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## A Slippery Slope: Topographic Variation as an Instrument

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**December 2025**

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# A Slippery Slope: Topographic Variation as an Instrument

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## Abstract

Exploiting exogenous natural variation to study the impact of hard-to-randomize policies based on instrumental variables (IVs) is a widespread research design in economics. The key identification assumption underlying this design is the exclusion restriction, requiring the IV to affect the outcome variable only through the instrumented treatment variable. We review the literature using topography as an IV to show that systematic violations of this assumption are likely because of topography's ubiquity in socio-economic relationships. Furthermore, as topography often lacks first-stage strength, even subtle violations of the exclusion restriction undermine any causal inference. Instead of the vindication that often accompanies IV applications, we advocate a falsificationist approach to the use of topographic IVs, grounded in precaution and skepticism. We apply this approach to a seminal example of a topographic IV, Dinkelman (2011).

**JEL-Codes:** C26, C36, C52, O13, O18.

**Keywords:** Causal inference, collider bias, topography, exclusion restriction.

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## 1. Introduction

The credibility revolution, with its emphasis on design-based approaches to studying causal relationships, has been the dominant paradigm in empirical economics since the early 2000s (Angrist and Pischke 2009; Card 2022). Randomization is the benchmark of this paradigm, but if this is not possible, researchers resort to quasi-experimental alternatives, with Instrumental variables (IVs) as one of the most prolific examples (Garg and Fetzer 2025). The idea of IVs is to tease out the causal relationship between a policy and a socio-economic outcome variable by using a source of variation that shifts the policy but is otherwise exogenous to the relationship of interest. Topographic variation is such an example that has frequently attracted the interest of economists seeking an IV to study important yet hard-to-randomize policies.

In this paper, we show that despite topography's uncontested exogeneity, its *ubiquity* in socio-economic relationships makes it an IV that is difficult to defend in many settings. Topography simply affects too many variables to justify that only the causal pathway under examination is affected. This challenges the exclusion restriction assumption, requiring that the IV only affects the socio-economic outcome variable through the instrumented treatment variable – and not through other channels. Common practice in IV applications is to ensure the exclusion restriction by conditioning on control variables. However, given topography's ubiquity this is often not legitimate without running into a bad control problem due to *collider bias*. Collider bias occurs when control variables are also correlated with unobservable confounders. We furthermore show that topography is rarely a strong IV, according to the first-stage relationship between the IV and the instrumented treatment variable. Pragmatic inference that accepts some bias from subtle exclusion restriction violations becomes misleading when the IV is weak, as recent insights from the econometrics literature suggest (Andrews et al. 2019; Lee et al. 2022; Keane and Neal 2024). We demonstrate that there is little awareness in the literature for neither the collider bias nor the inferential consequences of weak IVs.

The evidence we provide is based on how topographic IVs are used in practice. We conduct a systematic review of the leading 120 economics journals between 2011 and 2023 and identify 161 articles that use topography as a source of exogenous variation. We consider both IV studies and reduced-form analyses. We extract outcome variables for all studies and the instrumented treatment variables for IV studies to draw the *causal web* surrounding topography. The causal web illustrates the numerous relationships between topographic

variation and socio-economic outcome variables studied in the literature. This visualizes the pervasiveness of topography for many socio-economic research questions, raising doubts concerning the exclusion restriction assumption. The variables scattered across the causal web also deepen collider bias concern: Using the data from our causal web, we show that many IV studies control for variables that are instrumented treatment variables in other studies, demonstrating that the authors of those other studies considered these variables to be correlated to unobservable confounders in their setting. Context-specific assumptions about the absence of confounders are then needed to prevent collider bias.

Our causal web does not imply that topographic IVs are necessarily flawed. However, we argue that one should, a priori, expect a topographic IV to violate the exclusion restriction, not to fulfil it. In contrast, IV studies, we contend, typically do not begin from such a pessimistic prior. Instead, they tend to benignly vindicate the exclusion restriction through qualitative reasoning, sometimes complemented by selective quantitative tests. We argue that a different methodological stance is warranted, what we call a *revised-prior falsificationist approach*. The idea is not new in principle and rather builds on established Popperian and post-Popperian ideas of critical rationalism, claiming that falsificationism should extend beyond theories to the methods by which they are tested.

We then showcase how the falsificationist approach can change the assessment and, potentially, the verdict of an IV's validity. For this, we re-examine a seminal article in the topographic IV literature, Dinkelman (2011). We juxtapose the robustness checks provided in the original article with equally justified robustness checks that we derive from the same data set. While the tests in Dinkelman (2011) underpin the IV's validity, reinterpreting the data set through a falsificationist lens and contemplating all plausible robustness checks raises considerable concerns about exclusion restriction violations and collider bias.

Our paper contributes to a growing meta-analytical literature on how IVs are used in practice (Dieterly and Snell 2016; Young 2022). Similar concerns have been raised for other commonly used IVs, such as weather and historical patterns (Mellon 2025; Gallen and Raymond 2023; Morck and Yeung 2011). Gallen and Raymond (2023) expound problems induced by what they call “overuse” of IVs in the literature – a point similar to ours. They identify a set of “overused” IVs: rainfall, sibling structure, religion, ethnic fractionalization as well as elevation and

waterbodies.<sup>1</sup> Moreover, our topography causal web is a conceptual replication of the causal web for weather as an IV, established in Mellon (2025). We corroborate Mellon (2025)'s findings for topography as another frequently used IV. We push further by carving out the collider pitfall. Another key contribution we make is to carry recent advancements in the econometrics literature on weak IVs to the applied literature (Andrews et al. 2019; Angrist and Kolesar 2024; Keane and Neal 2024; Lee et al. 2022).

Our paper is also close to meta-analytical reviews in neighboring disciplines. For instance, Lal et al. (2024) reanalyze 67 IV articles in political science, documenting concerns about miscalculated standard errors and inappropriate first-stage  $F$ -statistics. Felton and Stewart (2025) examine 34 IV articles in leading sociology journals and find that basic IV assumptions are often unstated and that key diagnostics, such as the  $F$ -statistic, are frequently unreported. Both Lal et al. (2024) and Felton and Stewart (2025) also criticize the infrequent use of weak-IV robust inference, echoing similar concerns raised in economics (e.g., Keane and Neal 2024; Andrews et al. 2019). Several related papers propose different statistical tests and procedures addressing some of the problems outlined in this paper (e.g., Mellon 2025; Gallen and Raymond 2023; Felton and Stewart 2025; Lal et al. 2024). We complement these statistical procedures by our proposal for a falsificationist approach towards using IVs, especially those IVs that are suspected of “overuse”, such as topography.

## 2. IV assumptions revisited: exclusion restrictions, colliders, and weak IVs

Using causal graphs (Pearl 1998; Cunningham 2021), we revisit the assumptions underlying the IV approach, mainly to establish the terminology we use throughout the empirical part. Identifying the causal effect of a treatment  $X_1$  on an outcome  $Y$  is typically hampered by an unobservable confounder  $U$ , as depicted in Figure 1a. Regressing  $Y$  on  $X_1$  will therefore conflate the effect of  $X_1$  and  $U$  and leads to biased estimates. The IV approach uses exogenous variation from a variable  $Z$ , the instrument, to nevertheless identify the causal effect of  $X_1$  on  $Y$ . For this,  $Z$  must only affect  $Y$  through  $X_1$  (see Figure 1b). This is the exclusion restriction assumption. If variables  $X_j$  exist that link  $Z$  to  $Y$ , they must be controlled for in the econometric

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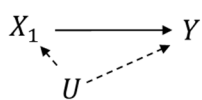
<sup>1</sup> Because of elevation and waterbodies, 12 articles in our systematic review also appear in Gallen and Raymond's sample.

implementation to maintain the exclusion restriction (see Figure 1c). If that variable  $X_j$  is not accounted for,  $Z$  has a direct effect on  $Y$ , violating the exclusion restriction (Figure 1d). Yet, controlling for  $X_j$  is only legitimate if  $X_j$  is neither correlated with the original unobserved confounder  $U$  (Figure 1e) nor a new unobservable confounder  $V$  that is correlated with  $X_j$  and  $Y$  (Figure 1f). If  $X_j$  is controlled for despite such confounding variables exist, a collider bias occurs (Felton and Stewart 2025; Deuchert and Huber 2017; Glynn et al. 2024). The collider bias – sometimes also referred to as post-instrument bias – is akin to the problem of bad controls in ordinary least square settings. Those variables  $X_j$  create a collider-confounder dilemma in which either a direct effect of  $Z$  on  $Y$  violates the exclusion restriction or a collider bias is introduced.

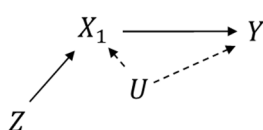
**Figure 1: Exclusion restriction assumptions and violations**

Panel A: Assumptions

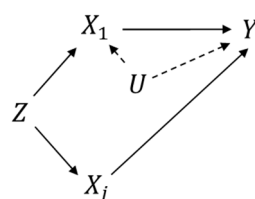
(a) Relationship of  $X_1$  and  $Y$  confounded by  $U$



(b) The basic IV model

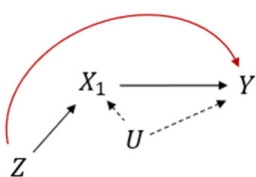


(c) Maintaining the exclusion restriction by conditioning on  $X_j$

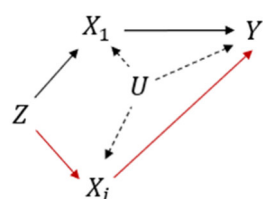


Panel B: Exclusion restriction violations

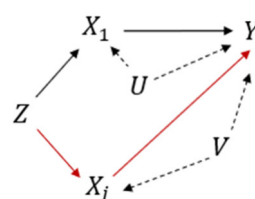
(d) Direct effect of  $Z$  on  $Y$



(e) Conditioning on a collider due to original  $U$



(f) Conditioning on collider due to new  $V$



Note: Red arrows indicate causal relationships that lead to violations of the exclusion restriction.

The second important assumption underlying the IV approach is the relevance of the IV, that is, the correlation between  $Z$  and  $X_1$  must be strong enough. Usually this is measured by the first-stage strength. The diagnosis of what constitutes a weak IV remains contested, as discussed below. The specific consequences are also debated and hinge on factors such as single IV vs. multiple IVs, homoskedasticity or heteroskedasticity, sample size and power, whether data is clustered, and whether it includes influential outliers.



Yet two implications are consolidated that are relevant in virtually all applied IV cases: First, weak IVs can distort statistical inference, by inflating  $t$ -test sizes and thereby causing over-rejection of null hypotheses (e.g., a 5% test may reject 12% of the time under weak IVs). They also render conventional confidence intervals unreliable. The state-of-the-art remedy is to use weak-IV-robust confidence intervals (Anderson and Rubin 1949; Andrews et al. 2019; Keane and Neal 2024). Given the unclear weak-IV diagnosis discussed below, recent practical guides for IV users recommend applying such confidence intervals regardless of instrument strength (Lal et al. 2024; Felton and Stewart 2025; Keane and Neal 2024; Young 2022).

