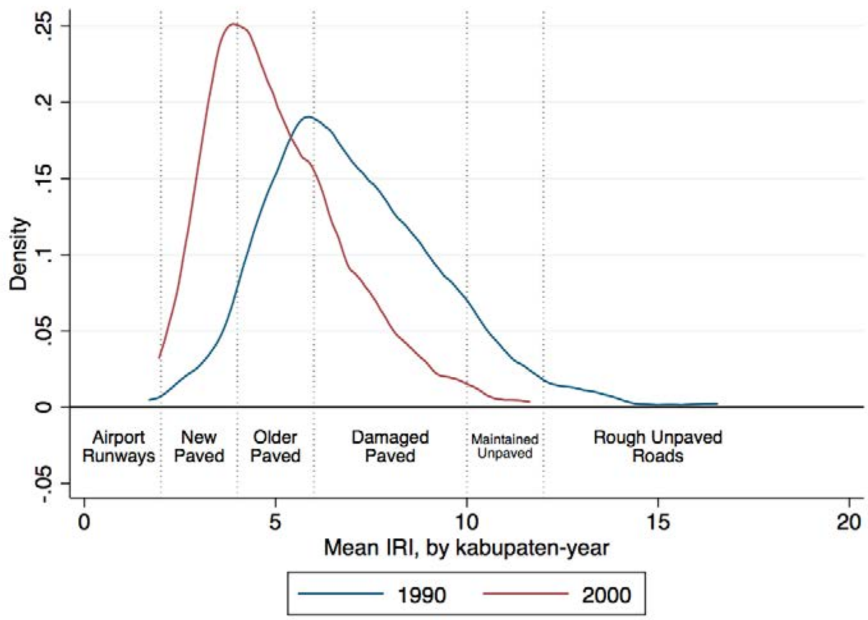
Notes: We report the results of cross-sectional regressions of the dependent variable on changes in road roughness. Each cell reports estimates of β from a separate regression, with the dependent variable listed in the row heading. All regressions include province fixed effects. For the percent change in population regression, we control for 1990 non-oil GDRP (in logs). For the migration regressions, we also include controls for the logs of 1990 population. Robust standard errors, clustered at the province level, are reported in parentheses. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. */**/*** denotes significant at the 10% / 5% / 1% levels. Two-stage false-discovery rate (FDR) sharpened q-values are reported in brackets below the standard errors (Benjamini et al., 2006; Anderson, 2008).

Table 8: Local Household Welfare Effect: Decomposition

	Mean	95% C.I.	Share Negative
Overall Δ Welfare	0.158	[-0.308, 0.620]	0.262
Wage Income from Labor Effect	0.121	[0.069, 0.174]	0.000
Total Farm and Non-farm Business Profit Effect	0.122	[-0.299, 0.584]	0.157
Housing Prices Effect	-0.004	[-0.007, -0.001]	0.198
Perishable Food Prices Effect	0.055	[0.034, 0.076]	0.000
Non-Perishable Food Prices Effect	-0.074	[-0.167, 0.019]	0.912
Non-Food Prices Effect	-0.062	[-0.139, 0.015]	0.912

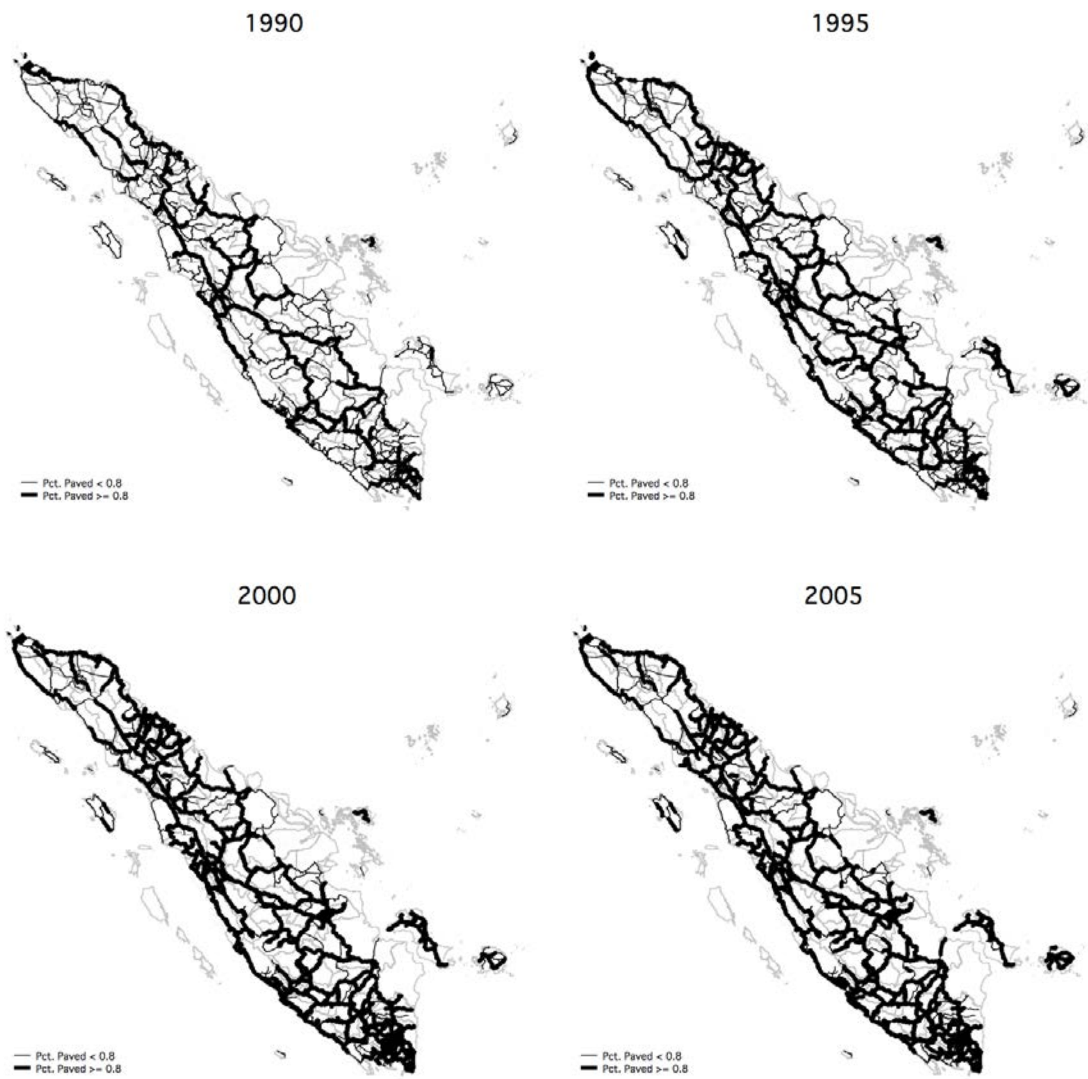
Notes: This table reports a decomposition of the estimated elasticity of road quality to welfare, based on equation (2). To construct confidence intervals, we use a parametric bootstrap procedure (Horowitz, 2001). In each bootstrap, we take a random sample (with replacement) from the 6,567 households in the IFLS-1, and we redraw each road quality elasticity parameter from a normal distribution, with a mean equal to that elasticity's point estimate and the standard deviation equal to that elasticity's standard error. We repeat this bootstrapping exercise for 1,000 replications.

Figure 1: Changes in the Distribution of Road Roughness



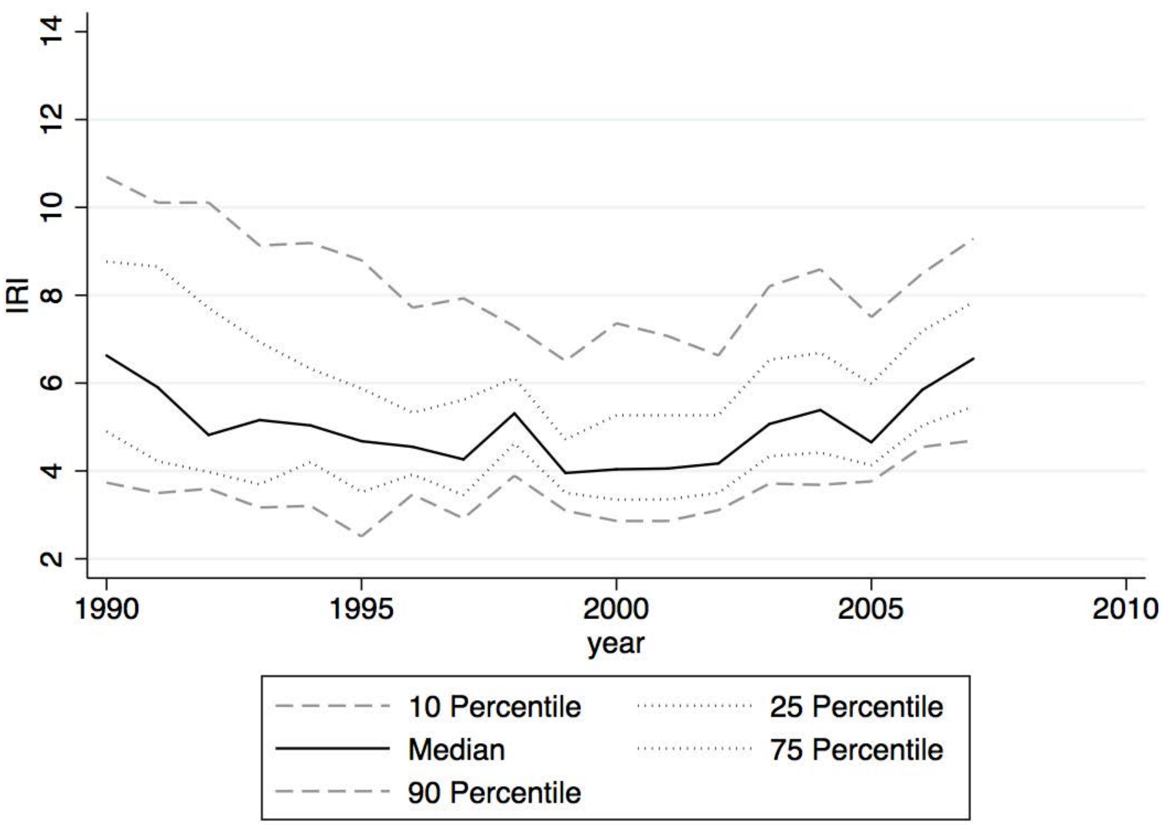
Notes: Authors' calculations using IRMS data. The mapping between IRI and pavement quality classifications is from Sayers and Karamihas (1998).

Figure 2: Evolution of Paved Surfaces on Sumatra's Road Network



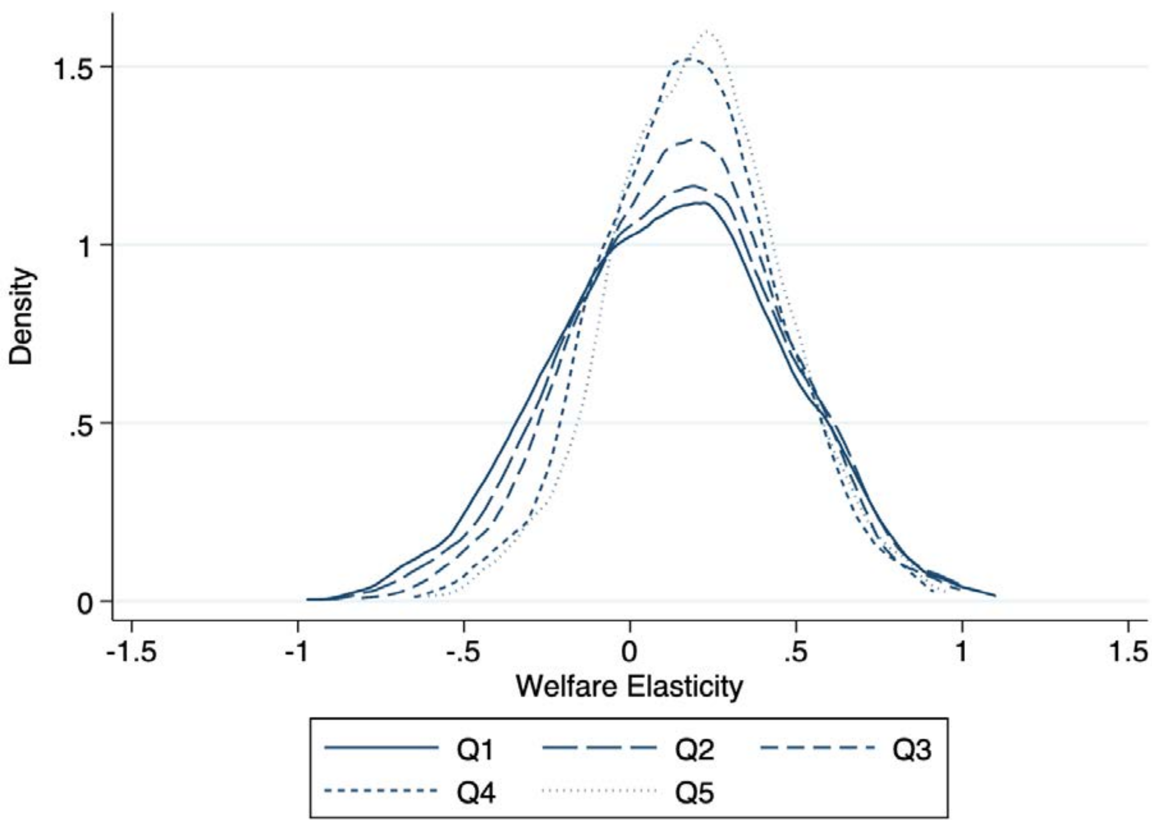
Notes: Authors' calculations using IRMS data. Thick black lines correspond to road sections that are 80 percent paved or greater, while thin black lines correspond to road sections that are less than 80 percent paved.