Second, weak IVs amplify two-stage least squares (2SLS) bias from violations of the exclusion restriction, including collider bias. This undermines the pragmatic reasoning often adopted by applied IV users, namely that an imperfect IV is still preferable to the naïve model in Figure 1a. The intuitive reasoning of IV users is that the confounding created by  $U$ , through its correlation with both  $X_1$  and  $Y$ , is stronger than the confounding in the imperfect IV setting. For a weak IV, however, this intuition breaks down (Felton and Stewart 2025; Andrews et al. 2019): The bias of the IV estimator under weakness is often larger than that for the ordinary regression (Keane and Neal 2024). When the IV is weak, it affects the instrumented treatment variable only for a small number of compliers, amplifying the influence of exclusion restriction violations and collider bias, even when these are otherwise minor. Importantly, this problem cannot be overcome by weak-IV robust confidence intervals. As Andrews et al. (2019) note, if weak IVs coincide with exclusion restriction violations, even “weak-instrument-robust confidence intervals do not have correct coverage for the true parameter value” (p.749).

For the diagnosis of weakness, different benchmarks exist, which are all tentative and apply to the case of just-identified IVs with one single IV and one instrumented treatment variable. Higher benchmarks are required for multiple-IV settings, since “the use of multiple instruments makes [...] the 2SLS bias and  $t$ -test size inflation problems much more severe” (Keane and Neal 2024, p. 210; see also Stock and Yogo 2005 and Lal et al. 2024). The conventional benchmark for single IVs uses an  $F$ -statistic of 10 as the critical value, which ensures that the 2SLS bias relative to OLS bias does not exceed 10% under homoscedasticity (Staiger and Stock 1997). More common in IV usage with panel data are heteroskedastic and clustered error terms, for which Olea and Pflueger (2013) propose a benchmark of 23.11. In contrast, Lee et al. (2022) imply a benchmark that reflects a different notion of weakness: it

ensures that any remaining test size distortion is negligible in practice, because the  $F$ -statistic is high enough for the  $t$ -statistic to be close enough to a normal distribution. This results in a much higher benchmark of 104.7. Angrist and Kolesár (2024) take a more optimistic view, suggesting that scrutinizing first-stage strength is not even necessary as long as one conditions only on first-stage effects with the expected sign. Their rationale is that sign consistency already rules out the most problematic weak-IV pathologies that generate large size distortions, so additional screening on the magnitude of the  $F$ -statistic may provide limited further protection. Keane and Neal (2024), reviewing alternative thresholds and simulation evidence, argue that “a strong case can be made” for requiring an  $F$ -statistic of “at least 50”, since conventional benchmarks still permit 2SLS bias and  $t$ -test size inflation problems.

### 3. Topography in the economics literature

#### 3.1 The systematic review

We conducted a systematic review of the economics literature that uses topography to examine causal effects on socio-economic outcomes. We covered all articles published between 2012 and 2023 in the top-120 economics journals according to the *Simple IDEAS/RePEc Impact Factor*. Appendix A provides all details on our systematic search process as well as article-specific and descriptive statistics. We selected articles that use topography as an IV as well as reduced-form designs with topography as the treatment (henceforth *IV articles* and *reduced-form articles*). The operationalized constructs of topography we include are land gradient, land ruggedness, and elevation. In many articles it is essentially impossible to distinguish between them since the terms are often used interchangeably, and in fact they are strongly correlated (Amatulli et al. 2018). We included articles irrespective of whether the IV is based on topographic variation alone or whether the IV combines topography with a non-topographic component in a compound IV (e.g. land gradient interacted with non-topographic component). We also included articles that use multiple IVs if one of those IVs is topography. The systematic review yielded a total of 161 articles, 116 IV articles and 45 reduced-form articles, evenly published over the 2012 to 2023 period.

Following Mellon (2025), the purpose of our systematic review is to draw a *causal web* around topography, providing a stylized overview of how topography is linked to the socio-economic

world according to scholars in the field.<sup>2</sup> For the visualization, we subsumed variables in categories that capture broader economic constructs. For example, “income” subsumes GDP, GDP per capita, regional economic growth, agricultural production, income, household and non-agricultural income (see Table A1 in the appendix for a comprehensive list of extracted variables and categories). This categorization is reasonable for our purpose of providing a stylized overview of topography’s ubiquity. Yet, such broad categories should be broken down when the validity of a specific IV is scrutinized, because then the operationalization of the topographic IV needs to be evaluated vis-à-vis the specific sub-category of income and other potential exclusion restriction variable categories.

Almost one-third of the IV articles are published in top-10 journals, and one-half in top-30 journals (following the IDEAS/RePEc ranking). For reduced-form studies these numbers are a bit lower at 22% in top-10 journals and 44% in top-30 journals. The most frequent journals in this sample of 161 articles are the *American Economic Review*, the *Journal of Development Economics*, the *Journal of Urban Economics*, and *World Development* (see Figure A2 in the appendix). Around 75% of the included IV articles use a topographic IV as their main identification strategy, while the remaining one quarter uses it as a robustness check. Moreover, 68% of IV articles combine topographic variation with other sources of variation to generate compound IVs. About 36% of IV articles use multiple IVs. These shares do not change substantively for the more recently published papers after 2017. Table A1 in the appendix lists the IV components for each article.

Beyond the IV, from each article, we extracted the instrumented treatment variables and the outcome variables. With respect to potential collider bias, we documented whether the article mentions such a threat of bias (irrespective of the terminology that is used). In terms of weak IVs, we extracted the first-stage  $F$ -statistic to assess the strength of the IV. In cases with multiple specifications, we took the  $F$ -statistic from the paper’s main result. In a few cases with multiple main specifications (e.g., for different outcomes), we extracted the  $F$ -value for each, thus yielding cases with more than one  $F$ -value for a single article. We also documented whether the analysis accounts for weak IVs, and if so, how.

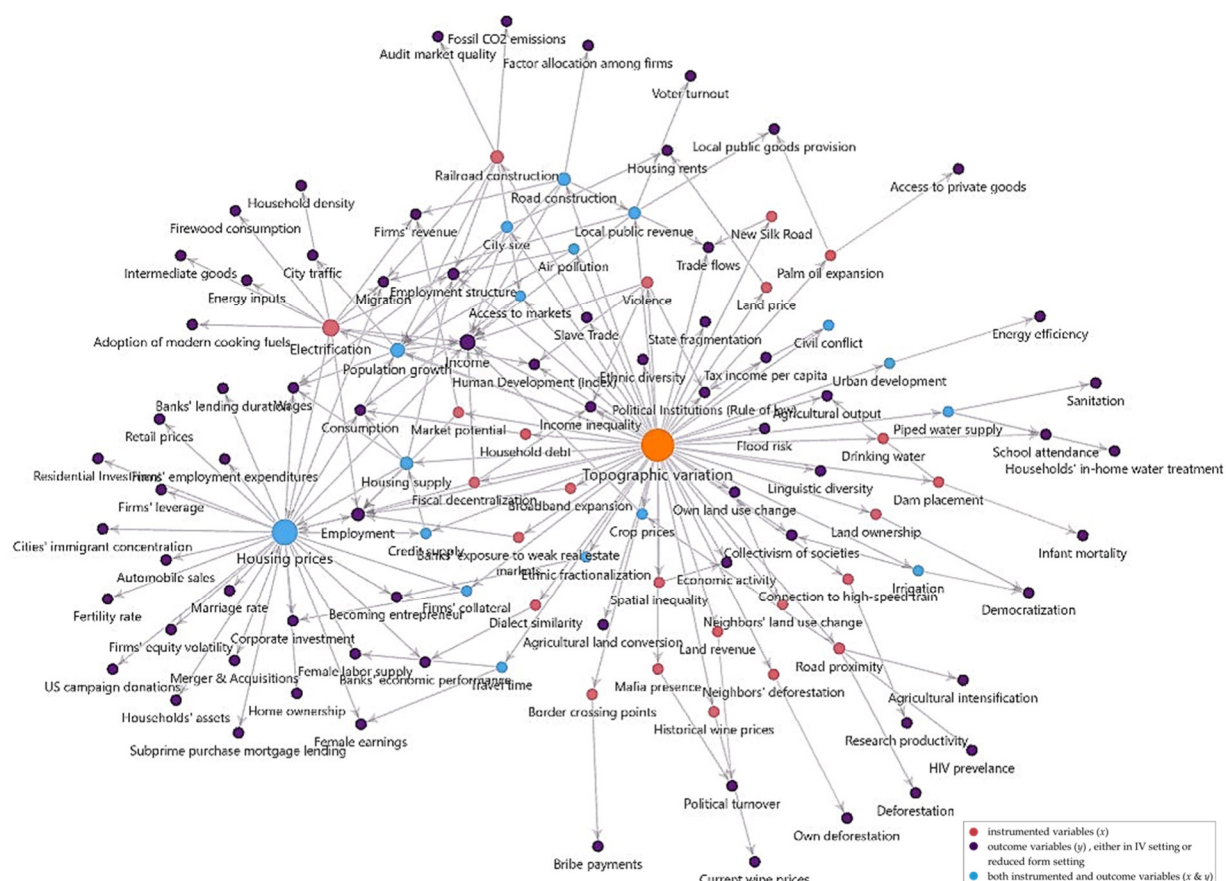
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<sup>2</sup> The notion of a *causal web* was introduced in epidemiology as a framework for multifactorial disease causation, emphasizing networks of interrelated factors rather than single or linear causes (see e.g., MacMahon et al. 1960; Rothman 1976; Krieger 1994).

### 3.2 The ubiquity of topography

Figure 2 depicts the causal web with cause-and-effect relationships as they were examined in the 161 articles in our sample. Nodes represent variables and arrows the causal direction. We include instrumented treatment variables and outcome variables, the latter irrespective of whether the variable is the outcome in an IV article or in a reduced-form article. The size of a node in Figure 2 represents the frequency with which the variable appeared in our sample. Note that this node size is an approximate measure since it depends on how we subsume variables in categories.

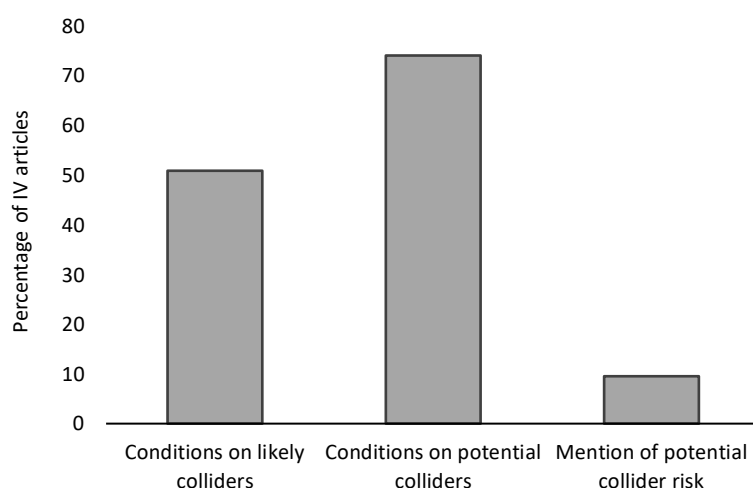
The key insight is that any variable that appears in the causal web is affected by topography  $Z$  and hence a potential exclusion restriction violation when  $Z$  is used as an IV for another treatment variable in the causal web. To justify using  $Z$  as an IV it must be argued that the channel between  $Z$  and the outcome is isolated within the causal web, at least for the specific context. Therefore, the causal web provides a list of variables that need to be explicitly considered and ruled out in any topography-based IV application. It contains some variables that are arguably very context specific, for example research productivity, Mafia presence or HIV prevalence. These specific variables arguably do not affect  $Z \rightarrow Y$  relationships everywhere. Some variables, though, are indisputably pivotal for most other  $Z \rightarrow Y$  relationships. Income, housing prices and employment are such examples. The frequently studied effect of topography on urban form, reflected in variables such as housing prices, population growth, and traffic, is likely to be relevant for most economic research questions in urban settings. The prevalence of agricultural variables suggests that topography interferes with most research questions in more agrarian economies where agriculture is the main income source. The causal web also confirms topography's pertinence for infrastructure. At least for these research questions, topography can be considered ubiquitous, suggesting that IV usage will be hard to defend in most settings. In Appendix B, we show causal webs for subgroups of our full sample, including studies in rural areas, urban areas, and low- versus high-income countries.