Figure 3: Changes in the Distribution of Road Roughness



Notes: Authors' calculations using IRMS data.

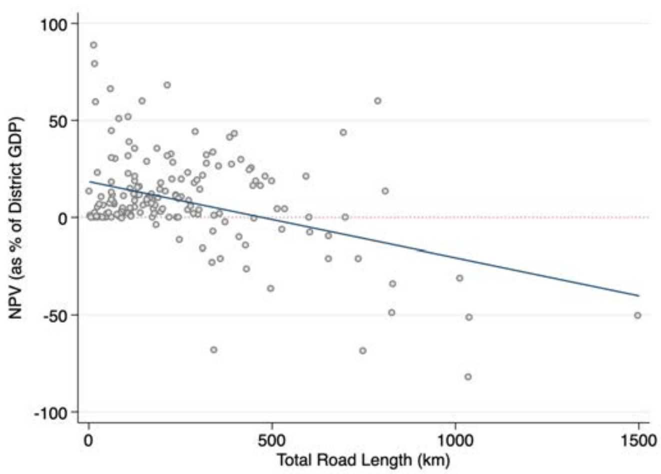
Figure 4: Distribution of Welfare Gains: By Initial Income Quartile Districts



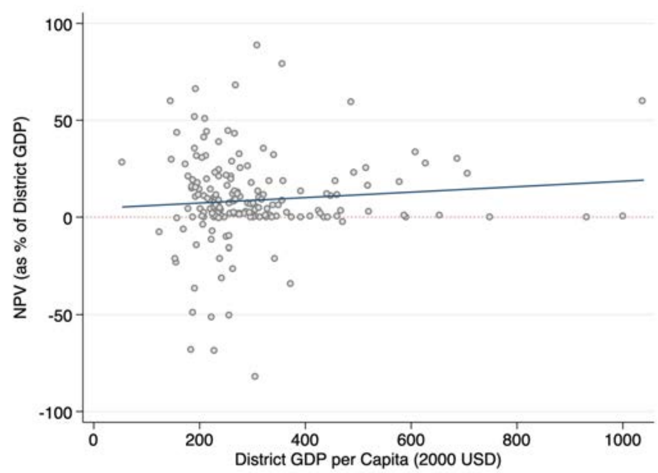
Notes: This figure reports kernel density estimates of the distribution of welfare effects of road quality improvements across households, based on equation (2). The data are based on 1,000 bootstrap replications, following (Horowitz, 2001). Separate kernel density estimates are made for each quantile of the distribution of total household expenditures. Q1 denotes the lowest expenditure quantile, while Q5 denotes the highest expenditure quantile.

Figure 5: Scatterplots of the Net Present Value of District Road Upgrades

PANEL A: NPV VS. ROAD LENGTH



PANEL B: NPV VS. DIST. GDP PER CAPITA



Notes: This figure presents scatterplots of the net present value of a counterfactual district road upgrading program (as a percentage of district GDP in 1990) against the total road length in the district (Panel A) and district GDP per capita in 1990 (Panel B).

Online Appendix

Gertler, P., Gonzalez-Navarro, M., Gračner, T. and Rothenberg, A. (2022): "Road Maintenance and Local Economic Development: Evidence from Indonesia's Highways"

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A Additional Tables and Figures

Table A.1: Summary Statistics: Budget Proxies

Panel A: National Roads	**Varname**	**Mean**	**Sd**	**N**
1. KM Upgraded (N, Province)	`kmUpgrade_N_prov`	380.95	464.08	5117
5. KM Upgraded (N, Province, Weighted)	`WTkmUpgrade_N_prov`	419.66	676.70	5117
3. Share KM Upgraded (N, Province)	`shareKmUpgrade_N_prov`	0.28	0.31	5117
7. Share KM Upgraded (N, Province, Weighted)	`shareWTkmUpgrade_N_prov`	0.31	0.49	5117
Panel B: Provincial Roads	**Varname**	**Mean**	**Sd**	**N**
2. KM Upgraded (P, Province)	`kmUpgrade_P_prov`	366.42	460.26	5117
6. KM Upgraded (P, Province, Weighted)	`WTkmUpgrade_P_prov`	602.69	949.61	5117
4. Share KM Upgraded (P, Province)	`shareKmUpgrade_P_prov`	0.24	0.27	5117
8. Share KM Upgraded (P, Province, Weighted)	`shareWTkmUpgrade_P_prov`	0.39	0.59	5117

Notes: Authors' calculations, from IRMS data. Weighted variables are weighted by the yearly change in road roughness.

Table A.2: Summary Statistics: Cross-Sectional Covariates

Panel A: Physical Characteristics	**Varname**	**Mean**	**Sd**	**N**
Log Area (sq meters)	`area`	7.39	1.76	279
Elevation (in meters), Source: HWSD	`elevation`	303.11	269.36	279
Percentage of Land with 0 <= slope < 0.5, Source: HWSD	`slope1`	0.05	0.05	279
Percentage of Land with 0.5 <= slope < 2, Source: HWSD	`slope2`	0.24	0.20	279
Percentage of Land with 2 <= slope < 5, Source: HWSD	`slope3`	0.21	0.11	279
Percentage of Land with 5 <= slope < 10, Source: HWSD	`slope4`	0.14	0.08	279
Percentage of Land with 10 <= slope < 15, Source: HWSD	`slope5`	0.08	0.05	279
Percentage of Land with 15 <= slope < 30, Source: HWSD	`slope6`	0.15	0.12	279
Percentage of Land with 30 <= slope < 45, Source: HWSD	`slope7`	0.08	0.07	279
Percentage of Land with slope >= 45, Source: HWSD	`slope8`	0.04	0.05	279
Average 30 arc-second Vector Ruggedness Measure (VRM)	`rugged3`	0.00	0.00	279
Log Avg Distance to Major Cities	`d_majorcities`	4.28	0.94	279
Log Avg Distance to Jakarta	`d_jakarta`	6.49	1.02	279
Log Avg Distance to Major Ports	`d_majorports`	4.28	0.82	279
Panel B: Land Cover	**Varname**	**Mean**	**Sd**	**N**
Cultivated land (percent); Source: HWSD	`cult_2000`	0.32	0.17	279
Forest land (percent), Source: HWSD	`for_2000`	0.28	0.19	279
Grass / scrub / woodland (percent), Source: HWSD	`grs_2000`	0.18	0.09	279
Barren / sparsely vegetated (percent), Source: HWSD	`nvg_2000`	0.00	0.00	279
Built-up land (percent), Source: HWSD	`urb_2000`	0.11	0.16	279
Water coverage (percent), Source: HWSD	`wat_2000`	0.03	0.07	279
Panel C: Census Data	**Varname**	**Mean**	**Sd**	**N**
Population in 1971 (millions), Census Data	`pop1971`	0.35	0.39	301
Population in 1980 (millions), Census Data	`pop1980`	0.43	0.49	301
Population in 1990 (millions), Census Data	`pop1990`	0.63	0.56	284
Population in 2000 (millions), Census Data	`pop2000`	0.72	0.66	284
Log GRDP at Current Prices ex. oil and gas, 1990	`gdrp_conp_nonoil_1990`	13.04	0.98	282
Panel D: Road Characteristics	**Varname**	**Mean**	**Sd**	**N**
Total Length of National Roads	`tot_length_N`	77.49	83.78	205
Average elevation (meters), National Roads	`rd_elev_N`	181.80	248.82	205
Absolute Change in Elevation, National Roads	`rd_elev_change_N`	31.42	41.15	205
Percent of National Roads w/ 0 <= slope < 0.5	`rd_slope1_N`	0.07	0.06	205
Percent of National Roads w/ 0.5 <= slope < 2	`rd_slope2_N`	0.38	0.21	205
Percent of National Roads w/ 2 <= slope < 5	`rd_slope3_N`	0.28	0.12	205
Percent of National Roads w/ 5 <= slope < 10	`rd_slope4_N`	0.13	0.10	205
Percent of National Roads w/ 10 <= slope < 15	`rd_slope5_N`	0.05	0.05	205
Percent of National Roads w/ 15 <= slope < 30	`rd_slope6_N`	0.06	0.08	205
Percent of National Roads w/ 30 <= slope < 45	`rd_slope7_N`	0.02	0.04	205
Percent of National Roads w/ slope >= 45	`rd_slope8_N`	0.01	0.04	205
Total Length of Provincial Roads	`tot_length_P`	93.05	103.63	205
Average elevation (meters), Provincial Roads	`rd_elev_P`	265.18	269.25	205
Absolute Change in Elevation, Provincial Roads	`rd_elev_change_P`	60.11	57.04	205
Percent of Provincial Roads w/ 0 <= slope < 0.5	`rd_slope1_P`	0.04	0.04	205
Percent of Provincial Roads w/ 0.5 <= slope < 2	`rd_slope2_P`	0.29	0.19	205
Percent of Provincial Roads w/ 2 <= slope < 5	`rd_slope3_P`	0.26	0.12	205
Percent of Provincial Roads w/ 5 <= slope < 10	`rd_slope4_P`	0.16	0.10	205
Percent of Provincial Roads w/ 10 <= slope < 15	`rd_slope5_P`	0.08	0.06	205
Percent of Provincial Roads w/ 15 <= slope < 30	`rd_slope6_P`	0.10	0.10	205
Percent of Provincial Roads w/ 30 <= slope < 45	`rd_slope7_P`	0.04	0.05	205
Percent of Provincial Roads w/ slope >= 45	`rd_slope8_P`	0.02	0.04	205

Notes: Authors' calculations, with data sources listed in the row headers. IRMS data were used to construct variables in Panel D.

Table A.3: Summary Statistics: Time-Varying Covariates

Panel A: District-Level Variables	Varname	Mean	Sd	N	First Year	Last Year
Log Total DAK (IDR Billion)	dak_total	2.33	1.24	4088	1994	2007
Log Total DBH SDA (IDR)	dbh_total	19.07	5.89	4088	1994	2007
Log Total DAU (IDR)	dau_total	23.84	5.36	4088	1994	2007
% of HH w/ Access to Safe Sanitation	hhSanitation	65.78	41.26	3504	1996	2007
% of HH w/ Access to Safe Water	hhSafeWater	50.98	29.18	3504	1996	2007
% of HH w/ Access to Electricity	hhElectricity	82.51	51.24	3504	1996	2007
Panel B: Province-Level Variables	**Varname**	**Mean**	**Sd**	**N**	**First Year**	**Last Year**
Log Total DAK (IDR Billion)	dak_total_prov	2.33	2.10	4088	1994	2007
Log Total DBH SDA (IDR)	dbh_total_prov	22.40	4.98	4088	1994	2007
Log Total DAU (IDR)	dau_total_prov	25.59	3.38	4088	1994	2007
% of HH w/ Access to Safe Sanitation	hhSanitation_prov	61.18	22.27	3504	1996	2007
% of HH w/ Access to Safe Water	hhSafeWater_prov	48.33	18.81	3504	1996	2007
% of HH w/ Access to Electricity	hhElectricity_prov	79.65	41.26	3504	1996	2007

Notes: Authors' calculations from INDO-DAPOER data.

Table A.4: Selected IVs for Table 1: Travel Times and Road Quality

			Other District IVs	
Panel A: IFLS Travel Times	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Log Travel Time to Nearest Provincial Capital	ttime_provC	448	3	s_pop1971_4 s_pop1980_7 s_rd_slope8_N_2
Log Travel Time to Nearest District Capital	ttime_kabuC	448	3	s_pop1971_4 s_pop1980_7 s_rd_slope8_N_2
Panel B: Roughness-Based Travel Times	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Log Travel Time to Nearest Provincial Capital	travTimeProvC	448	2	s_pop1971_4 s_rd_slope8_N_2
Log Travel Time to Nearest District Capital	travTimeCity	448	2	s_pop1971_4 s_rd_slope8_N_2

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.5: Road Quality and Travel Times to Nearest Provincial Capital

	DV: Log Travel Time to Prov. Capital (IFLS)		DV: Log Travel Time to Dist. Capital (IFLS)		DV: Log Travel Time to Prov. Capital (Roughness-Based)		DV: Log Travel Time to Dist. Capital (Roughness-Based)	
	FELS	**IV-Lasso**	**FELS**	**IV-Lasso**	**FELS**	**IV-Lasso**	**FELS**	**IV-Lasso**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Log Road Quality	-0.178**	-0.371***	-0.106	-0.440	-0.464***	-0.962***	-0.465***	-0.792***
	(0.073)	(0.128)	(0.143)	(0.293)	(0.030)	(0.084)	(0.043)	(0.106)
N	856	856	834	834	888	888	888	888
N Clusters	223	223	219	219	223	223	223	223
Adjusted R^2	0.899	0.900	0.741	0.741	0.991	0.990	0.953	0.950
Adjusted R^2 (within)	0.020	0.041	0.011	0.021	0.743	0.717	0.454	0.428
Kleibergen-Paap (KBP) Wald Rank F Stat		83.0		79.6		126.4		126.4
Under Id. Test (KP Rank LM Stat)		78.0		72.9		79.6		79.6
... p-Value		0.00		0.00		0.00		0.00
AR Wald Test (Weak IV Robust Inf.)		3.3		1.2		152.1		29.8
... p-Value		0.02		0.30		0.00		0.00
Sargan-Hansen J Test		1.3		1.3		7.4		0.1
... p-Value		0.51		0.51		0.01		0.73
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Community FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: We report the results of community-level panel regressions of different travel time measures to provincial and district capitals on road quality (both in logs). All regressions include community and year fixed effects. Robust standard errors, clustered at the community level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.6: Road Quality and Travel Times: All IFLS Villages

	FELS	Other District IV-Lasso		Stats	
Panel A: IFLS Travel Times	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log Travel Time to Nearest Provincial Capital	-0.197***	-0.338***	84.407	172.334	872
	(0.072)	(0.129)			
		[0.04]			
Log Travel Time to Nearest District Capital	-0.086	-0.337	64.017	46.241	850
	(0.139)	(0.274)			
		[0.09]			
Panel B: Roughness-Based Travel Times					
Log Travel Time to Nearest Provincial Capital	-0.458***	-0.933***	130.209	75.217	904
	(0.031)	(0.085)			
		[0.00]			
Log Travel Time to Nearest District Capital	-0.478***	-0.800***	130.209	21.272	904
	(0.047)	(0.106)			
		[0.00]			
Year FE	Yes	Yes			
Village FE	Yes	Yes			

Notes: We report the results of community-level panel regressions of the dependent variable on road quality (both in logs). This table is identical to Table 1 except that now we include all IFLS villages, instead of restricting the sample to only villages in districts with provincial capitals that did not change. Each cell reports β from a separate regression, with the dependent variable listed in the row heading. All regressions include community and year fixed effects. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. Robust standard errors, clustered at the community level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.7: Selected IVs for Table 2: Effects of Road Quality on Consumption, Income, and Employment

			Other-District IVs	
Panel A: Household-Level Outcomes	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Log HH Per-Capita Consumption Expenditures	lnpce_defl	448	3	s_pop1971_4 s_rd_slope8_N_2 s_rd_slope8_N_5
Log Farm Profits	lfarm_profit2	448	1	s_pop1971_4
Log Non-Farm Profits	lnonfarm_profit2	448	3	s_pop1971_4 s_pop1971_7 s_rd_slope8_N_5
Panel B: Individual-Level Outcomes	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Log Total Earnings	l2salary2f2	448	3	s_pop1971_4 s_pop1990_7 s_rd_slope8_N_2
Any Employment (0 1)?	working	448	2	s_pop1971_4 s_rd_slope8_N_2
Log Total Hours Worked	whrs_mth_n	448	2	s_pop1971_4 s_pop1971_7
Agriculture ... Working (0 1)?	working_agri	448	2	s_pop1971_4 s_pop1980_7
Manu / Other Formal ... Working (0 1)?	working_manuOthFor	448	2	s_pop1971_4 s_pop1980_7
Other, Informal ... Working (0 1)?	working_otherInformal	448	2	s_pop1971_4 s_pop1980_7

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.8: Effects of Road Quality on Consumption, Income, and Employment: Non-Movers

	FELS	Other District IV-Lasso		Stats	
Panel A: Household-Level Outcomes	**(1)**	**(2)**	**KBP**	$\overline{Y}$	N
Log HH Per-Capita Consumption Expenditures	0.116***	0.181**	143.952	11.050	20281
	(0.042)	(0.088)			
Log Farm Profits	-0.911	-0.005	153.833	11.314	6517
	(0.699)	(1.023)			
Log Non-Farm Profits	-0.053	0.900	90.469	12.179	4046
	(0.583)	(1.025)			
Panel B: Individual-Level Outcomes					
Log Total Earnings	0.061*	0.174***	79.569	1.417	16368
	(0.033)	(0.051)			
Log Total Hours Worked	0.005	-0.117	85.268	198.245	21312
	(0.039)	(0.075)			
Any Employment (0 1)?	-0.035	-0.055	91.895	0.704	33418
	(0.022)	(0.038)			
Agriculture ... Any Employment (0 1)?	-0.063***	-0.007	85.332	0.428	21315
	(0.019)	(0.046)			
Manufacturing / Other Formal ... Any Employment (0 1)?	0.080***	0.091*	85.332	0.957	21315
	(0.023)	(0.049)			
Other, Informal ... Any Employment (0 1)?	-0.087***	-0.157***	85.332	0.472	21315
	(0.023)	(0.046)			
Year FE	Yes	Yes			
Individual FE	Yes	Yes			

Note: We report the results of individual-level panel regressions with individual and survey-wave fixed effects. This table is identical to Table 2 except that we only estimate effects on non-moving individuals and households. Robust standard errors, clustered at the village level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.9: Selected IVs for Table 3: Road Quality and District-Level Manufacturing Outcomes

			Other-District IVs	
Panel A: Firm Counts	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Any Firms (0 1)	anyFirms	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Log Number of Opened Firms	logOpen	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Log Number of Closed Firms	logClose	448	6	s_pop1990_4 s_wat_2000_4 s_rd_slope3_N_4 s_tot_length_N_4 s_dak_total_4 s_dak_total_prov_4
Percent Δ Number of Firms	pctDeltaFirms	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Panel B: Production	**Variable**	**# Total**	**# Sel.**	**Selected IVs**
Log Output	logOutput	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Log Value Added	logValAdded	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Log Total Employment	logNumWorkers	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4
Log Output per Worker	logOutputPerWorker	448	6	s_pop1990_4 s_wat_2000_4 s_slope2_4 s_rd_slope3_P_4 s_dak_total_4 s_dak_total_prov_4

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.10: Effects of Road Quality on Log Number of Opened Firms, by Industry

	IV-Lasso **(1)**
Log Number of Opened Firms	0.606***
	(0.130)
... 31. Food and Beverages	0.213*
	(0.122)
... 32. Textiles	0.090
	(0.084)
... 33. Wood Products	0.157*
	(0.082)
... 34. Paper Products	0.027
	(0.025)
... 35. Chemical Products	0.017
	(0.051)
... 36. Ceramics & Glass	0.106*
	(0.059)
... 38. Metal & Machines	0.017
	(0.058)
... 39. Other Products	-0.057*
	(0.032)
Year FE	Yes
District FE	Yes

Note: This table reports the coefficients from regressions of the number of opened firms, by industry, on road quality (both in logs). The first row replicates the specification from Table 3, row 1, but we report effects separately by 2-digit industry in subsequent rows. All regressions include district and year fixed effects. Robust standard errors, clustered at the district level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.11: Selected IVs for Table 4: Firm-Level Manufacturing

			Other-District IVs	
	Variable	**# Total**	**# Sel.**	**Selected IVs**
Log Output	logOutput		3	s_pop1990_4 s_dak_total_4 s_dak_total_prov_8
Log Value Added	logValAdded		3	s_pop1990_4 s_dak_total_4 s_dak_total_prov_8
Log Total Labor	ln_L		3	s_pop1990_4 s_dak_total_4 s_dak_total_prov_8
Log Output per Worker	logOutputPerWorker		3	s_pop1990_4 s_dak_total_4 s_dak_total_prov_8

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.12: Selected IVs for Table 5: Prices and Road Quality

	DepVar	# Total	# Sel.	Other-District Selected IVs
Log Factory Wage	lwage_factd	448	2	s_pop1971_4 s_pop1990_4
Log Farm Wage	lwage_farmd	448	1	s_pop1971_4
Log Perishables Price	lL_perish1d	448	4	s_pop1971_4 s_pop1980_7 s_rd_slope8_N_2 s_rd_slope8_N_5
Log Non-Perishables Price	lL_nonperish1d	448	3	s_pop1971_4 s_pop1980_7 s_rd_slope8_N_5
Log Land Value (Hedonic FE)	log_land_value_FE	448	1	s_pop1971_4
Log Rent (Hedonic FE)	log_rent_FE	448	2	s_pop1971_4 s_rd_slope8_N_2

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.13: Hedonic Regressions

	DV: Log Rent	DV: Log Land Value
	(1)	(2)
Type of dwelling: Single Unit, Single Level	0.077**	-0.010
	(0.033)	(0.092)
Type of dwelling: Single Unit, Multi Level	0.179***	0.070
	(0.033)	(0.103)
Type of dwelling: Duplex	0.111***	0.098
	(0.036)	(0.107)
Type of dwelling: Multi Unit, Single Level	0.112***	0.026
	(0.037)	(0.142)
House is surrounded by human and animal waste	0.015	-0.052
	(0.017)	(0.033)
House is surrounded by piles of trash	0.012	-0.017
	(0.015)	(0.030)
House is surrounded by stagnant water	-0.027*	-0.008
	(0.015)	(0.036)
There is a stable under / next to house	-0.017	0.049*
	(0.012)	(0.025)
House has sufficient ventilation	0.023**	0.066**
	(0.011)	(0.028)
Owned house	0.064***	0.043
	(0.012)	(0.047)
House rented/contracted	-0.083***	0.029
	(0.019)	(0.147)
Yard is moderately sized	0.037***	0.108***
	(0.010)	(0.025)
Room number in the house	-0.063***	0.080***
	(0.003)	(0.006)
Ceramic floor	0.210***	0.264***
	(0.022)	(0.064)
Tiled floor	0.093***	0.244***
	(0.021)	(0.052)
Cement floor	0.013	0.156***
	(0.017)	(0.046)
Lumber floor	0.009	0.147**
	(0.028)	(0.062)
Bamboo floor	-0.040	0.247**
	(0.049)	(0.118)
Masonry outer wall	0.166***	0.203***
	(0.018)	(0.045)
Lumber outer wall	0.048**	0.177***
	(0.019)	(0.043)
Concrete roof	0.183***	0.176
	(0.061)	(0.257)
Wooden roof	0.107**	0.059
	(0.048)	(0.110)
Metal roof	0.054*	0.054
	(0.028)	(0.065)
Tiled roof	0.095***	-0.021
	(0.029)	(0.067)
Asbestos roof	0.104***	-0.227*
	(0.037)	(0.120)
Electricity in the house	0.083***	0.132***
	(0.020)	(0.045)
Piped water used for cooking	-0.007	-0.053
	(0.024)	(0.091)
Pump/Well water used for cooking	-0.069***	0.107
	(0.023)	(0.079)
Well/Spring/Rain water used for cooking	-0.133***	0.055
	(0.024)	(0.072)
River water used for cooking	-0.079**	-0.132
	(0.039)	(0.091)
Purchased water used for cooking	-0.064	-0.038
	(0.105)	(0.317)
Inside water source	0.027**	0.077**
	(0.011)	(0.030)
Own toilet	0.085***	0.094***
	(0.012)	(0.028)
Drainage ditch (flowing)	0.044***	0.041
	(0.010)	(0.026)
Drainage ditch (stagnant)	-0.008	-0.000
	(0.018)	(0.036)
Trash collected by sanitation service	0.071***	
	(0.016)	
N	25567	9671
Regression F-Stat	30.731	16.256
Adj. R^2	0.399	0.308
Adj. R^2 (Within)	0.057	0.078
Community × Wave FE	Yes	Yes

Note: All regressions include community × survey wave fixed effects. Robust standard errors, clustered at the village level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.14: Road Quality and Community Prices: Median Values vs. Hedonic Estimates

	FELS	Other District IV-Lasso		Stats	
	(1)	(2)	KBP	$\overline{Y}$	N
Log Land Value (Hedonic FE)	0.393***	0.786***	149.001	3790.753	579
	(0.133)	(0.270)			
Log Rent (Hedonic FE)	0.140**	0.200*	140.148	3838.634	901
	(0.061)	(0.105)			
Median Log Land Value	0.471**	0.679**	123.346	3856.951	751
	(0.196)	(0.308)			
Median Log Rent	0.097	0.165	97.286	3852.859	922
	(0.072)	(0.119)			
Year FE	Yes	Yes			
Village FE	Yes	Yes			