**Figure 2: Main causal web for topographic variation**

Note: 116 IV articles and 45 reduced-form articles are included. The direction of the arrows indicates the causal order, and the size of the nodes is proportional to the frequency of the variable in the systematic review. Outcome variables can be outcomes in IV or in reduced-form articles.

### 3.3 A minefield of colliders

The ubiquity of topography outlined in the previous section means that when topography is used as an IV, many variables exist so that ignoring them violates the exclusion restriction and controlling for them introduces collider bias. Despite this hazard, Figure 3 indicates that collider bias is rarely acknowledged in the topography-based IV literature. Only a few articles in our sample mention or discuss threats of collider bias (9%). Meanwhile, 74% of IV articles condition on variables that appear somewhere in the causal web and are thus *potential colliders*. Furthermore, the third bar of Figure 3 shows that 51% of the IV articles condition on variables that scholars in other articles instrumented for because of some suspected correlation to a confounder. We refer to them as *likely colliders*. Only 7% of studies that condition on a potential collider and 6% of those that condition on a likely collider acknowledge or discuss the bias that may result from doing so (not shown in Figure 3).

**Figure 3: Conditioning on colliders in topographic IV articles**

*Note: 116 IV articles are included. Reduced-form articles are not included in this graph. The first bar refers to IV articles that condition on variables that appear in the causal web in Figure 2 (potential colliders). The second bar to IV articles that condition on variables that are instrumented treatment variables in the causal web (likely colliders). The third bar shows the percentage of IV articles that do not explicitly discuss or mention potential collider problems. Three articles do not provide sufficient information on control variables and are therefore not included in this graph.*

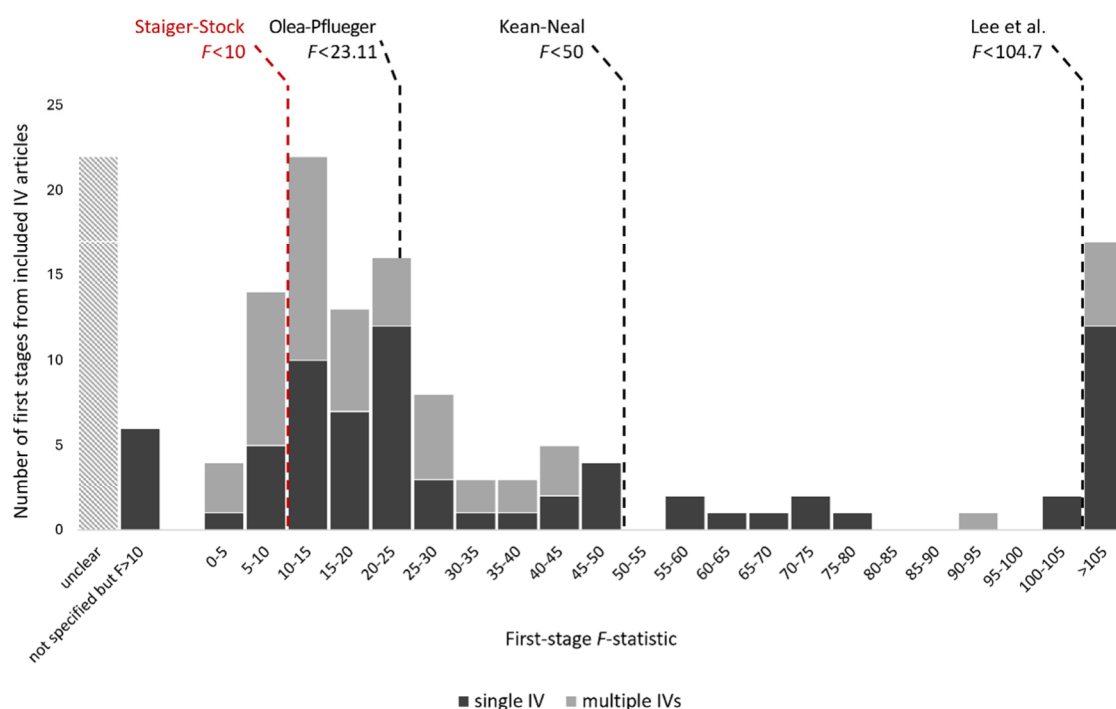
### 3.4 The interaction between ubiquity and weakness

A lenient interpretation of our causal web is that inference based on topographic IVs is still better than no inference – and better than correlating  $Y$  and  $X_1$  by an ordinary regression model. As discussed in Section 2, this lenient interpretation applies to strong IVs and provided the exclusion restriction violations are not too pronounced. The lenient interpretation is not warranted for weak IVs. We therefore now examine the strength of IVs in our sample, which is captured by the first-stage  $F$ -statistic, depicted in Figure 4 for the 147 main specifications in the 116 IV articles. For simplicity, we apply the single-IV benchmarks to multiple-IV studies as well. This is also conservative, considering that the latter would require higher thresholds.

Figure 4 shows that topography is only rarely a strong IV. The median  $F$ -statistic is 23.40, while 22 articles (19% of IV articles) do not provide any information about the  $F$ -statistic at all. Among those articles that do report an  $F$ -statistic, between 15% and 86% of IVs qualify as weak, depending on which benchmark we apply (see Table B1 in the appendix for exact numbers). Using the Staiger and Stock (1997) rule of thumb ( $F > 10$ ), 15% of IVs in our sample are weak, while about 50% of  $F$ -statistics are below the Olea and Pflueger (2013) benchmark of 23.11. A noteworthy share of first stages, about 20%, cluster just above the conventional Staiger-Stock threshold, with  $F$ -statistics between 10 and 15. This is in line with the evidence provided in Brodeur et al. (2020) and Andrews et al. (2019) of screening on first-stage strength. Applying

higher benchmarks, 77% of IVs are classified as weak under the threshold of 50 proposed by Keane and Neal (2024), and 86% under the benchmark of 104.7 implied by Lee et al. (2022). In Table B1 in the appendix we report a series of subgroup analyses demonstrating that the  $F$ -statistic patterns do not change considerably when we restrict the sample to the top-30 journals, more recent articles published between 2018–2023, and IVs in main specifications (and not just as robustness checks).

**Figure 4: First-stage  $F$ -statistics reported in topographic-variation IV articles**



*Note: The figure reports 147 first-stage  $F$ -statistics from 116 IV articles, with multiple  $F$ -statistics included when an article reports more than one main specification. 22 articles do not report a value for the  $F$ -statistic, of which 7 provide a statement that it is above 10 (see the two bars on the left). The figure also displays four weak-IV benchmarks referenced in the literature, with Staiger–Stock’s  $F > 10$  being the mostly frequently used rule of thumb.*

Only 11 articles in our sample provide weak-IV robust confidence intervals, among them six of the eleven studies with  $F$ -statistics below 10. As outlined in Section 2, these robust confidence intervals are not interpretable in the presence of even subtle exclusion restriction violations. Bias sensitivity tests such as from Conley et al. (2012) or Nevo and Rosen (2012) exist, but only 5 articles in our sample apply those. One article (Lessem et al. 2023) uses the weak-IV-robust  $t$ -test correction recently proposed by Lee et al. (2022).

#### 4. Applying the falsificationist approach to Dinkelman (2011)

The evidence we have provided in this paper so far suggests that a lot more skepticism is warranted when using topographic IVs and, as a reader, when interpreting the inference derived from them. We postulate that the use of topographic IVs should be rooted in falsificationism, including rigorous attempts to refute the IV's validity. We argue that such an approach contrasts with common defensive IV strategies, where scholars report evidence benevolently with respect to their IV's validity. Our argument is supported by selective reporting practices observed in applied economics and across the social sciences (see for example Dreber et al. 2024; Fitzgerald 2024; Lal et al. 2024; Simonsohn et al. 2020; Brodeur et al. 2020; Glaeser 2006; Young 2022). In this section, we use the example of a seminal topographic-IV study, Dinkelman (2011, henceforth: DM2011), to showcase the falsificationist approach. We first recapitulate DM2011's approach and the vindication of the IV (Section 4.1). In Section 4.2, we use the very data that is available in the DM2011 replication package to show that applying the falsificationist approach uncovers challenges to the exclusion restriction that are not included in DM2011. Like DM2011, we conduct tests of the exclusion restriction and scrutinize a potential collider. The only difference between our approach and DM2011 is that our intention is not to defend but to falsify the identification assumption.

##### 4.1 DM2011 revisited

DM2011's headline result is that the extension of rural electricity infrastructure in South Africa leads to an increase in women employment rates by around 9 percentage points (p. 3080, 3096, 3105). This effect is considerable given a baseline women employment rate of about 7%. No similar effect for men is observed. As a mechanism, DM2011 suggests that, once the power grid is available, women spend less time on firewood collection and more time under electric light. Therefore, they can increase their labor supply. DM2011 uses the land gradient as IV, based on the assumption that it exogenously affects infrastructure construction cost. The article has had a significant impact on the rural electrification literature but also on the use of topographic IVs in other literatures. As of 2025, it is among the most cited articles from the 2011 AER volume, and it has collected more than 1,500 citations on Google Scholar.

DM2011's key exclusion restriction assumption is that land gradient affects the employment rate only through its effect on electrification. To ensure this, DM2011 conditions on covariates



$X_j$  such as household density, distance to the grid, distance to town, and distance to the nearest major road. Implicitly, DM2011 assumes that these control variables are not correlated with unobservable confounders as depicted in Figure 1c. DM2011 does not explicitly discuss potential collider bias that would emerge if that assumption was violated. DM2011 conducts some robustness checks with respect to the role of migration and agricultural income, but we focus our examination on road access as the most evident causal pathway that challenges the exclusion restriction. DM2011 conducts a robustness check by re-estimating the main IV regression while excluding communities directly intersected by a major national road. DM2011's logic is that if this robustness check affected the results, it would indicate that roads co-determine the electrification effect, making an interpretation difficult. DM2011's robustness check leaves the results practically unchanged, with only a slight decrease in statistical significance, which DM2011 interprets as evidence that road access is unlikely to be an important driver of the increase in female employment.<sup>3</sup> DM2011 does not discuss this robustness check from an explicit collider perspective. Nevertheless, the stability of results in this robustness check indeed increases the confidence that roads are, in practice, not a meaningful collider.

DM2011 also conducts a placebo test to check whether there is a direct effect of the land gradient on employment, which would be a violation of the exclusion restriction, as depicted in Figure 1d. For this she picks areas electrified before 1996, so prior to the 1996–2001 grid roll-out period examined in her main analysis. DM2011 observes no correlation between the land gradient and the employment rate in those areas electrified pre-1996, supporting the exclusion restriction assumption. DM2011 concludes that “gradient is unlikely to directly affect employment outcomes conditional on covariates” (p. 3080).

## 4.2 The falsificationist placebo approach

DM2011 uses areas electrified before 1996 as a placebo population. In contrast, we consider as an alternative placebo population the sub-sample of communities that were still *not* electrified in 2001, so at the end of DM2011's treatment period. The idea is the same: a correlation between

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<sup>3</sup> DM2011 also uses regional fixed effects capturing time-invariant differences in employment growth rates in the labor market. These fixed effects do not account for time-varying effects such as changes in road access during the 1996–2001 period or differing development trends across communities that were connected at different points in time prior to 1996 (see, for example, Fenske 2013; Hurtt et al. 2011; Michalopoulos and Papaioannou 2014).

the land gradient and female employment would suggest a violation of the exclusion restriction. The falsificationist approach that we propose calls for conducting both placebo tests, not only one. Results are shown in Table C1 in the appendix. We successfully replicate DM2011's test, which confirms the exclusion restriction. However, our alternative test indicates a significant correlation between land gradient and employment in the new placebo sample. The falsificationist approach thus leads to the need for defending the exclusion restriction against the result of the second test by formulating an additional assumption about how these populations differ: one must assume that the alternative placebo population is incomparable to the study population.

### 4.3 A falsificationist perspective on roads (as a collider)

Our causal web in Section 3 suggest that other infrastructure types are potentially problematic as collider variables.<sup>4</sup> We therefore now examine the role of road access in DM2011. We simply expand DM2011's heterogeneity analysis in which she excluded communities directly intersected by a major road. This specific robustness check confirmed her main results. However, we show that the patterns change considerably when expanding the heterogeneity analysis to different levels of road access. For this, we re-run DM2011's robustness check, but now for varying definitions of distance to the next major road, see Figure 5. The point estimates vary considerably, contradicting the DM2011 verdict that roads do not have a consequential role. The falsificationist perspective hence suggests that we cannot attenuate concerns about roads as a collider. Without additional information and assumptions about why road placement in South Africa should be uncorrelated to confounders it is likely that the DM2011 analysis faces the classical dilemma situation: either drop roads as a control variable, leading to an exclusion restriction violation as depicted in Figure 1d, or include roads as a control variable and thereby introduce collider bias as depicted in Figure 1e.

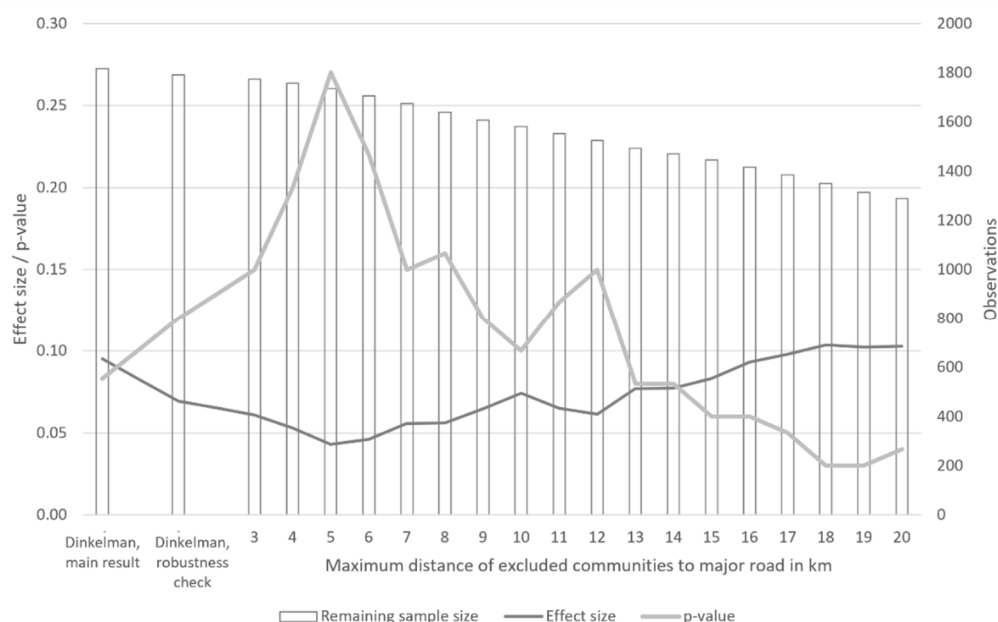
The possibility that roads can be an alternative causal channel through which land gradient may influence women employment can be illustrated by swapping the research question. We now use road access as the treatment variable and include electrification as a control (akin to reversing  $X_1$  and  $X_j$  in Figure 1e) and compare the results to the original specification. Thereby,

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<sup>4</sup> See Lee et al. (2020) for a discussion of DM2011's exclusion restriction assumption.

we also check whether land gradient predicts road access (the first stage) and whether roads are associated with women employment (the second stage). As can be seen in Table C2 in the appendix, the results for roads are very similar to the DM2011 results for electrification. This indicates that a very similar paper could have been written, just for roads as the variable of interest. As a matter of course, both DM2011 and this hypothetical paper on roads would suffer from the same shortcoming, the collider bias induced by controlling for the other infrastructure type, respectively. Nevertheless, this comparison underpins the inconclusiveness of whether electrification or road access drive the results – or in fact another unobserved variable that is correlated with both infrastructure types.

**Figure 5: IV estimates of electrification effect on employment excluding communities by distance to roads**



*Note: Dinkelman's main result and results from her robustness check that excludes communities cut by a major national road are presented on the left of the figure. The rest of the figure shows results when excluding communities at 3 to 20 km distance between the centroid of the community and the nearest major road. The share of treatment units remains stable over the different analyses, with between 21 and 25% of dropped sites being treatment units. The distances of major roads in Dinkelman's robustness check are mostly below 3km. The median distance in the sample is 33 km.*

We further probe into the importance of roads by conducting the Cinelli-Hazlett bias analysis (Cinelli and Hazlett 2025). The intuition is to check whether the bias that occurs when excluding the potential collider variable is noteworthy or not. If the resulting bias is minimal, one might choose to exclude the variable instead of introducing a collider bias. The test evaluates how strongly the potential collider, roads in this case, needs to be correlated with both the IV and the outcome to render the original results statistically insignificant. The

analysis shows that the estimated electrification effect would stop being statistically significant at the 10% (5%) level if an unaccounted control variable such as road access explained about 1.1% (0.4%) of residual variation in the women employment rate that is not explained by the original model without road access. There is no agreed threshold for when the Cinelli-Hazlett bias analysis should trigger concern. These values, however, are small enough to unequivocally reject the approach of excluding roads from the model.

#### **4.4 Falsificationist dealing with IV weakness**

We saw in our systematic review that topography often has weak-IV problems. Land gradient in DM2011 is weak by all conventional standards. The first-stage  $F$ -statistic of 8.3 even falls below the commonly accepted threshold of 10 (Staiger and Stock 1997). DM2011 provides weak-IV robust AR confidence intervals in main tables, but our falsificationist perspective on the DM2011 assumption casts serious doubts on the exclusion restriction and thus the validity of these confidence intervals. It is also noteworthy that DM2011 throughout the paper refers to the point estimates for the employment effects (9 to 9.5 percentage points), not the AR confidence intervals ranging between 2 and 26 percentage points.

Moreover, the paper contains a consequential coding error. The AR confidence intervals reported in the paper are not, as stated, the 95% confidence intervals but the 90% confidence intervals. Hence, the reported intervals are substantially narrower than they should be. Correcting this coding error shows that the true 95% confidence interval is above zero yet unbounded, ranging from 1 percentage point to infinity. While the qualitative conclusion of a positive effect does not change, this correction is consequential because it eliminates any finite upper bound on the effect size, thereby weakening the interpretability of the causal claim. In sum, any inference based on the DM2011 analysis is difficult to defend once the falsificationist approach is applied.

### **5. Conclusion**

Our paper shows that topography – frequently used as an IV in economics – sits within a dense causal web relevant to many outcomes of interest. This ubiquity heightens the risk of exclusion restriction violations and of collider bias. We also synthesize recent econometric advances on

how instrument strength affects inference, particularly when identifying assumptions are in doubt, and apply these insights to the topography-IV literature. Our results document that there is very little awareness of how prudent IVs need to be handled. In particular, control variables intended to protect the exclusion restriction are frequently deployed too casually without sufficient attention to the collider bias they may induce.

We study the topographic IV literature as a case study, and the extent to which our observations generalize to other IV applications is somewhat speculative. But meta-analytical evidence from within economics and neighboring social sciences suggests that the casual handling of IVs is not only an issue within the literature that exploits topographic variation. IVs always operate in a field of tension: if they are too relevant, they usually evoke exclusion restriction violation concerns, because it is unlikely that they shift only the one instrumented treatment variable and not other variables in the causal web as well. More subtle IVs easily become weak, leading to a situation in which even decent exclusion restriction violations induce bias that is larger than the original endogeneity bias in a naïve linear regression model.

The remedy we propose – a falsificationist approach – is no silver bullet, not least because to readers and referees it may be difficult to distinguish from the prevailing practice: a ‘vindication’ stance that offers plausibility arguments with little systematic stress-testing. We also acknowledge that it is likely unrealistic to expect researchers to rigorously falsify their own identifying strategy. For that reason, published IV designs should be routinely subjected to critical replication and reanalysis by independent scholars applying a falsificationist lens, in the spirit of Merton’s principle of organized skepticism (Ankel-Peters et al. 2023; Christensen and Miguel 2018; Peterson and Panofsky 2021). This might lead to a new equilibrium in which those IV applications survive that are indeed able to tease out causality for research questions that are otherwise impossible to scrutinize using the credibility revolution toolkit.

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## Supporting Information

### Appendix A: Search process and output of systematic literature review

We follow a multi-stage search process: First, we search titles, abstracts and keywords in the citation database SCOPUS and full texts among the first 300 entries of Google Scholar for articles that have one of the following search terms: topography, gradient, slope, elevation, ruggedness, terrain, steep, land, surface, geography, and geology. We defined our eligibility criterion of being published in a top-120 economics journal based on the *Simple IDEAS/RePEc Impact Factor* ranking as of 10th June 2022. We then narrowed down these articles to those capturing the stricter definition of topographic variation, related to slope, elevation, and ruggedness. To specifically identify IV studies, we search for combinations of these search terms with the word “instrument”. Second, we manually add studies meeting our criteria from Gallen and Raymond (2023), a broader review on exclusion-restriction violations. Third, we apply a comprehensive forward and backward citation search using the articles identified in the first two steps. Fourth, we apply another round of forward and backward citation search to those studies identified in the third step. We later updated our systematic review with articles published in 2022 and 2023 by repeating the comprehensive forward and backward citation search.