Notes: We report the results of community-level panel regressions of the dependent variable on road quality (both in logs). Each cell reports β from a separate regression, with the dependent variable listed in the row heading. Dependent variable means are reported in levels. The "KBP" column reports the Kleibergen and Paap (2006) Wald Rank F statistic. Robust standard errors, clustered at the community level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.15: Effects of Road Quality: Instrument Robustness

		Other District IV-Lasso				
	FELS	Baseline	Drop Time Varying	Drop Max Pop	Drop Adjacent	Own District IV-Lasso
Panel A: Roughness-Based Travel Times	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Log Travel Time to Nearest Provincial Capital	-0.464***	-0.962***	-0.962***	-0.961***	-0.956***	-1.093***
	(0.030)	(0.084)	(0.084)	(0.084)	(0.089)	(0.095)
N	888	888	888	888	888	888
Kleibergen-Paap (KBP) Wald Rank F Stat		126.43	126.43	124.38	109.90	32.29
Panel B: Household-Level Outcomes						
Log HH Per-Capita Consumption Expenditures	0.127***	0.217***	0.217***	0.241***	0.194**	-0.075
	(0.041)	(0.082)	(0.082)	(0.080)	(0.083)	(0.103)
N	22,036	22,036	22,036	22,036	22,036	22,036
Kleibergen-Paap (KBP) Wald Rank F Stat		107.39	107.39	162.90	133.08	75.70
Panel C: Individual-Level Employment Outcomes						
Agriculture ... Working (0 1)?	-0.059***	-0.001	-0.014	-0.015	0.018	-0.033
	(0.018)	(0.045)	(0.041)	(0.042)	(0.046)	(0.041)
N	22,934	22,934	22,934	22,934	22,925	22,934
Kleibergen-Paap (KBP) Wald Rank F Stat		89.39	94.87	93.47	150.40	37.07
Manu / Other Formal ... Working (0 1)?	0.086***	0.097**	0.118***	0.118***	0.079	0.175***
	(0.022)	(0.048)	(0.043)	(0.043)	(0.049)	(0.054)
N	22,934	22,934	22,934	22,934	22,925	22,934
Kleibergen-Paap (KBP) Wald Rank F Stat		89.39	94.87	93.47	150.40	37.07
Other, Informal ... Working (0 1)?	-0.091***	-0.151***	-0.155***	-0.156***	-0.132***	-0.194***
	(0.022)	(0.046)	(0.040)	(0.041)	(0.046)	(0.051)
N	22,934	22,934	22,934	22,934	22,925	22,934
Kleibergen-Paap (KBP) Wald Rank F Stat		89.39	94.87	93.47	150.40	37.07
Panel D: District-Level Manufacturing Outcomes						
Log Number of Opened Firms	0.067	0.606***	0.627***	0.605***	0.652***	0.584***
	(0.061)	(0.130)	(0.141)	(0.130)	(0.134)	(0.136)
N	3,383	3,383	3,383	3,383	3,383	3,383
Kleibergen-Paap (KBP) Wald Rank F Stat		74.54	96.28	74.34	57.55	89.61
Log Output per Worker	0.311***	0.320**	0.302*	0.326**	0.311**	0.383***
	(0.087)	(0.134)	(0.157)	(0.135)	(0.140)	(0.126)
N	3,234	3,234	3,234	3,234	3,234	3,234
Kleibergen-Paap (KBP) Wald Rank F Stat		71.84	87.98	71.29	57.26	89.01
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Cross-Section FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: We report the results of panel regressions of different dependent variables on road quality (both in logs). All regressions include year fixed effects and cross-sectional fixed effects (community FE in Panel A; household FE in Panel B; individual FE in Panel C; and district FE in panels D). Cluster robust standard errors are reported in parentheses, with community-level clustering in Panels A, B, and C and district-level clustering in Panel D. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.16: Effects of Road Quality: Robustness to Controls and Sample Splits

		IV-Lasso								
	FELS	**Baseline**	**No Oil / Gas**	**No Mining**	**FDI**	**PLN**	**TV**	**Schools**	**Health Facil.**	**Only 1998+**
Panel A: Roughness-Based Travel Times	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Log Travel Time to Nearest Provincial Capital	-0.464***	-0.962***	-0.965***	-0.955***	-1.014***	-0.944***	-0.971***	-0.948***	-1.004***	-1.078***
	(0.030)	(0.084)	(0.087)	(0.088)	(0.089)	(0.083)	(0.086)	(0.082)	(0.088)	(0.103)
N	888	888	744	820	888	888	888	888	888	446
Kleibergen-Paap Wald Rank *F* Stat		126.43	79.83	118.24	118.18	117.61	114.78	125.90	117.39	44.39
Panel B: Household-Level Outcomes										
Log HH Per-Capita Consumption Expenditures	0.127***	0.217***	0.313***	0.367***	0.215**	0.270***	0.215**	0.218***	0.227***	0.374***
	(0.041)	(0.082)	(0.085)	(0.084)	(0.084)	(0.082)	(0.088)	(0.080)	(0.087)	(0.094)
N	22036	22036	18243	19970	22036	22036	22036	22036	22036	11726
Kleibergen-Paap Wald Rank *F* Stat		107.39	99.36	105.81	104.04	94.74	92.98	110.41	91.88	104.85
Panel C: Individual-Level Employment Outcomes										
Agriculture ... Any Employment (0 1)?	-0.059***	-0.001	-0.036	-0.013	0.004	0.010	0.007	-0.000	0.002	0.065
	(0.018)	(0.045)	(0.046)	(0.045)	(0.047)	(0.045)	(0.046)	(0.045)	(0.047)	(0.069)
N	22934	22934	19132	20711	22934	22934	22934	22934	22934	10502
Kleibergen-Paap Wald Rank *F* Stat		89.39	88.83	84.36	87.41	80.67	85.17	89.86	81.34	45.34
Manu. / Other Formal ... Any Employment (0 1)?	0.086***	0.097**	0.111**	0.113**	0.089*	0.107**	0.090*	0.099**	0.093*	0.080
	(0.022)	(0.048)	(0.047)	(0.046)	(0.050)	(0.048)	(0.050)	(0.048)	(0.050)	(0.061)
N	22934	22934	19132	20711	22934	22934	22934	22934	22934	10502
Kleibergen-Paap Wald Rank *F* Stat		89.39	88.83	84.36	87.41	80.67	85.17	89.86	81.34	45.34
Other, Informal ... Any Employment (0 1)?	-0.091***	-0.151***	-0.158***	-0.156***	-0.144***	-0.164***	-0.148***	-0.153***	-0.158***	-0.077
	(0.022)	(0.046)	(0.044)	(0.042)	(0.047)	(0.047)	(0.048)	(0.046)	(0.049)	(0.057)
N	22934	22934	19132	20711	22934	22934	22934	22934	22934	10502
Kleibergen-Paap Wald Rank *F* Stat		89.39	88.83	84.36	87.41	80.67	85.17	89.86	81.34	45.34
Panel D: District-Level Manufacturing Outcomes										
Log Number of Opened Firms	0.067	0.606***	0.671***	0.660***	0.608***	0.625***	0.614***	0.574***	0.610***	0.923***
	(0.061)	(0.130)	(0.152)	(0.139)	(0.130)	(0.133)	(0.136)	(0.130)	(0.132)	(0.349)
N	3383	3383	2805	2822	3383	3379	3379	3379	3379	1791
Kleibergen-Paap Wald Rank *F* Stat		74.54	65.51	69.23	75.93	67.74	67.31	72.76	75.50	136.91
Log Output per Worker	0.311***	0.320**	0.321**	0.306**	0.288**	0.323**	0.322**	0.286**	0.321**	0.196
	(0.087)	(0.134)	(0.155)	(0.148)	(0.131)	(0.135)	(0.135)	(0.134)	(0.133)	(0.323)
N	3234	3234	2659	2676	3234	3232	3232	3232	3232	1742
Kleibergen-Paap Wald Rank *F* Stat		71.84	62.97	66.77	73.42	65.20	64.81	70.03	72.93	77.82
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cross-Section FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: We report the results of panel regressions of different dependent variables on road quality (both in logs). All regressions include year fixed effects and cross-sectional fixed effects (community FE in Panel A; household FE in Panel B; individual FE in Panel C; and district FE in panels D). Cluster robust standard errors are reported in parentheses, with community-level clustering in Panels A, B, and C and district-level clustering in Panel D. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.17: Road Quality and District-Level Manufacturing Outcomes: Nearby Districts

	Other District IV-Lasso	
	Local	$d \leq 100$
Panel A: Firm Counts	**(1)**	**(2)**
Log Number of Opened Firms	0.606***	0.151
	(0.130)	(0.355)
Log Number of Closed Firms	-0.070	-0.623
	(0.187)	(0.521)
Percent Δ Number of Firms	0.125***	0.027*
	(0.043)	(0.015)
Panel B: Production		
Log Output	0.544**	-0.106
	(0.237)	(0.281)
Log Value Added	0.451*	-0.196
	(0.237)	(0.294)
Log Total Employment	0.239**	-0.011
	(0.118)	(0.076)
Log Output per Worker	0.320**	-0.060
	(0.134)	(0.251)
Year FE	Yes	Yes
District FE	Yes	Yes

Notes: We report the results of district-level panel regressions of the dependent variable on road quality. Column 1 replicates the results from Table 3, while column 2 defines outcomes based on firm counts and production for all districts within 100 km of the given district. All regressions include district and year fixed effects. Robust standard errors, clustered at the district level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Table A.18: Selected IVs for Table 7: Road Quality and District-Level Migration Outcomes

			Other-District IVs	
	DepVar	**# Total**	**# Sel.**	**Selected IVs**
Percent Δ Population (2000-1990)	pctPopDelta	564	1	s_area_9
Log Total Recent Migrants (Kabu)	log_migTotal	564	1	s_area_9
Log Total Recent Migrants (Prov)	log_migTotal_prov	564	1	s_area_9

Notes: The selected variable names are listed in Appendix Table A.2 and Appendix Table A.3, interacted with the 2000-1995 change in the budget proxy listed in Appendix Table A.1 with the corresponding number from that table.

Table A.19: Estimating the Housing Expenditure Share

	Actual Rent			Imputed Rent		
Expenditure Quartile	**Mean**	**Median**	N	**Mean**	**Median**	N
1	0.116	0.092	526	0.119	0.088	5287
2	0.108	0.088	666	0.095	0.071	5872
3	0.097	0.081	733	0.091	0.061	6025
4	0.089	0.071	872	0.092	0.059	6030
5	0.080	0.057	734	0.124	0.065	6240

Notes: Authors' calculations, using IFLS-1 data.

Table A.20: Expenditure Shares of Non-Housing Consumption

	Mean			Median			
Expenditure Quartile	**Perishable**	**Non-Perishable**	**Non-Food**	**Perishable**	**Non-Perishable**	**Non-Food**	N
1	0.102	0.579	0.319	0.083	0.591	0.294	1392
2	0.106	0.545	0.349	0.093	0.551	0.331	1438
3	0.117	0.505	0.378	0.106	0.511	0.364	1439
4	0.112	0.455	0.433	0.105	0.450	0.424	1440
5	0.096	0.350	0.553	0.082	0.331	0.569	1442

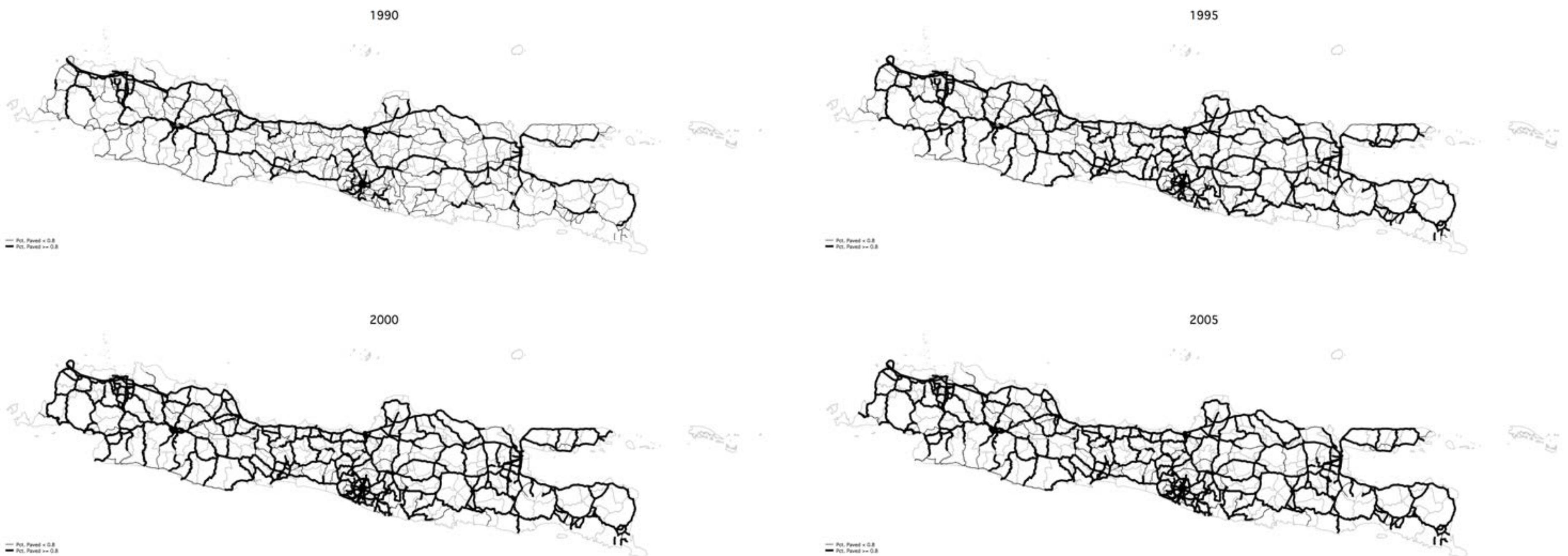
Notes: Authors' calculations, using IFLS-1 data.