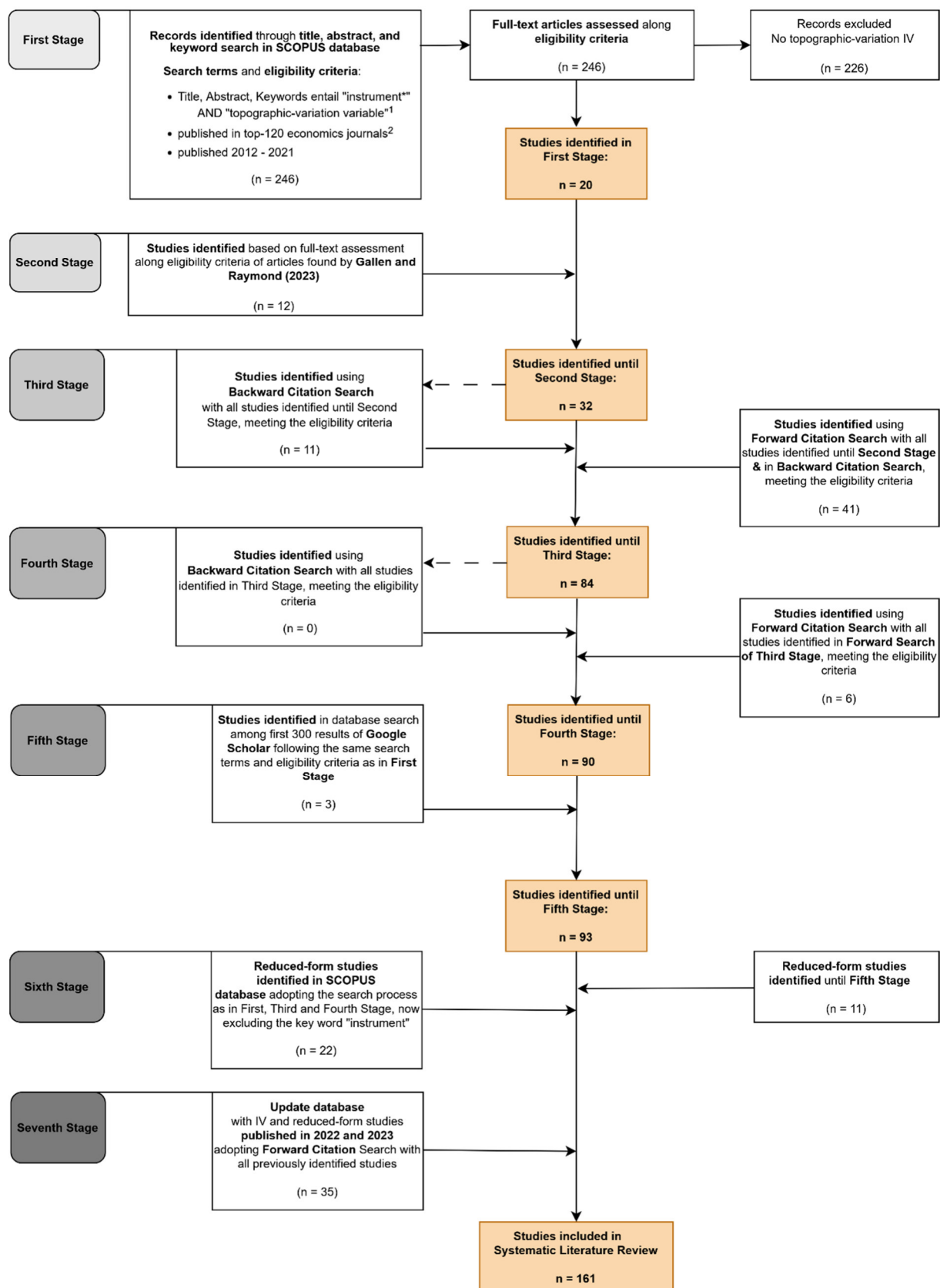
Topographic-variation IV studies not covered by our review because of our eligibility criteria related to publication journal and date include studies from (slightly) lower-ranked journals (e.g. Shrestha 2020 in *Economic Development and Cultural Change* and Alacevich and Zejcirovic 2020 in the *Journal of Comparative Economics*), studies published before 2012 (e.g. Mian and Sufi 2011; Dinkelman 2011; and Duflo and Pande 2007), and studies published after 2021 (e.g. Dendup 2022).

The flow chart in Figure A1 illustrates this search process as implemented. This illustration deviates from the above description in that the above description considers the fifth and sixth stage as integrated into the first four stages, which they conceptually are. The outcome of the search process is identical, irrespective of whether the stages are carried out in parallel or in sequence.

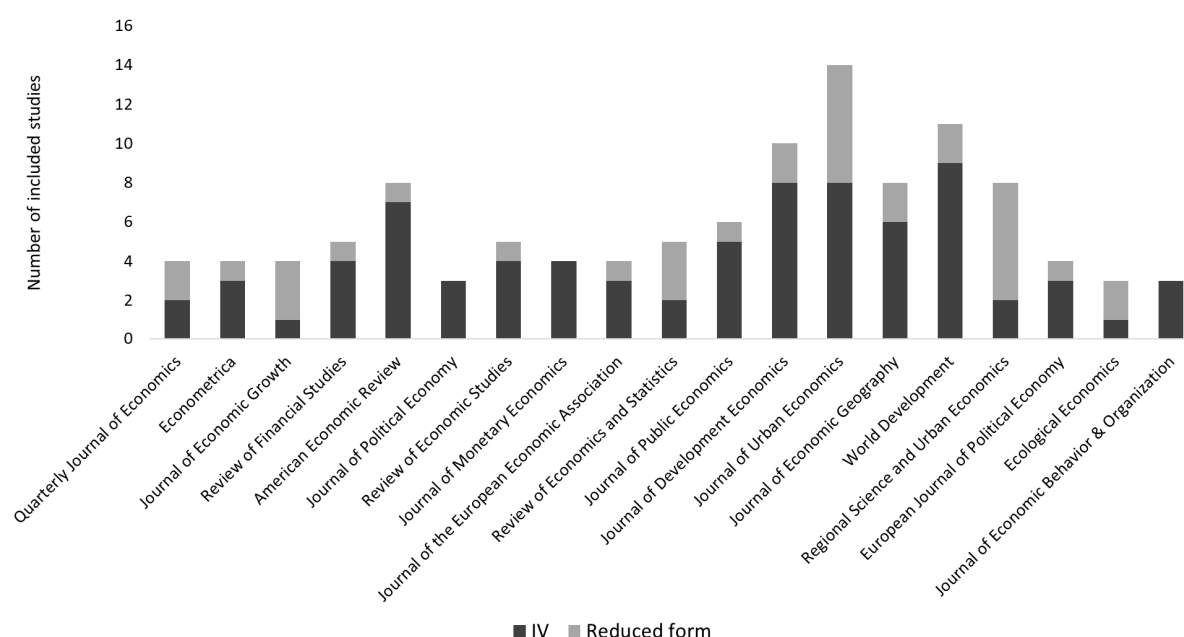
Beyond the study's specific instrument, the instrumented variable, and outcome variables listed in Table A1, we extracted information to inform on the conditioning on colliders and descendants, mechanisms, the first stage strength of the instruments, the study population (i.e. country), observation period, and information on how the topographic-variation instrument is constructed, i.e. whether it is a single measure (e.g. slope above 15%) or an index (e.g. slope interacted with elevation difference or non-topographic components). The journals in which the different studies were published are shown in Figure A2.

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**Figure A1: Flow chart of systematic review search process**

Note: <sup>1</sup> Topographic-variation variable terms include topography, gradient, slope, elevation, ruggedness, terrain, steep, land, surface, geography, geology. <sup>2</sup> According to Simple IDEAS/RePEc Impact Factor ranking as of 10<sup>th</sup> June 2022.

**Figure A2: Included studies by economics journals**

Note: The graph shows the number of studies for all journals with at least three included studies. The studies in the graph sum up to 127 studies, thus representing almost 80% of all included studies.

**Table A1: Details on studies identified in systematic literature review**

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
<b>IV studies</b>					
1	Aaberge, R., Eika, L., Langørgen, A., & Mogstad, M. (2019). Local governments, in-kind transfers, and economic inequality. <i>Journal of Public Economics</i> , 180, 103966.	geographical characteristics such as meters of river, <b>steepness of terrain</b> , average precipitation	local public revenue from hydropower plants	residential mobility (migration)	Norway 1982-2013
2	Accetturo, A., Lamorgese, A. R., Mocetti, S., & Pellegrino, D. (2021). Housing supply elasticity and growth: Evidence from Italian cities. <i>Journal of Economic Geography</i> , 21(3), 367-396.	land consumption in 1971, <b>land slope</b> , fraction of surface covered by water bodies, <b>land fragmentation</b> , demand shocks	housing supply	1. employment 2. wages 3. housing prices	Italy 1971, 1981, 1991, 2001, 2011
3	Achten, S. & Lessmann, C. (2020). Spatial inequality, geography and economic activity. <i>World Development</i> , 136, 105114.	light, climate, distance to water bodies, <b>terrain properties (soil constraints, elevation and ruggedness)</b> , biomes	spatial inequality (measured via night light activity)	1. economic activity	Iberian peninsula 2008-2012

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
4	Adelino, M., Schoar, A., & Severino, F. (2015). House prices, collateral, and self-employment. <i>Journal of Financial Economics</i> , 117(2), 288-306.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	1. employment 2. migration 3. firms' collateral	USA 2002-2007
5	Aguirre, A. (2016). The risk of civil conflicts as a determinant of political institutions. <i>European Journal of Political Economy</i> , 42, 36-59.	<i>multiple instruments:</i> <b>rough terrain</b> ; rainfall volatility	civil conflict	executive constraints on ruler (political institutions)	globally 20 <sup>th</sup> century
6	Akalbeo, B., Martinez-Vazquez, J., & Yedgenov, B. (2023). Fiscal decentralization and structural versus cyclical unemployment levels. <i>European Journal of Political Economy</i> , 80, 102477.	<i>multiple instruments:</i> <b>geographical fragmentation index; ruggedness, land area</b>	fiscal decentralization	employment	globally 1991-2012
7	Aladangady, A. (2017). Housing Wealth and Consumption: Evidence from Geographically Linked Microdata. <i>American Economic Review</i> , 107(11), 3415-3446.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010)</b> ; interest rate; and combinations thereof	housing prices	consumption	USA 1986-2008
8	Albert, C., & Monras, J. (2022). Immigration and Spatial Equilibrium: The Role of Expenditures in the Country of Origin. <i>American Economic Review</i> , 112(11), 3763–3802.	<i>Two instruments:</i> 1. unavailable land (share of land unavailable for development within a radius of 50 km from each MSA's central business district)  2. land unavailability derived from elevation changes (Saiz 2010)	housing prices	cities' immigrant concentration	USA 1980-2010
9	Alimov, A. (2016). Product market effects of real estate collateral. <i>Journal of Corporate Finance</i> , 36, 75-92.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> interest rate	housing prices	firms' collateral	USA 1996-2013
10	Allcott, H., Collard-Wexler, A., & O'Connell, S. D. (2016). How Do Electricity Shortages Affect Industry? Evidence from India. <i>American Economic Review</i> , 106(3), 587-624.	water availability dependent on elevation changes for hydro electricity	electricity shortages from hydroelectric power	1. energy inputs 2. intermediate goods 3. employment, 4. firms' revenue	India 1992-2010
11	Amior, M. & Halket, J. (2014). Do households use home-ownership to insure themselves? Evidence across U.S. cities. <i>Quantitative Economics</i> , 5(3), 631-674.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	home ownership	USA 1995-2000

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
12	Andersen, J. J., Fiva, J. H., & Natvik, G. J. (2014). Voting when the stakes are high. <i>Journal of Public Economics</i> , 110, 157-166.	<b>land gradient, slope of river</b> , precipitation, water flow in rivers	hydropower income (local public revenue)	voter turnout	Norway 2007
13	Anderson, G., Bahaj, S., Chavaz, M., Foulis, A., & Pintér, G. (2023). Lending Relationships and the Collateral Channel. <i>Review of Finance</i> , 27(3), 851–887.	(mortgage interest rate* <b>land unavailability derived from elevation changes (Saiz 2010)</b> )* firm's initial collateral holding	firm's collateral	corporate investment	USA 2002-2013
14	Asriyan, V., Laeven, L., & Martin, A. (2022). Collateral Booms and Information Depletion. <i>Review of Economic Studies</i> , 89(2), 517–555.	real mortgage rate* <b>land unavailability derived from elevation changes (Saiz 2010)</b>	(residential) housing prices	lending relationship duration	USA 1993-2016
15	Awaworyi Churchill, S. (2017). Fractionalization, entrepreneurship, and the institutional environment for entrepreneurship. <i>Small Business Economics</i> , 48(3), 577-597.	<i>multiple instruments</i> : latitude; variation in land quality; <b>elevation changes</b>	ethnic fractionalization	becoming entrepreneur	globally 2006-2010
16	Baker, S. R. (2018). Debt and the Response to Household Income Shocks: Validation and Application of Linked Financial Account Data. <i>Journal of Political Economy</i> , 126(4), 1504-1557.	<i>multiple instruments</i> : <b>land unavailability derived from elevation changes (Saiz 2010)</b> * homeowner status 2008; firm shocks as an instrument for income	household debt	consumption	USA 2008-2013
17	Baniya, S., Rocha, N., & Ruta, M. (2020). Trade effects of the New Silk Road: A gravity analysis. <i>Journal of Development Economics</i> , 146, 102467.	<b>ruggedness</b> , proximity to coast	New Silk Road	trade flows	globally 2013
18	Beaudry, P., Green, A., & Sand, B. (2012). Does industrial composition matter for wages? A test of search and bargaining theory. <i>Econometrica</i> , 80 (3), 1063-1104.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	city-industry wages (wages)	USA 1970-2007
19	Bednarek, P., Kaat, D. M. T., Ma, C., & Rebucci, A. (2021). Capital Flows, Real Estate, and Local Cycles: Evidence from German Cities, Banks, and Firms. <i>The Review of Financial Studies</i> , 34(10), 5077-5134.	<i>multiple instruments</i> : <b>land unavailability derived from elevation changes (steep-slope terrain)</b> ; share of refugees; and combinations thereof	housing prices	city's economic growth (income)	Germany 2009-2014
20	Bennett, D. (2012). Does clean water make you dirty? Water supply and sanitation in the Philippines. <i>Journal of Human Resources</i> , 47(1), 146-173.	<i>multiple instruments</i> : <b>elevation changes</b> ; geology; distance to limestone	pipel water supply	1. sanitation 2. school attendance	Philippines (Cebu) 1983-2005

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
21	Bensassi, S., & Jarreau, J. (2019). Price discrimination in bribe payments: Evidence from informal cross-border trade in West Africa. <i>World Development</i> , 122, 462-480.	terrain ruggedness	border crossing points	bribe payments	Benin 2011
22	Bentzen, J. S., Kaarsen, N., & Wingender, A. M. (2017). Irrigation and autocracy. <i>Journal of the European Economic Association</i> 15(1), 1-53.	irrigation potential (temperature, precipitation, cloud cover, altitude, crop-specific evapotranspiration, soil texture, <b>slope of the terrain, land suitable for agriculture</b> )	irrigation, land inequality (land ownership)	democracy index (democratization)	globally 19 <sup>th</sup> and 20 <sup>th</sup> century
23	Berger, D., & Vavra, J. (2015). Consumption Dynamics During Recessions. <i>Econometrica</i> , 83(1), 101-154.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	automobile sales	USA 1999-2011
24	Bertazzini, M. C. (2022). The long-term impact of Italian colonial roads in the Horn of Africa, 1935-2015. <i>Journal of Economic Geography</i> , 22(1), 181-214.	ruggedness, land cover	road placement	population density (population growth)	Horn of Africa 1935-2015
25	Bertrand, M., & Morse, A. (2016). Trickle-Down Consumption. <i>Review of Economics and Statistics</i> , 98(5), 863-879.	annual national house price index * <b>land unavailability derived from elevation changes (Saiz 2010)</b>	housing prices	household income (income)	USA 1980-2006
26	Bhattarai, S., Schwartzman, F., & Yang, C. (2021). Local scars of the US housing crisis. <i>Journal of Monetary Economics</i> , 119, 40-57.	<i>multiple instruments: land unavailability derived from elevation changes (Saiz 2010); dummy for lower tercile of orthogonalized 2002-05 house price shocks</i>	housing prices	1. GDP (income) 2. employment 3. population growth	USA 2006-2018
27	Bian, W., Ji, Y., & Zhang, H. (2019). Does dialect similarity add value to banks? Evidence from China. <i>Journal of Banking &amp; Finance</i> . 101, 226-241.	absolute difference of the proportion of mountainous areas in counties in which the chairman and the CEO were born	dialect similarity	banks' economic performance	China 2007-2014
28	Blanc, E., & Strobl, E. (2014). Is small better? A comparison of the effect of large and small dams on cropland productivity in South Africa. <i>The World Bank Economic Review</i> , 28(3), 545-576.	<i>multiple instruments: river gradient; river gradient* dam allocation policy</i>	dam placement	agricultural productivity	South Africa 1994-2000



	<b>Results</b>	<b>Instruments and their components<sup>1</sup></b>	<b>Treatment Variables<sup>2</sup></b>	<b>Outcomes<sup>3</sup></b>	<b>Context</b>
29	Bogart, D., You, X., Alvarez-Palau, E. J., Satchell, M., & Shaw-Taylor, L. (2022). Railways, divergence, and structural change in 19th century England and Wales. <i>Journal of Urban Economics</i> , 128, 103390.	<b>slope</b> , distance to town	railroad construction	1. population density 2. employment structure	England, Wales 1851-1891
30	Borge, L. E., Parmer, P., & Torvik, R. (2015). Local natural resource curse? <i>Journal of Public Economics</i> , 131, 101-114.	<b>land gradient, slope of river</b> , precipitation, water flow in rivers	local public revenue from hydropower plants (local public revenue)	efficiency in local public goods provision (local public goods provision)	Norway 2001-2007
31	Büchel, K., & Kyburz, S. (2018). Fast track to growth? Railway access, population growth and local displacement in 19th century Switzerland. <i>Journal of Economic Geography</i> , 20(1), 155-195.	distance to railway, <b>slope</b> , water bodies	railroad construction	migration	Switzerland 1837-1900
32	Buggle, J. C. (2020). Growing collectivism: Irrigation, group conformity and technological divergence. <i>Journal of Economic Growth</i> , 25(2), 147-193.	irrigation potential (rainfall levels, evapotranspiration, thermal and moisture growing periods, soil textures, <b>terrain slopes, elevation</b> , and crop-specific thermal and water requirements)	irrigation	collectivism of societies	globally 16 <sup>th</sup> century
33	Buonanno, P., Prarolo, G., & Vanin, P. (2016). Organized crime and electoral outcomes. Evidence from Sicily at the turn of the XXI century. <i>European Journal of Political Economy</i> , 41, 61-74.	<i>multiple instruments: difference in elevation within municipality</i> ; agro-ecological suitability; historical mafia presence	mafia presence	election outcomes (political turnover)	Sicily 1994-2013
34	Campello, M., Connolly, R. A., Kankanalli, G., & Steiner, E. (2022). Do real estate values boost corporate borrowing? Evidence from contract-level data. <i>Journal of Financial Economics</i> , 144(2), 611–644.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	corporate investment	USA 2000-2017
35	Canavire-Bacarreza, G., Martinez-Vazquez, J., & Yedgenov, B. (2020). Identifying and disentangling the impact of fiscal decentralization on economic growth. <i>World Development</i> , 127, 104742.	<i>multiple instruments: elevation heterogeneity (mountainous area)</i> ; country size	fiscal decentralization	economic activity (income)	globally 1981-2012

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
36	Carmignani, F. (2013). Development outcomes, resource abundance, and the transmission through inequality. <i>Resource and Energy Economics</i> , 35(3), 412-428.	<i>multiple instruments:</i> mountainous area; rough terrain; elevation changes	violence	1. Human Development (Index) 2. inequality 3. political institutions (rule of law)	globally 1970 - 2010
37	Carvalho, D. (2018). How Do Financing Constraints Affect Firms' Equity Volatility? <i>The Journal of Finance</i> , 73(3), 1139-1182.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> national housing price index* five-year lag of the ratio of real estate assets to total assets	change in the value of real estate holdings (housing prices)	firms' equity volatility	USA 1990-2010
38	Chakraborty, I., Goldstein, I., & MacKinlay, A. (2018). Housing price booms and crowding-out effects in bank lending. <i>The Review of Financial Studies</i> , 31(7), 2806-2853.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010);</b> 30-year fixed mortgage interest rate; and combinations thereof	housing prices	1. banks' credit supply (credit supply) 2. firms' investments (corporate investment)	USA 1988-2006
39	Chakravorty, U., Pelli, M., & Ural Marchand, B. (2014). Does the quality of electricity matter? Evidence from rural India. <i>Journal of Economic Behavior &amp; Organization</i> , 107, 228-247.	<b>density of transmission lines influenced by mountainous topography*</b> initial value of electrification	electrification	income per capita (income)	India 1994-2005
40	Chaney, T., Sraer, D., & Thesmar, D. (2012). The collateral channel: How real estate shocks affect corporate investment. <i>American Economic Review</i> , 102(6), 2381-2409.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> long-term interest rates	housing prices	corporate investment	USA 1993-2007
41	Chen, T., & Kung, J. K.-S. (2016). Do land revenue windfalls create a political resource curse? Evidence from China. <i>Journal of Development Economics</i> , 123, 86-106.	<b>steep terrain (slope)*</b> interest rate, <b>steep terrain (slope)*</b> average national housing prices	land revenue	political turnover	China 1999-2008
42	Chen, Y. (2023). Environmental regulation, local labor market, and skill heterogeneity. <i>Regional Science and Urban Economics</i> , 101, 103898.	<i>multiple instruments:</i> thermal inversion intensity in 1998; thermal power plant suitability ( <b>elevation, ruggedness</b> , suitability for agriculture, distance to coal mine, oil or gas fields, large river, small stream, coal source, earthquake spot...)	air pollution	1. (local) employment structure 2. population growth	China 1982-2010