Table A.21: Estimating Road Deterioration Profiles

	Unpaved Roads	**Paved Roads**
	(1)	**(2)**
Years Since Last Upgrade	0.120	0.063
	(0.002)***	(0.000)***
N	51,198	743,569
Adjusted R^2	0.67	0.66
F Statistic	454.8	3496.1
Road Segment FE	Yes	Yes
Year FE	Yes	Yes

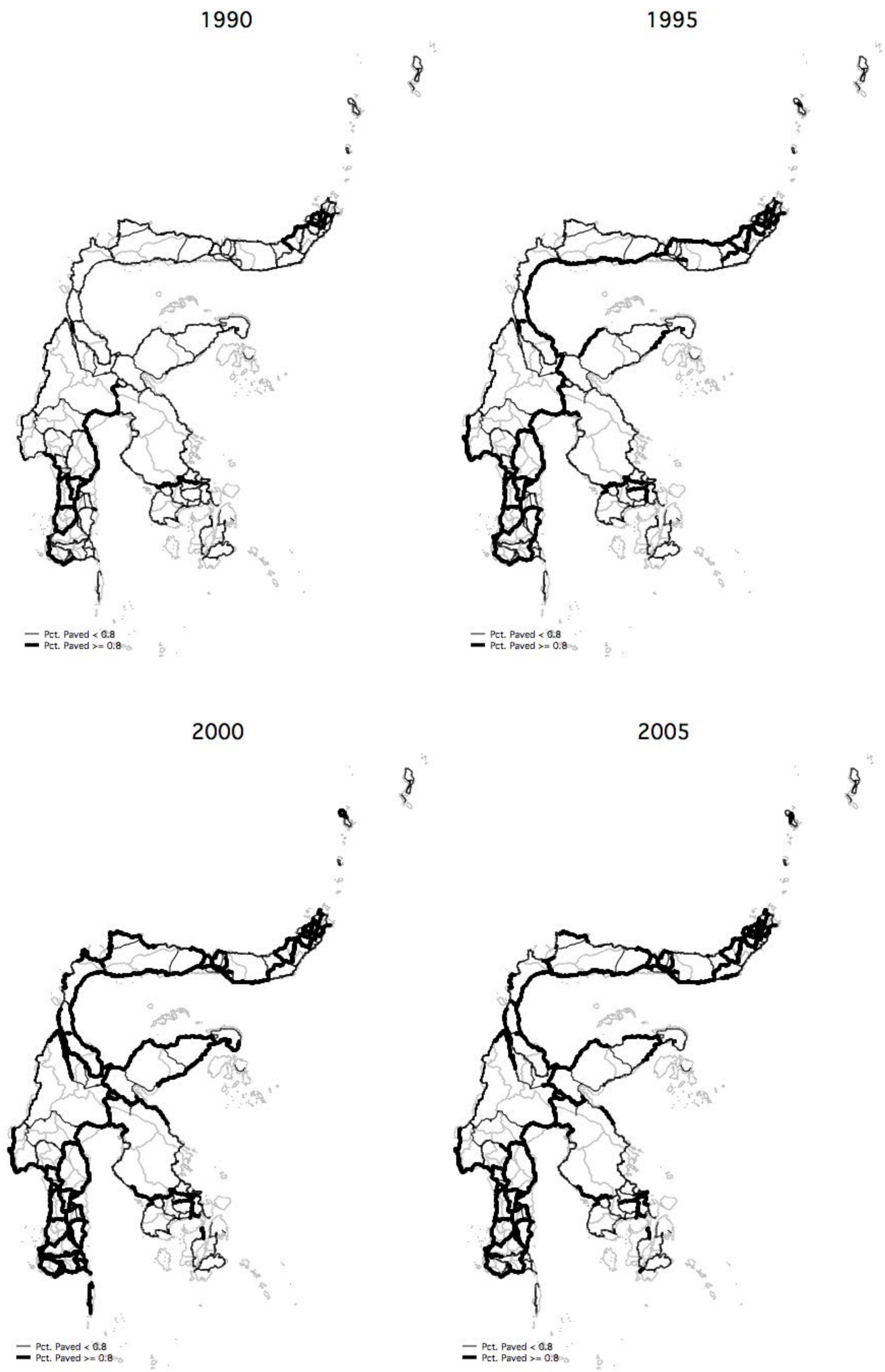
Notes: Robust standard errors, clustered at the road segment level, are reported in parentheses. */**/*** denotes significant at the 10% / 5% / 1% levels.

Figure A.1: Evolution of Paved Surfaces on Java's Road Network



Notes: Authors' calculations using IRMS data. Thick black lines correspond to road sections that are 80 percent paved or greater, while thin black lines correspond to road sections that are less than 80 percent paved.

Figure A.2: Evolution of Paved Surfaces on Sulawesi's Road Network

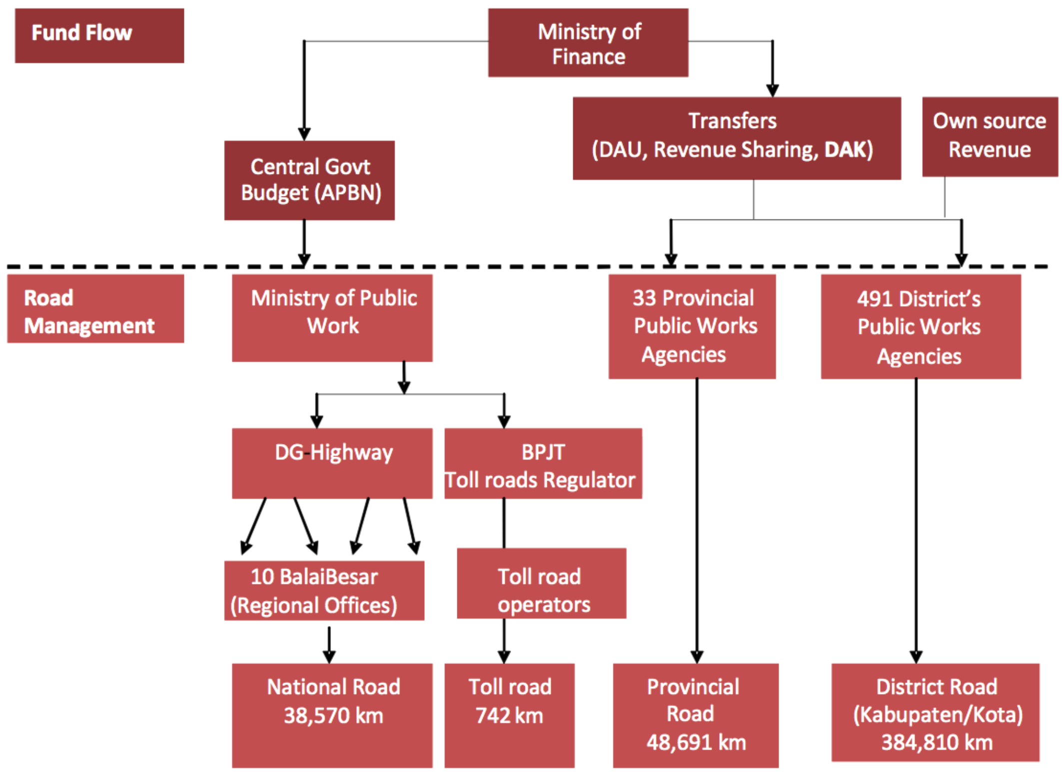


Notes: Authors' calculations using IRMS data. Thick black lines correspond to road sections that are 80 percent paved or greater, while thin black lines correspond to road sections that are less than 80 percent paved.

Figure A.3: IFLS Villages

Notes: This figure displays a map of the original IFLS villages from wave 1 of the IFLS in 1993. The black polygons correspond to IFLS-1 communities, while the grey polygons display the locations of other communities in Indonesia.

Figure A.4: Institutional Arrangements for Indonesia's Road Sector



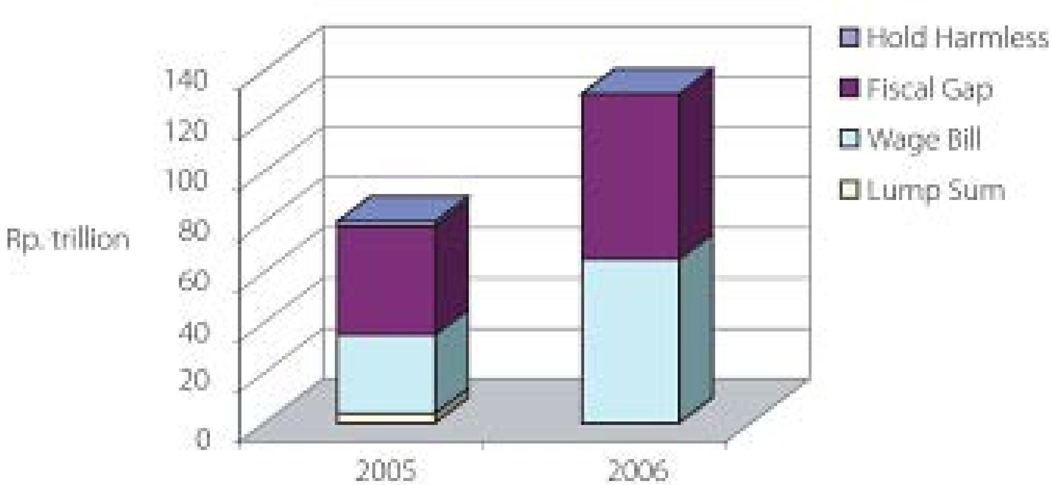
Source: World Bank (2012).

Figure A.5: The evolution of technical criteria in the DAK formula for roads and their respective weights

No.	Technical criteria	Description	2008	2009	2010	2011
1	Length of road	Length of road which is legally acknowledge through the decree of the head of local government	30%	25%	25%	25%
2	Road condition	Length of road with non-stable condition	30%	40%	35%	25%
3	Good road performance		20%			
4	Accessibility	Defined by the length of road divided by total area			20%	10%
5	Mobility	Length of road per 1000 population in the province/kabupaten			20%	10%
6	Ownership/concern by LG	Determined by the percentage of original APBD allocated to the road sector		20%		10%
7	Reporting	Consistency in submitting of quarterly report, physical progress, financial progress	20%	15%		20%

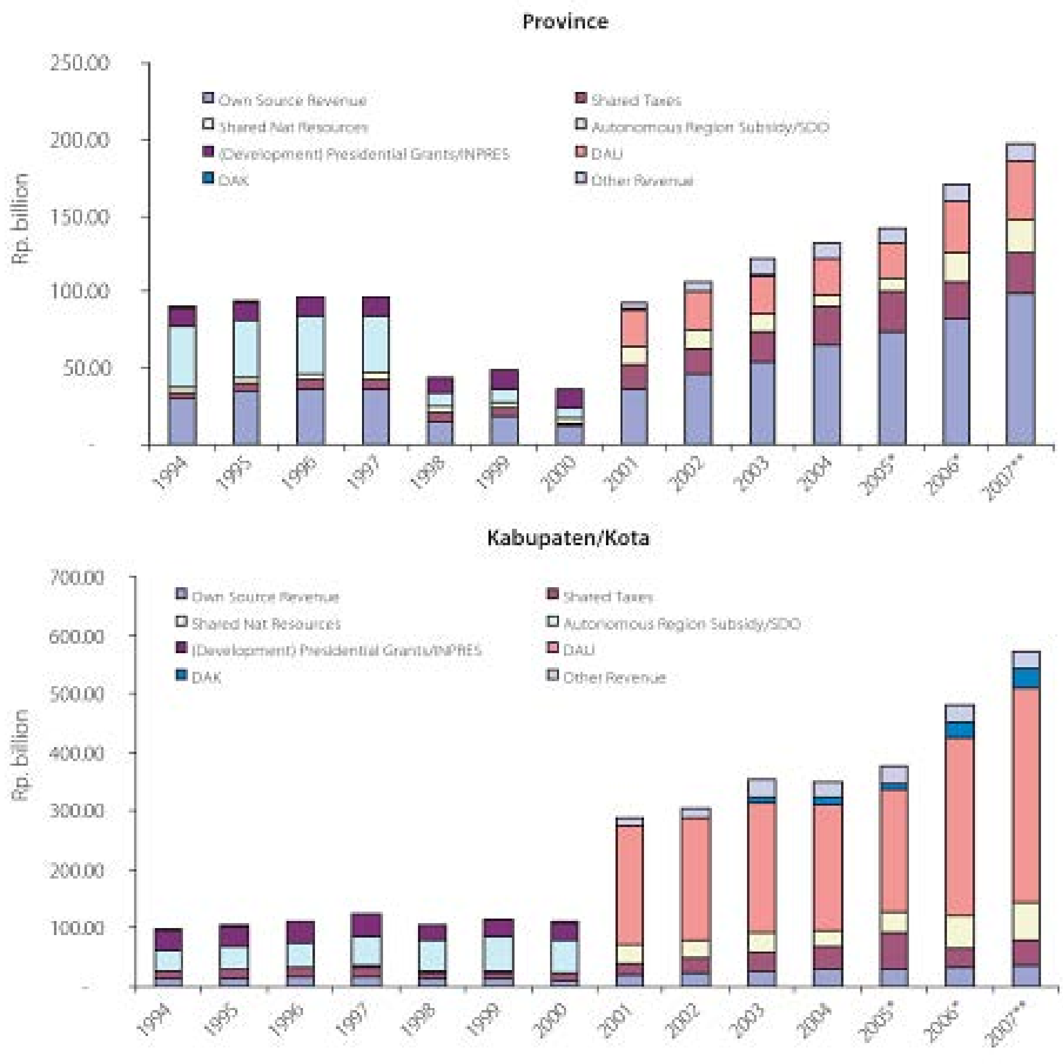
Source: World Bank (2012).