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
43	Chetty, R., Sandor, L., & Szeidl, A. (2017). The effect of housing on portfolio choice. <i>The Journal of Finance</i> , 72(3), 1171-1212.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> year-of-purchase average house price	housing prices	households' assets	USA 1990-2008
44	Conklin, J. N., Frame, W. S., Gerardi, K., & Liu, H. (2022). Villains or scapegoats? The role of subprime borrowers in driving the US housing boom. <i>Journal of Financial Intermediation</i> , 51, 100906.	land unavailability ( <b>slope</b> , water bodies)	housing prices	subprime purchase mortgage lending, i.e. high credit risk	USA 2002-2006
45	Corradin, S., & Popov, A. (2015). House prices, home equity borrowing, and entrepreneurship. <i>The Review of Financial Studies</i> , 28(8), 2399-2428.	change in national house prices, <b>land unavailability derived from elevation changes (Saiz 2010)</b>	home equity	self-employment (becoming entrepreneur)	USA 1996-2006
46	Costinot, A., Donaldson, D., & Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. <i>Journal of Political Economy</i> , 124(1), 205-248.	exogenous supply shocks based on field's growing characteristics and yield (soil, <b>land gradient, elevation...</b> ), crop specifics, additional inputs (machinery, fertilizer...)	crop prices	global production/ GDP (income)	globally 21 <sup>st</sup> century
47	Cvijanović, D. (2014). Real estate prices and firm capital structure. <i>The Review of Financial Studies</i> , 27(9), 2690-2735.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> changes in real estate prices* firm's real estate holdings 1993	housing prices	firms' leverage	USA 1993-2006
48	Damania, R., Russ, J., Wheeler, D., & Barra, A. F. (2018). The road to growth: Measuring the tradeoffs between economic growth and ecological destruction. <i>World Development</i> , 101, 351-376.	<i>multiple instruments:</i> <b>ruggedness and slope;</b> and Euclidean distance to nearest market; and combinations thereof	1. access to markets 2. violence 3. road proximity	1. agricultural production (income) 2. agricultural production (income) 3. deforestation	DR Congo 2000-2012
49	Dendup, N. (2022). Returns to grid electricity on firewood and kerosene: Mechanism. <i>Journal of Environmental Economics and Management</i> , 111, 102606.	<i>multiple instruments:</i> <b>land gradient;</b> distance to power plant	electrification	1. firewood consumption 2. energy consumption (energy inputs)	Bhutan 2007-2017
50	Dettling, L. J., & Kearney, M. S. (2014). House prices and birth rates: The impact of the real estate market on the decision to have a baby. <i>Journal of Public Economics</i> , 110, 82-100.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> national version of the FHFA house price index	housing prices	fertility rate	USA 1990-2007

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
51	Diamond, R. (2016). The determinants and welfare implications of US workers' diverging location choices by skill: 1980–2000. <i>American Economic Review</i> , 106(3), 479–524.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010)</b> ; land regulation	housing supply	worker's location choice (employment structure)	USA 1980-2000
52	Dinkelman, T., & Schulhofer-Wohl, S. (2015). Migration, congestion externalities, and the evaluation of spatial investments. <i>Journal of Development Economics</i> , 114, 189–202.	land gradient	electrification	1. migration 2. household density	South Africa 1996-2001
53	Djemai, E. (2018). Roads and the spread of HIV in Africa. <i>Journal of Health Economics</i> , 60, 118–141.	<b>slope</b> (in additional specifications: location of historical routes, location of hypothetical lines connecting historical cities)	road proximity	HIV prevalence	Cameroon, Ethiopia, Kenya, Malawi, Zimbabwe 2003-2016
54	Dong, X., Zheng, S., & Kahn, M. E. (2020). The role of transportation speed in facilitating high skilled teamwork across cities. <i>Journal of Urban Economics</i> , 115, 103212.	<i>multiple instruments:</i> historical railroad access; <b>city slope</b>	city's connection to high-speed-railway	work productivity, i.e. published papers of Chinese universities (research productivity)	China 2001-2016
55	Duranton, G., & Turner, M. A. (2018). Urban form and driving: Evidence from us cities. <i>Journal of Urban Economics</i> , 108, 170–191.	<i>multiple instruments:</i> <b>uninhabitable land surface</b> ; earthquake intensity; landslide intensity	urban density (population growth)	city traffic	USA 1990-2010
56	Egger, P. H., Loumeau, G., & Loumeau, N. (2023). China's dazzling transport-infrastructure growth: Measurement and effects. <i>Journal of International Economics</i> , 142, 103734.	<b>ruggedness</b> , latitude, distance to prefecture	road-/railway-construction	population growth	China 2000-2013
57	Emran, M. S., & Hou, Z. (2013). Access to markets and rural poverty: evidence from household consumption in China. <i>The Review of Economics and Statistics</i> , 95(2), 682–697.	<i>multiple instruments:</i> distance to waterbodies; distance to business center; <b>elevation; slope</b> ; and combinations thereof	access to domestic and international markets (access to markets)	per capita consumption (consumption)	China 1995
58	Ersahin, N., & Irani, R. M. (2020). Collateral shocks and corporate employment*. <i>Review of Finance</i> , 24(1), 163–187.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> long-term interest rate* market value of real estate in 1993	local real estate growth (housing prices)	firms' employment expenditures	USA 1993-2006

	<b>Results</b>	<b>Instruments and their components<sup>1</sup></b>	<b>Treatment Variables<sup>2</sup></b>	<b>Outcomes<sup>3</sup></b>	<b>Context</b>
59	Faber, B. (2014). Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System. <i>The Review of Economic Studies</i> , 81(3), 1046-1070.	<b>slope, gradient, elevation</b> , water bodies	road construction	1. firms' revenue, 2. local public revenue 3. total GDP (income) 4. population growth	China 1990-2007
60	Faberman, R. J., & Freedman, M. (2016). The urban density premium across establishments. <i>Journal of Urban Economics</i> , 93, 71-84.	<i>multiple instruments:</i> <b>mean elevation, ruggedness</b> ; water bodies; soil types; number of universities; and combinations thereof	urban density (population growth)	wages	USA 1992-1997
61	Farré, L., Jofre-Monseny, J., & Torrecillas, J. (2023). Commuting time and the gender gap in labor market participation. <i>Journal of Economic Geography</i> , 23(4), 847-870.	city compactness (based on cities' topography)	commuting (travel time)	female labor supply	USA 1990-2011
62	Farrokhi, F. (2021). Skill, agglomeration and inequality in the spatial economy. <i>International Economic Review</i> , 62(2), 671-721.	land unavailability derived from elevation changes (Saiz 2010), natural amenities	city size	wages	USA 1980-2000
63	Favara, G., & Imbs, J. (2015). Credit supply and the price of housing. <i>American Economic Review</i> , 105(3), 958-992.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010)</b> ; deregulation of branch banking	credit supply	1. housing prices 2. housing supply	US urban counties with available mortgage data 1994-2005
64	Feld, L. P., Frey, C., Schaltegger, C. A., & Schmid, L. A. (2021). Fiscal federalism and income inequality: An empirical analysis for Switzerland. <i>Journal of Economic Behavior &amp; Organization</i> , 185, 463-494.	<i>multiple instruments:</i> <b>geographical fragmentation (index of topography, altitude, mountainous area)</b> ; harmonization law; jurisdictional fragmentation	fiscal decentralization	income inequality	Switzerland 1945-2016
65	Feng, Y., Yuan, H., Liu, Y., & Zhang, S. (2023). Does new-type urbanization policy promote green energy efficiency? Evidence from a quasi-natural experiment in China. <i>Energy Economics</i> , 124, 106752.	<b>urban slope*</b> national economic growth target	urban development	energy efficiency	China 2003-2017
66	Fenske, J., Kala, N., & Wei, J. (2023). Railways and cities in India. <i>Journal of Development Economics</i> , 161, 103038.	<b>(slope, distance to railroad)*</b> year	railroad construction	1. population growth 2. market access	India 1881-1931

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
67	Flannery, M. J., Lin, L., & Wang, L. (2022). Housing booms and bank growth. <i>Journal of Financial Intermediation</i> , 52, 100993.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	bank asset growth (banks' economic performance)	USA 2001-2006
68	Fougere, D., Lecat, R., & Ray, S. (2019). Real estate prices and corporate investment: Theory and evidence of heterogeneous effects across firms. <i>Journal of Money, Credit and Banking</i> , 51(6), 1503-1546.	<b>land unavailability derived from elevation changes*</b> interest rate	housing prices	investment behavior of firms (corporate investment)	France 1998-2015
69	Frick, S. A., & Rodríguez-Pose, A. (2018). Change in urban concentration and economic growth. <i>World Development</i> , 105, 156-170.	ruggedness	urban concentration (population growth)	economic growth (income)	globally 1985-2010
70	Gaggl, P., Gray, R., Marinescu, I., & Morin, M. (2021). Does electricity drive structural transformation? Evidence from the United States. <i>Labour Economics</i> , 68, 101944.	<b>hydro-electric potential derived from land gradient</b> , stream flow, and engineering constraints	electrification	employment structure	USA 1910-1940
71	Gergaud, O., Plantina, A., Ringeval-Deluze, A. (2017). Anchored in the past: Persistent price effects of obsolete vineyard ratings in France. <i>Journal of Economic Behavior &amp; Organization</i> , 133, 39-51.	soil, <b>slope</b> , weather of neighboring vineyards	historical wine prices	current wine prices	France 2002-2012
72	Giroud, X., & Mueller, H. M. (2017). Firm leverage, consumer demand, and employment losses during the great recession. <i>The Quarterly Journal of Economics</i> , 132(1), 271-316.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	employment	USA 2007-2009
73	Glancy, D. (2021). Housing bust, bank lending & employment: Evidence from multimarket banks. <i>Journal of Banking &amp; Finance</i> , 127, 106111.	land unavailability derived from elevation changes (Saiz 2010)	banks' exposure to weak real estate markets	employment	USA 2007-2010
74	Greaney, B., & Walsh, C. (2023). Demand, growth, and deleveraging. <i>Review of Economic Dynamics</i> , 51, 795–812.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	1. becoming entrepreneur 2. employment	USA 1980-2017
75	Grogan, L., & Sadanand, A. (2013). Rural electrification and employment in poor countries: Evidence from Nicaragua. <i>World Development</i> , 43, 252-265.	<i>multiple instruments: slope</i> ; past population density	electrification	employment	Nicaragua 1998-2005

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
76	Guerrieri, L., & Iacoviello, M. (2017). Collateral constraints and macroeconomic asymmetries. <i>Journal of Monetary Economics</i> , 90, 28-49.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	automobile sales	USA 2002-2010
77	Gupta, R., & Pelli, M. (2021). Electrification and cooking fuel choice in rural India. <i>World Development</i> , 146, 105539.	<b>hydro-electric power availability derived from topographic cost considerations</b> ; night light intensity	electrification	adoption of modern cooking fuels	India 2004-2009
78	Guren, A. M., McKay, A., Nakamura, E., & Steinsson, J. (2021). Housing wealth effects: The long view. <i>The Review of Economic Studies</i> , 88(2), 669-707.	annual national house price index* <b>land unavailability derived from elevation changes (Saiz 2010)</b>	housing prices	employment	USA 1978-2017
79	Harari, M. (2020). Cities in bad shape: Urban geometry in India. <i>American Economic Review</i> , 110(8): 2377-2421.	<b>topological constraints, slopes, steep terrain</b> , water bodies	city shape (city size)	1. population, wages 2. housing rents	India 1950-2010
80	Hochard, J., & Barbier, E. (2017). Market accessibility and economic growth: Insights from a new dimension of inequality. <i>World Development</i> , 97, 279-297.	<i>multiple instruments: terrain slope; elevation</i> ; historical road network; land area	market access	economic growth (income)	globally 2000-2012
81	Hoffmann, M., & Stewen, I. (2020). Holes in the dike: The global savings glut, U.S. house prices, and the long shadow of banking deregulation. <i>Journal of the European Economic Association</i> , 18(4), 2013-2055.	<i>multiple instruments: land unavailability derived from elevation changes (Saiz 2010)</i> ; capital inflows; and combinations thereof	mortgage lending (credit supply)	housing prices	USA 1997-2005
82	Holl, A. (2012). Market potential and firm-level productivity in Spain. <i>Journal of Economic Geography</i> , 12(6), 1191-1215.	<i>multiple instruments: historical road network; terrain ruggedness</i> ; historical market potential; and combinations thereof	market potential	1. productivity (firms' revenue) 2. labor supply (employment)	Spain 1991-2005
83	Hornung, E. (2015). Railroads and Growth in Prussia. <i>Journal of the European Economic Association</i> , 13(4), 699-736.	slope, terrain irregularities	railroad construction	population growth	Prussia 1840-1871
84	Hossain, M. I., Duong, H. N., Al Mamun, M., & Docherty, P. (2023). Collateral shocks and M&A decisions. <i>Journal of Corporate Finance</i> , 82, 102433.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> mortgage interest rates	housing prices	merger and acquisitions	USA 1994-2015
85	Jaimovich, E. (2019). Roadways, input sourcing, and patterns of specialization. <i>European Economic Review</i> , 120, 103319.	Gini* <b>terrain roughness</b> (elevation measures, mountainous area index)	roadway density* Gini (road construction)	trade flows	globally 2005-2014