Figure A.6: Changes in DAU composition over time



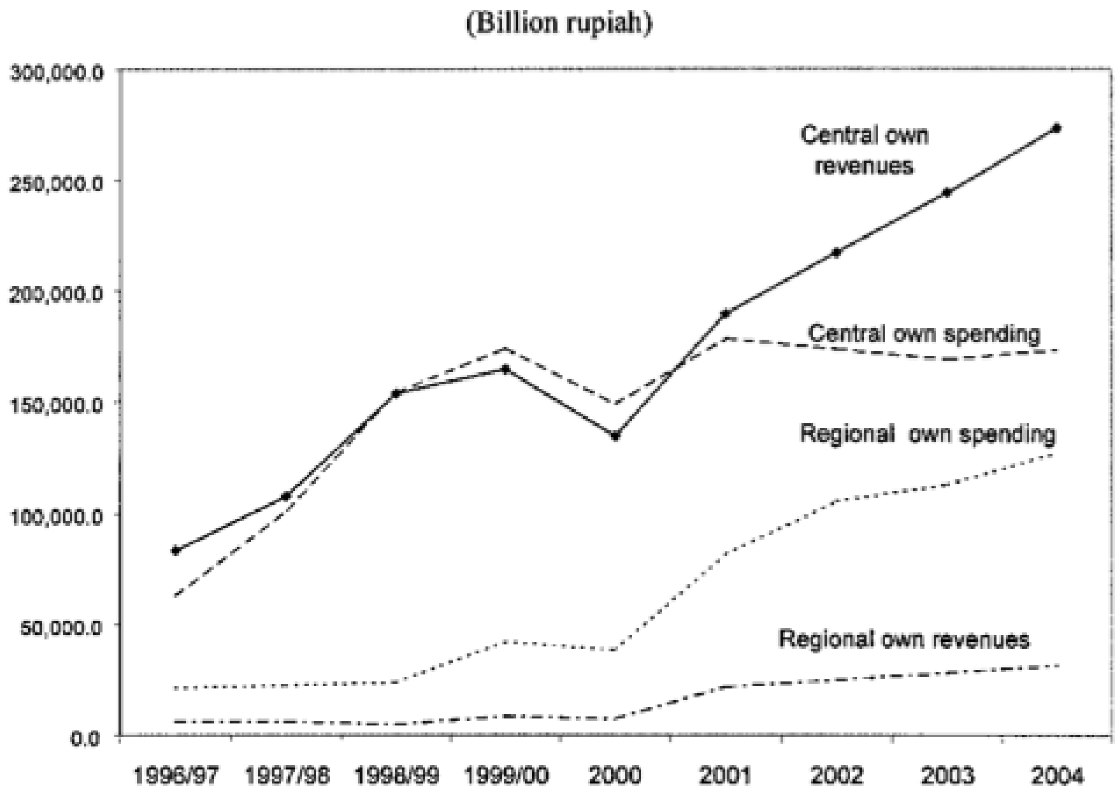
Notes: World Bank staff calculations, from World Bank (2008).

Figure A.7: Sub-national Revenue over Time



Notes: World Bank staff calculations, from World Bank (2008).

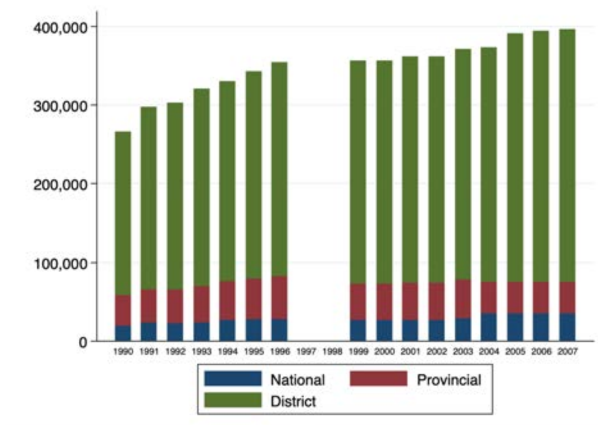
Figure A.8: Growth in Revenues for Road Maintence



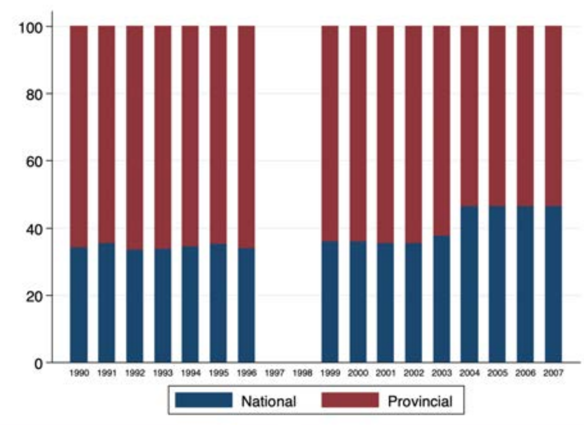
Notes: From Ahmad and Mansoor (2002), in billions of rupiah.

Figure A.9: Road Length by Administration Status

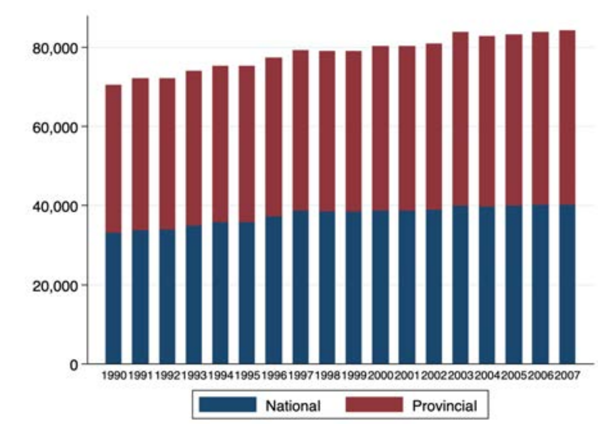
(A) BPS (LENGTH)



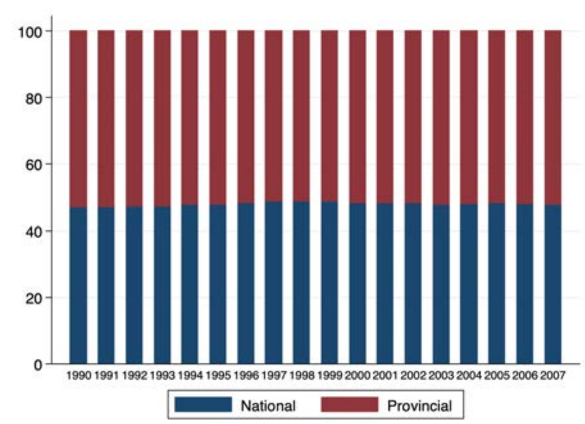
(B) BPS (SHARE OF NATIONAL + PROVINCIAL)



(C) IRMS (LENGTH)



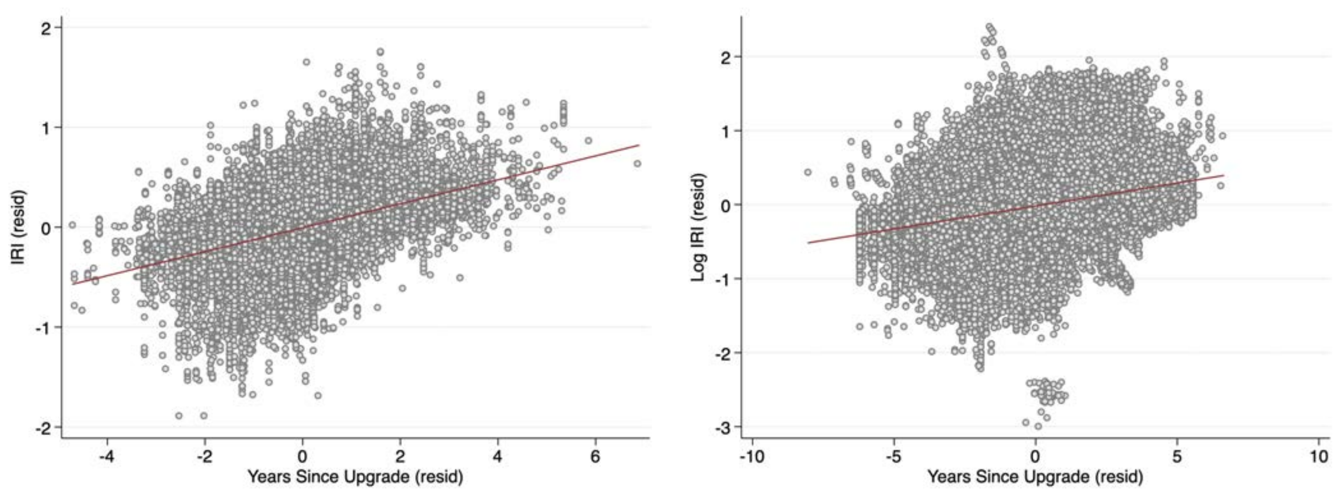
(D) IRMS (SHARE OF NATIONAL + PROVINCIAL)



Notes: Panels A and B are from various editions of BPS publications on National Transportation Statistics. These publications were not produced in 1997 and 1998, explaining the missing data for these periods. These panels cover all roads in Indonesia. Panels C and D are from IRMS data, which only cover national and provincial roads on Java, Sumatra, and Sulawesi.

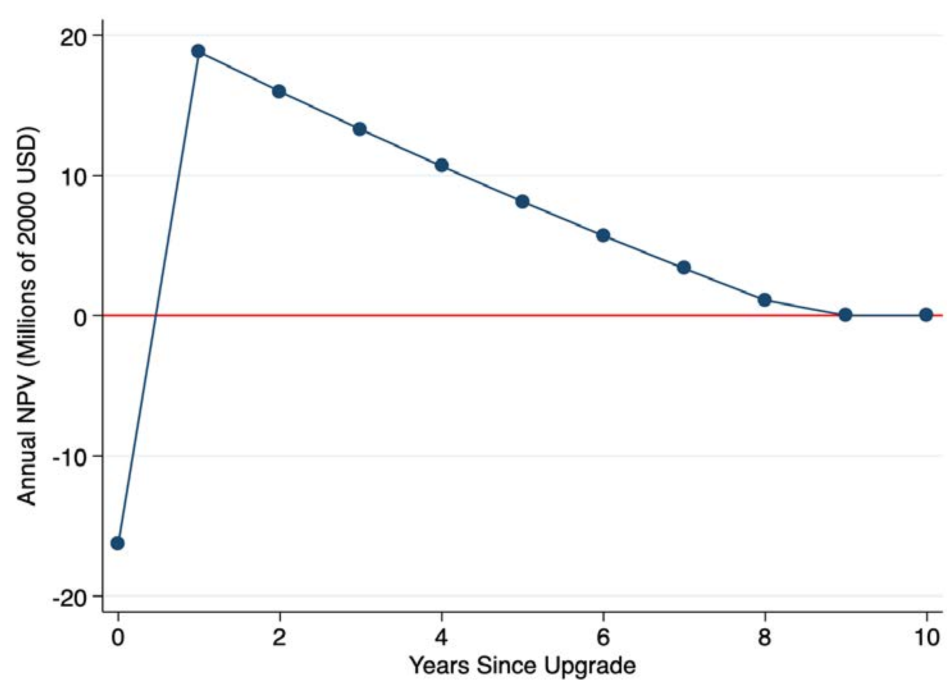
Figure A.10: Road Roughness and Years Since Upgrade: Residual-on-Residual Plots

(A) Unpaved Roads **(B) Paved Roads**



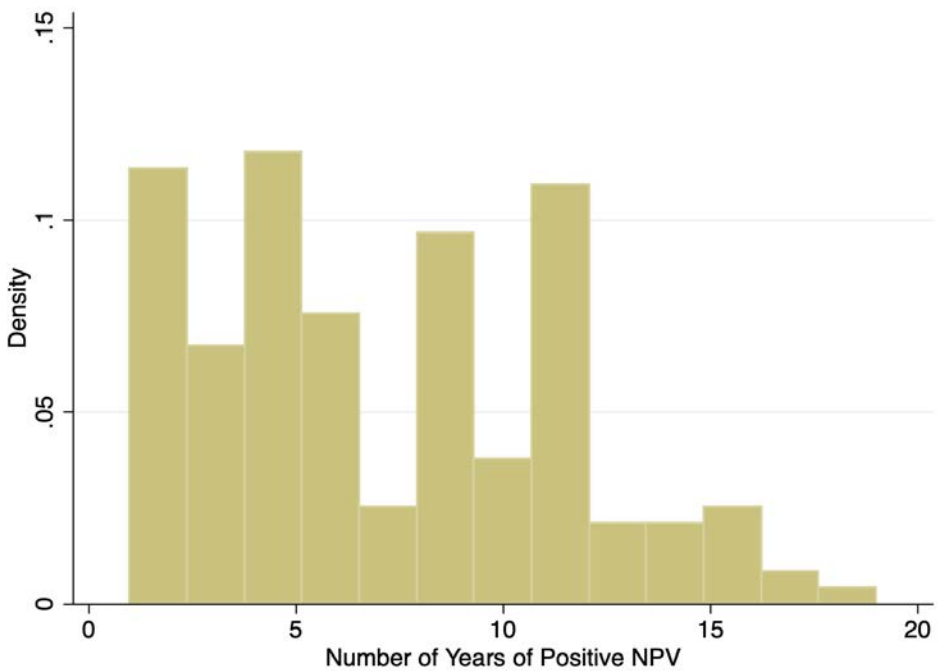
Notes: This figure reports residual-on-residual plots of the regression relationships estimated in Appendix Table A.21.

Figure A.11: Annual Benefits vs. Costs of Upgrading Roads: District Labuhan Batu



Notes: This figure presents an example of the annual benefits minus the costs of upgrading roads for District Labuhan Batu in North Sumatra. The entire cost of the upgrade is borne in the first year, while the benefits accrue for 9 years before deterioration reduces road conditions back to their previous levels.

Figure A.12: Distribution of Years that NPV is Positive



Notes: This figure reports a histogram of the number of years in which the net present value of the counterfactual district road upgrading program is positive. The median district with positive NPV has 6 years of positive benefits before road deterioration reduces road quality back to its previous levels.

B Data Appendix

B.1 Road Quality Data

Data on the quality of Indonesia's highway networks were produced by DPU as part of Indonesia's Integrated Road Management System (IRMS). This appendix section begins by providing some background on road management in Indonesia, describing the road classification system and discussing IRMS coverage. It then discusses the measures of road quality that are collected in IRMS and how they are measured. I then discuss how the road network data were created.

B.1.1 Background on Road Management

Indonesia's national road network is currently managed and maintained by the Department of Public Works (*Departemen Pekerjaan Umum*, DPU), specifically by the Directorate General of Highways (*Direktorat Jenderal Bina Marga*). According to Law No. 38, 2004, roads are classified into four different types of roads, primarily based on their function for users. Arterial roads (*jalan arteri*) serve as the major transportation linkages between urban areas, and are characterized by longer distances, higher speeds, and limited access. Speeds are meant to be a minimum of 60 km/h, and width should be at least 11 meters to accommodate larger traffic volumes. Collector roads (*jalan kolektor*) serve "collector or distributor transportation" and are characterized by medium distance travel with medium speeds. Collector roads are subdivided into primary collector roads (*jalan kolektor primer*), which should have a minimum speed of 20 km/h and width of 9 meters, and secondary collector roads, which should have a minimum speed of 20 km/h and width of 9 meters. Local roads (*jalan lokal*) and Neighborhood Roads (*jalan lingkungan*) serve local areas at lower speeds, and are characterized by unlimited access.

Roads can also be classified by their management authority, or "status" (*wewenang penyelenggaraan*). Generally, arterial and primary collector roads are managed by the national government (specifically by DPU). Secondary and tertiary collector roads are managed by provincial governments, while local and neighborhood roads are managed by the kabupaten, kecamatan, and desa governments. Table B.1 describes the road classification system, minimum speed and width guidelines, and management authorities.

Table B.2 depicts the coverage of the IRMS dataset by road function and managing authority, as measured by counts of the number of kilometer-post observations that appear in the entire dataset. Most of the observations, and indeed most of the road network, is made up by collector roads (K1-K3), though the category with the next largest coverage is the arterial roads. Local and neighborhood roads are not very well surveyed in this dataset. Although the network of village and kabupaten roads is doubtless extremely dense, I cannot use this dataset to say very much about it. But since the data do cover arterial and collector roads, the major roads connecting regions and cities in Indonesia, this dataset seems particularly well suited for evaluating models of economic geography and regional trade.

B.1.2 Measures of Road Quality

There are a number of different devices that transport engineers have developed to collect measurements of road quality, and there are several different measures of road quality. The most widely used measure of road roughness, and the measure used in this study, is the international roughness index (IRI), developed by the World Bank in the 1980s. IRI is constructed as a filtered ratio of a standard vehicle's accumulated suspension motion (in meters), divided by the distance travelled by the vehicle during measurement (in kilometers). Expressed in units of slope (m/km), IRI is a characteristic of a vehicle's longitudinal profile. Importantly, since it is a measure of a physical quantity, IRI is standardized, as opposed to other subjective measures of ride quality. Figure 1 shows the relationship between different ranges of IRI and surface type; generally, larger roughness levels correspond to worse surfaces, but the mapping is not one-to-one.

Bennett et al. (2007) distinguish between several different types of devices for measuring road roughness and provide a good overview of their relative strengths and weaknesses. Over the course of its existence, Indonesia's IRMS has largely made use of two different types of measuring devices.[41] Before 1999, roads were surveyed using devices like the ROMDAS, which estimate IRI indirectly. The ROMDAS machine is a calibrated bump integrator, which must first be calibrated and estimates IRI from correlation equations. It is very useful for measuring roughness on bumpy roads and can record high levels of IRI, but the device must be calibrated manually, and measurement error can occur if the device is miscalibrated.

The ROMDAS device is also portable, meaning that it can be used inside different vehicles (each of which would require unique calibrations). The portability contrasts with devices like the high-speed laser profilometer, which is essentially a separate vehicle reserved entirely for the purposes of collecting road quality data. The device uses lasers and optical techniques to scan the road as it is traversed and create measures of surface profiles. These instruments are very accurate, but are much more expensive. Moreover, they might become mis-calibrated on extremely rough roads. Indonesia started using the high speed laser profilometer for collecting its road quality data in 1999, licensing vehicles from the Australian government.

Road width and surface type are more straightforward variables to measure, involving visual inspection and simple measurement. I categorize a kilometer-post interval as being unpaved if it is either an earth, gravel, or sand road, or if it was given a granular base (crushed stone) treatment, a first step in the process of paving.

B.1.3 Creation of Road Network Data

Using GIS shapefiles of the road network provided to me by DPU, I have georeferenced the kilometer post observations of road quality, in order to capture the evolution of Indonesia's transportation network over space and time. This proved to be a challenging exercise, because the identifiers for each road-link-interval observation were not consistent over time, and because the identifiers in the shapefile and in the linearly referenced dataset were often different, even though both did refer to exactly the same link.

Once the IRMS interval data was successfully merged to the regional network shapefiles, I converted the GIS database of road links into a weighted graph of arcs and nodes, as commonly used in the transportation literature. Nodes represent locations (such as ports, cities, or the centroids of kabupatens, my

[41] I am very grateful for the extensive discussions I've had with Glen Stringer about IRMS; this section of the appendix benefits highly from our conversations.

unit of analysis), arcs represent the possibility of traveling between two nodes, and weights represent the cost of moving goods along a given arc. Weights were constructed according to the IRMS data on road quality, and for simplicity, the cost of moving along each road was assumed to be the same, no matter which way you were traveling.[42]

For computational reasons, I have used a simplified representation of Indonesia's road network, where the number of nodes and links was small enough for network algorithms to operate on it using a desktop computer.[43] Table B.3 depicts the number of network arcs, the total distance of the network, and merge statistics for the kilometer-post observations. Merge statistics are pretty good for arterial and collector roads, but the quality of merges falls substantially for local and neighborhood roads, due most likely to poor shapefile coverage for that type of road network.

The interval observations were not matched directly to their exact locations in the network, because I had no knowledge of the exact location of the kilometer posts. To deal with this, I first aggregated the kilometer-post interval observations to the road-link level by constructing distance-weighted averages of the road quality variables. Each network arc-year observation was then assigned the value of this average road quality variable that corresponds to its road link.[44]

B.1.4 Roughness, Speed, and Ride Quality

One effect that rough roads have on vehicles is that they require the driver to travel at lower speeds. When faced with potholes, ragged pavement, or poor surfaces, drivers slow down, and this reduction in speed increases travel time and hence the cost of travel. Of course, there is not a one-to-one relationship between road roughness and speed, because drivers choose the speed at which they travel, and different preferences for smoothness of the ride or the desired arrival time might induce different choices of speed.

Yu et al. (2006) explore the relationship between *jolt*, or the "jerk" experienced by road users, and subjective measures of ride quality and road roughness at different speeds.[45] Using survey data in which users were asked to rate the quality of particular rides, the authors find that people experience greater discomfort while traveling at higher speeds on rough roads, but lowering speed on rough roads can reduce discomfort. The authors provide a mapping between subjective measures of ride quality and roughness at different speeds, and this mapping can be used to infer the maximum speed that one can travel in order to achieve a ride of a certain quality, given pavement roughness. Table B.4 reproduces this mapping. Because travel times were unreasonably long for high quality rides given Indonesia's rough roads, and because the subjective quality measures were chosen by Western drivers, I have focused on the poor ride quality speed thresholds in my empirical work.

[42] Another tedious issue involved the construction of junction points where the road links intersected. The shapefiles were originally stored as MapInfo files, an older shapefile format that required conversion for use with Arcview, and in this conversion, information on where the roads crossed was lost, requiring painstaking editing. The shapefiles were also not designed to be used in any network analysis, so much care had to be taken to make them usable.

[43] The road lines were straightened using the "Generalize" command from ET Geotools, which employs the Ramer-Douglas-Peucker algorithm for reducing the number of points that represents a line.

[44] In some cases, when a network arc had no data for a particular year, I assigned the network arc the average value of road quality for arcs with the same function. This was done because constructing the transport cost variables involved a search over the entire network, and if certain network arcs were coded as missing, this could distort the search substantially. Overall, imputation amounted to no more than 5 percent of network arc observations in any given year.

[45] *Jolt* is officially defined as the vector that specifies the time-derivative of acceleration; in other words, the third derivative of the vertical displacement of vehicle to time t.

Given the maximum speed that one can travel on roads of different roughness levels, it is straightforward to calculate travel times for each network arc, the primary measure of transport costs used in this study. Note that the travel times on road sections were computed using the detailed kilometer-post interval roughness data. These were then aggregated to the network arcs using distance-weighted averages.

B.2 Administrative Boundaries

Administrative boundary shapefiles were constructed by BPS for use during the 2000 Household Census. These shapefiles contain the polygon boundaries of all provinces, kabupatens, kecamatans, and desas for the entire extent of the Indonesian archipelago. However, after the fall of Suharto and a massive decentralization program, many new kabupatens were created, splitting existing kabupatens into new ones. For instance, in 1990 there were 290 kabupatens and kotas, but by 2003, there were 416 kabupatens and kotas. The fact that administrative boundaries are not fixed over time create difficulties for the analysis.

Because of the need for a geographic unit of analysis that was consistently defined over time, I used kabupaten borders as they were defined in 1990. BPS provided the administrative boundary shapefile for 2000, as well as a correspondence table between kabupaten codes in 2000 and kabupaten codes from 1990 to the present. This information was processed using ArcView to create the 1990 shapefiles that form the basis of the analysis. Throughout the paper, all survey data were appropriately merged back to the 1990 kabupaten definitions.

Table B.1: Indonesia's Road Classification System

Function	Code	Minimum Speed	Minimum Width	Management Authority
Arterial	A	60 km/h	11 m	National
Collector-1	K1	40 km/h	9 m	National
Collector-2	K2	20 km/h	9 m	Provincial
Collector-3	K3	20 km/h	9 m	Provincial
Local	L	20 km/h	7.5 m	Kabupaten & Desa
Neighborhood	Z	15 km/h	6.5 m	Kabupaten & Desa

Source: Departemen Pekerjaan Umum, 2008

Table B.2: Road Function and Managing Authority, Kilometer-Post Observations, 1990-2007

	Road Function			Managing Authority		
	Code	**Number of Obs.**	**Share of Total**	**Code**	**Number of Obs.**	**Share of Total**
	A	52,917	0.17	**N**	93,808	0.30
	K1	40,889	0.13	**P**	132,649	0.42
	K2	121,386	0.39	**K**	15,862	0.05
Java	**K3**	10,714	0.03	**S**	72,068	0.23
	L	15,862	0.05			
	Z	72,619	0.23			
	Total	314,387	1.00	**Total**	314,387	1.00
	A	103,160	0.20	**N**	202,915	0.39
	K1	99,782	0.19	**P**	263,409	0.50
	K2	235,750	0.45	**K**	11,391	0.02
Sumatra	**K3**	27,632	0.05	**S**	45,680	0.09
	L	11,391	0.02			
	Z	45,680	0.09			
	Total	523,395	1.00	**Total**	523,395	1.00
	A	54,496	0.21	**N**	143,147	0.54
	K1	87,728	0.33	**P**	72,198	0.27
	K2	71,234	0.27	**K**	18,232	0.07
Sulawesi	**K3**	1,887	0.01	**S**	29,371	0.11
	L	18,232	0.07			
	Z	29,371	0.11			
	Total	262,948	1.00	**Total**	262,948	1.00

Source: IRMS and author's calculations. Data come from kilometer-post observations. Standard deviations in parentheses.

Table B.3: Number of Network Arcs, Distances, and Merge Statistics (by road function)

		Road Function						
		A	**K1**	**K2**	**K3**	**L**	**Z**	**Miss**
	# of Arcs	1168	889	2618	309	315	37	.
	# of Road IDs	220	129	354	43	72	6	.
	Total Distance	2944.91	1970.65	5832.59	750.39	663.44	92.16	.
	Link-Years Merged	16538	13685	38719	3876	4689	14572	3015
Java	**Link-Years Unmerged**	1838	735	1842	45	971	21772	157
	% Merged	0.90	0.95	0.95	0.99	0.83	0.40	0.95
	Arc-Years Merged	20,844	16002	46350	5562	5670	666	.
	Arc-Years Unmerged	180	0	774	0	0	0	.
	% Merged	0.99	1.00	0.98	1.00	1.00	1.00	.
	# of Arcs	1485	1205	2975	453	277	22	41
	# of Road IDs	207	165	412	87	66	6	13
	Total Distance	4964.69	4469.43	11551.28	1492.97	571.67	56.44	147.56
	Link-Years Merged	24755	20035	49171	6808	2603	8730	1406
Sumatra	**Link-Years Unmerged**	718	373	537	52	394	9722	12
	% Merged	0.97	0.98	0.99	0.99	0.87	0.47	0.99
	Arc-Years Merged	26730	21690	51876	7830	4986	396	0
	Arc-Years Unmerged	0	0	1674	324	0	0	738
	% Merged	1.00	1.00	0.97	0.96	1.00	1.00	0.00
	# of Arcs	1624	2319	2051	15	391	.	45
	# of Road IDs	113	116	150	4	44	.	1
	Total Distance	2836.96	3805.92	4369.33	28.35	732.96	.	70.34
	Link-Years Merged	24006	24006	34711	30911	551	5670	5674
Sulawesi	**Link-Years Unmerged**	25	356	410	339	9	118	4755
	% Merged	1.00	0.99	0.99	0.99	0.98	0.98	0.54
	Arc-Years Merged	25794	35694	33660	270	7038	.	0
	Arc-Years Unmerged	3438	6048	3258	0	0	.	810
	% Merged	0.88	0.86	0.91	1.00	1.00		0.00

Source: IRMS and author's calculations. Missing function information is attributable to poorly coded shapefiles. Arc-Years could be unmerged potentially because there were no surveys done on that particular link; statistics are computed assuming a balanced panel. Road IDs are defined in the shapefile, while Link IDs are defined from the IRMS data.

Table B.4: Roughness and Ride-Quality Speed Limits

Max Speed	**Good**	**Fair**	**Mediocre**	**Poor**
120 km/h	IRI $\in [0.00, 1.49]$	IRI $\in [0.00, 1.89]$	IRI $\in [0.00, 2.70]$	IRI $\in [0.00, 3.24]$
100 km/h	IRI $\in [1.49, 1.79]$	IRI $\in [1.89, 2.27]$	IRI $\in [2.70, 3.24]$	IRI $\in [3.24, 4.05]$
80 km/h	IRI $\in [1.79, 2.24]$	IRI $\in [2.27, 2.84]$	IRI $\in [3.24, 4.05]$	IRI $\in [4.05, 4.63]$
70 km/h	IRI $\in [2.24, 2.57]$	IRI $\in [2.84, 3.25]$	IRI $\in [4.05, 4.63]$	IRI $\in [4.63, 5.40]$
60 km/h	IRI $\in [2.57, 2.99]$	IRI $\in [3.25, 3.79]$	IRI $\in [4.63, 5.40]$	IRI $\in [5.40, 6.25]$
50 km/h	IRI $\in [2.99, 3.59]$	IRI $\in [3.79, 4.54]$	IRI $\in [5.40, 6.25]$	IRI $\in [6.25, 8.08]$
40 km/h	IRI $\in [3.59, 4.49]$	IRI $\in [4.54, 5.69]$	IRI $\in [6.25, 8.08]$	IRI $\in [8.08, 10.80]$
30 km/h	IRI $\in [4.49, 5.99]$	IRI $\in [5.69, 7.59]$	IRI $\in [8.08, 10.80]$	IRI $\in [10.80, 16.16]$
20 km/h	IRI $\in [5.99, 8.99]$	IRI $\in [7.59, 11.39]$	IRI $\in [10.80, 16.16]$	IRI $\in [16.16, 32.32]$
10 km/h	IRI $\in [8.99, \infty)$	IRI $\in [11.39, \infty)$	IRI $\in [16.16, \infty)$	IRI $\in [32.32, \infty)$

Source: Author's calculations and Yu et al. (2006), Table 2. IRI denotes the international roughness index, measured in m/km. Ride quality levels are subjective and measured on a 5-point scale ("Very Good", "Good", "Fair", "Mediocre", and "Poor").

C Welfare Decomposition Appendix

In this section, we provide an approximation for how a marginal improvement in road quality impacts welfare for incumbent households. To do so, we combine reduced form estimates of the effects of road quality on outcomes in different types of locations, presented in Section 6, with a simple model of household utility maximization.

Our simple framework clarifies the ways that a small change in road quality impacts households through its effects on different sources of income and on different prices. To present this framework, we proceed with a bit of notation. Let i index households and let j index types of locations, which initially have either low or high populations (i.e. $j \in \{L, H\}$). Let $U_i = U(\mathbf{c}_i, H_i)$ denote household i's utility function, which is defined over a vector of consumer goods, $\mathbf{c}_i = (c_{i1}, c_{i2}, ..., c_{iK})'$, and housing, H_i. Also let $k = 1, ..., K$ index the different types of consumables goods available to households.

Ignoring subscripts, the general household's utility maximization problem is given by:

$$\max_{\mathbf{c},H} U(\mathbf{c}, H) \quad \text{s.t.} \quad Y = \mathbf{p_c} \cdot \mathbf{c} + p_H H$$

where $\mathbf{p_c}$ is a vector of consumer prices, p_H represents housing prices, Y collects the household's total income from all potential sources, and $\cdot$ is the dot product operator.

Specializing to a Cobb-Douglas functional form, we can write:

$$\max_{\mathbf{c}_i,H_i} \theta \left(\prod_{k=1}^{K} c_{ik}^{\alpha_k} \right) H_i^{1-\alpha} \quad \text{s.t.} \quad Y_i = \sum_{k=1}^{K} p_k c_{ik} + p_H H_i \tag{17}$$

where θ and $\{\alpha_k\}_{k=1}^K$ are constants, and where we assume that $1 = \sum_{k=1}^K \alpha_k + \alpha$. Note that in (17), we have omitted location subscripts, but prices, $\{p_k\}_{k=1}^K$ and p_H, will obviously differ across locations in equilibrium. Given (17), it is straightforward to show that the household's indirect utility function is given by:

$$V = \theta \left(\prod_{k=1}^{K} \alpha_k^{\alpha_k} \right) (1-\alpha)^{1-\alpha} p_c^{-\alpha} p_H^{-(1-\alpha)} Y \tag{18}$$

Taking logs of (18), we have:

$$\ln V = \underbrace{\ln \theta + \left(\sum_{k=1}^{K} \alpha_k \ln \alpha_k \right) + \alpha \ln \alpha}_{} + \ln Y - \sum_{k=1}^{K} \alpha_k \ln p_k - (1-\alpha) \ln p_H$$

$$\ln V = \text{cons} + \ln Y - \sum_{k=1}^{K} \alpha_k \ln p_k - (1-\alpha) \ln p_H$$

Totally differentiating this expression with respect to road quality, A, we obtain:

$$\frac{\partial \ln V}{\partial \ln A} = \underbrace{\frac{\partial \ln Y}{\partial \ln A}}_{(A)} - \underbrace{\sum_{k=1}^{K} \alpha_k \frac{\partial \ln p_k}{\partial \ln A}}_{(B)} - (1-\alpha) \underbrace{\frac{\partial \ln P_H}{\partial \ln A}}_{(C)}$$

This expression tells us that changing road quality impacts the household's welfare through its effect on total income (term A), through its impact on consumer prices (term B), and through its impact on housing prices (term C).

To make progress on the first term, (A), we note that Y is the total wage income that the household earns from a variety of sectors, plus the total net profits from farm and non-farm business income:

$$Y = Y_L + \pi$$

where Y_L measures labor income and π measures the household's combined farm and non-farm business profits. Using this, we can rewrite (A) as follows:

$$\begin{aligned}
\frac{\partial \ln Y}{\partial \ln A} &= \frac{1}{Y}\left[\frac{\partial Y_L}{\partial \ln A} + \frac{\partial \pi}{\partial \ln A}\right] \\
&= \frac{1}{Y}\left[\frac{Y_L}{Y_L}\frac{\partial Y_L}{\partial \ln A} + \frac{\pi}{\pi}\frac{\partial \pi}{\partial \ln A}\right] \\
&= \frac{1}{Y}\left[Y_L\left(\frac{1}{Y_L}\frac{\partial Y_L}{\partial \ln A}\right) + \pi\left(\frac{1}{\pi}\frac{\partial \pi}{\partial \ln A}\right)\right] \\
&= \frac{1}{Y}\left[Y_L\left(\frac{\partial \ln Y_L}{\partial \ln A}\right) + \pi\left(\frac{\partial \ln \pi}{\partial \ln A}\right)\right]
\end{aligned}$$

where we multiply by all derivatives by 1 in the second line, and we use the relationship that

$$\frac{\partial y}{\partial \ln x} \cdot \frac{1}{y} = \frac{\partial \ln y}{\partial \ln x}$$

in the third line.[46]

The second term, (B), is just a weighted sum of the elasticities of prices with respect to road quality across goods, where the weights are equal to expenditure shares. The third term, (C), is the elasticity of housing prices with respect to road quality, multiplied by $(1-\alpha)$, the share of the consumer's income spent on housing.

Let $\mathcal{E}_{y,x}$ denote the elasticity of y with respect to x, and define $\theta_{Y_L} \equiv Y_L/Y$ and $\theta_\pi \equiv \pi/Y$ as the share of labor income and total profits in total income, respectively, we can write our expression for how

[46]To prove this, let $z = \exp y$, so that $\ln z = y$. Then, we have:

$$\begin{aligned}
\frac{\partial y}{\partial \ln x} &= \frac{\partial \ln z}{\partial \ln x} = \frac{\partial z}{\partial x} \cdot \frac{x}{z} \\
\implies \frac{\partial y}{\partial \ln x} &= \frac{\partial \exp y}{\partial x} \cdot \frac{x}{\exp y} \\
\implies \frac{\partial y}{\partial \ln x} &= \exp y \cdot \frac{\partial y}{\partial x} \cdot \frac{x}{\exp y} \\
\implies \frac{\partial y}{\partial \ln x} &= \frac{\partial y}{\partial x} \cdot x \\
\implies \frac{\partial y}{\partial \ln x} \cdot \frac{1}{y} &= \frac{\partial y}{\partial x} \cdot \frac{x}{y}
\end{aligned}$$

welfare changes for a marginal improvement in road quality as follows:

$$\mathcal{E}_{V,A} = \theta_{Y_L}\mathcal{E}_{Y_L,A} + \theta_{\pi}\mathcal{E}_{\pi,A} - \sum_{j=1}^{J}\alpha_j\mathcal{E}_{p_j,A} - (1-\alpha)\,\mathcal{E}_{p_H,A} \tag{19}$$