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
86	Jedwab, R., Kerby, E., & Moradi, A. (2017). History, path dependence and development: Evidence from colonial railways, settlers, and cities in Kenya. <i>The Economic Journal</i> , 127(603), 1467-1494.	<b>topography, slopes, lakes</b>	railway placement (railroad construction)	settlement (population growth)	Kenya 1901-2009
87	Jessoe, K. (2013). Improved source, improved quality? Demand for drinking water quality in rural India. <i>Journal of Environmental Economics and Management</i> , 66(3), 460-475.	<i>multiple instruments:</i> district covered by soft rock ( <b>ruggedness</b> ); <b>hilly surface</b> ; aquifer depth	household's drinking water source (piped water supply)	household's in-home water treatment	rural India 1998
88	Johnson, W. R. (2014). House prices and female labor force participation. <i>Journal of Urban Economics</i> , 82, 1-11.	<i>multiple instruments:</i> buildable land; <b>slope</b>	housing prices, travel time	1. female labor supply 2. female earnings	USA 2000
89	Kaplan, G., Mitman, K., & Violante, G. L. (2020). Non-durable consumption and housing net worth in the Great Recession: Evidence from easily accessible data. <i>Journal of Public Economics</i> , 189, 104176.	land unavailability derived from elevation changes (Saiz 2010)	housing net value (housing prices)	non-durable consumption (consumption)	USA 2007-2009
90	Khorunzhina, N. (2021). Intratemporal nonseparability between housing and nondurable consumption: Evidence from reinvestment in housing stock. <i>Journal of Monetary Economics</i> , 117, 658-670.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010)*</b> interest rate, house size; lagged local house-price index; lagged local house-price index * lagged state house-price index	housing stock (housing supply)	non-durable consumption (consumption)	USA 2005-2015
91	Kolko, J. (2012). Broadband and local growth. <i>Journal of Urban Economics</i> , 71(1), 100-113.	slope	broadband expansion	employment	USA 1999-2006
92	Krishna, V. V., & Kubitz, C. (2021). Impact of oil palm expansion on the provision of private and community goods in rural Indonesia. <i>Ecological Economics</i> , 179, 106829.	<b>slopes*</b> palmoil exports	palm oil expansion	1. local public goods provision 2. access to private goods	Indonesia 2003-2015
93	Laeven, L., & Popov, A. (2017). Waking up from the American Dream: On the experience of young Americans during the housing boom of the 2000s. <i>Journal of Money, Credit and Banking</i> , 49(5), 861-895.	<i>multiple instruments:</i> <b>land unavailability derived from elevation changes (Saiz 2010)</b> ; local industrial structure	housing prices	1. home ownership 2. marriage rate 3. fertility rate	USA 2001-2006
94	Leisibach, P., Luechinger, S., Roellin, J., & Schaltegger, C. A. (2023). The effects of natural resource revenues on municipal finance. <i>Economic Policy</i> , 38(115), 567-600.	<b>land gradient, slope of river</b> , precipitation, water flow in rivers (combined)	local public revenue from hydropower plants	1. income 2. local public goods provision	Switzerland 1987-2015



	<b>Results</b>	<b>Instruments and their components<sup>1</sup></b>	<b>Treatment Variables<sup>2</sup></b>	<b>Outcomes<sup>3</sup></b>	<b>Context</b>
95	Lessem, R., Niebler, S., & Urban, C. (2023). Do house prices affect campaign contributions? <i>Economics and Politics</i> , 35(2), 629–660.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> annual national house prices	housing prices	US campaign donations	USA 2016
96	Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. <i>American Economic Journal: Applied Economics</i> , 5(2), 200-231.	<b>topographic factors:</b> distance to river, <b>average and maximum gradient of the river</b> , maximum waterflow, indicator for whether located in the Amazon	hydro-dam and grid placement (electrification)	1. Human Development (Index) 2. housing prices	Brazil 1960-2000
97	Liu, C., Wang, W., Wu, Q., & Zhang, H. (2021). Highway networks and allocative efficiency: Firm-level evidence from China. <i>Journal of Transport Economics and Policy (JTEP)</i> , 55(4), 283-307.	<b>slope, gradient, elevation</b> , water bodies (instrument adopted from <i>Faber 2014</i> )	highway expansion (road construction)	factor allocation among firms	China 2010s
98	Loutskina, E., & Strahan, P. E. (2015). Financial integration, housing, and economic volatility. <i>Journal of Financial Economics</i> , 115(1), 25-41.	<i>multiple instruments:</i> share new non-jumbo loan; total fraction of borrowers within +/- 5% of the jumbo-loan cutoff in year t-1; change in the jumbo loan cutoff between t-1 and t; <b>Saiz elasticity of housing supply</b> ; and combinations thereof	housing prices	economic growth (income)	USA 1994-2006
99	Luo, J., Xu, L., & Zurbrugg, R. (2017). The impact of housing wealth on stock liquidity. <i>Review of Finance</i> , 21(6), 2315-2352.	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> change in annual national housing prices	housing prices	households' assets	USA 1991-2012
100	Mehrotra, N., & Sergeyev, D. (2021). Financial shocks, firm credit and the Great Recession. <i>Journal of Monetary Economics</i> 117, 296-315.	annual national house price index* <b>land unavailability derived from elevation changes (Saiz 2010)</b>	housing prices	job creation, job destruction (employment)	USA 2008-2012
101	Mettetal, E. (2019). Irrigation dams, water and infant mortality: Evidence from South Africa. <i>Journal of Development Economics</i> , 138, 17-40.	slope, land gradient	agricultural water use (dam placement)	infant mortality	South Africa 1980-2002
102	Mian, A., & Sufi, A. (2014). What explains the 2007-2009 drop in employment? <i>Econometrica</i> , 82(6), 2197-2223.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	employment	USA 2007-2009

	<b>Results</b>	<b>Instruments and their components<sup>1</sup></b>	<b>Treatment Variables<sup>2</sup></b>	<b>Outcomes<sup>3</sup></b>	<b>Context</b>
103	Mian, A., Rao, K., & Sufi, A. (2013). Household balance sheets, consumption, and the economic slump. <i>The Quarterly Journal of Economics</i> , 128(4), 1687-1726.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	consumption	USA 2006 - 2009
104	Nie, L., & Zhang, Z. (2023). Is high-speed rail heading towards a low-carbon industry? Evidence from a quasi-natural experiment in China. <i>Resource and Energy Economics</i> , 72, 101355.	<i>multiple instruments: (river, <b>slope and relief</b>)*year</i>	railroad construction	industrial CO2 emissions	China 2004-2014
105	Pan, Y., Shroff, N., & Zhang, P. (2023). The dark side of audit market competition. <i>Journal of Accounting and Economics</i> , 75(1), 101520.	slope	railroad construction	audit market competition	China 2008-2017
106	Parkhomenko, A. (2023). Local causes and aggregate implications of land use regulation. <i>Journal of Urban Economics</i> , 138, 103605.	<i>Multiple instruments: <b>irregular topography</b>; distance to salt water</i>	land price	house rent	USA 2005-2007
107	Richards, P. (2018). It's not just where you farm; it's whether your neighbor does too. How agglomeration economies are shaping new agricultural landscapes. <i>Journal of Economic Geography</i> , 18(1), 87-110.	<b>slope, elevation</b> , distance to road	neighbors' land use change	own land use change	Brazil 2001-2011
108	Robalino, J. A., & Pfaff, A. (2012). Contagious development: Neighbor interactions in deforestation. <i>Journal of Development Economics</i> , 97(2), 427-436.	<i>multiple instruments: neighbors' slopes; neighbors' neighbors' slopes</i>	neighbors' deforestation decision (neighbors' deforestation)	own deforestation decision (own deforestation)	Costa Rica 1984-1997
109	Roca, J. D., & Puga, D. (2017). Learning by working in big cities. <i>The Review of Economic Studies</i> , 84(1), 106-142.	<i>multiple instruments: <b>slope; elevation</b>; water bodies; historical roads; past city size</i>	city size	income	Spain 2004-2009
110	Stroebe J., & Vavra J. (2019). House prices, local demand, and retail prices. <i>Journal of Political Economy</i> , 127(3), 1391-1436.	land unavailability derived from elevation changes (Saiz 2010)	housing prices	retail prices	USA 2001-2011
111	Vandecasteele, J., Beyene, S. T., Minten, B., & Swinnen, J. (2018). Big cities, small towns, and poor farmers: Evidence from Ethiopia. <i>World Development</i> , 106, 393-406.	<i>multiple instruments: <b>ruggedness, elevation, slope</b>; and Euclidean distance to nearest market; and combinations thereof</i>	transportation costs (road proximity)	1. agricultural intensification 2. crop prices	Ethiopia 2012

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
112	Waxman, A., Liang, Y., Li, S., Barwick, P. J., & Zhao, M. (2020). Tightening belts to buy a home: Consumption responses to rising housing prices in urban China. <i>Journal of Urban Economics</i> , 115, 103190.	multiple instruments: lagged government revenue; <b>slope (standard deviation of elevation)*</b> lagged government revenue	housing prices	consumption	China 2011-2013
113	Wrenn, D. H., Yi, J., & Zhang, B. (2019). House prices and marriage entry in China. <i>Regional Science and Urban Economics</i> , 74, 118-130.	multiple instruments: <b>slope</b> ; water bodies; and combinations thereof	housing prices	marriage rate	China 2000-2005
114	Wu, M., Yu, L., & Zhang, J. (2023). Road expansion, allocative efficiency, and pro-competitive effect of transport infrastructure: Evidence from China. <i>Journal of Development Economics</i> , 162, 103050.	( <b>terrain ruggedness, land cover, and elevation</b> )* budget ratio of road in year t	road construction	factor allocation among firms	China 1998-2007
115	Zhang, J., & Xu, L. C. (2016). The long-run effects of treated water on education: The rural drinking water program in China. <i>Journal of Development Economics</i> , 122, 1-15.	topography, hills, land gradient	drinking water	schooling attendance	China 1989-2011
116	Zhou, X. (2022). Mortgage borrowing and the boom-bust cycle in consumption and residential investment. <i>Review of Economic Dynamics</i> , 44, 244–268.	annual change in the national house price* <b>land unavailability derived from elevation changes (Saiz 2010)</b>	housing prices	1. (residential) consumption 2. residential investment	USA 1999-2015
<b>Reduced-form studies</b>					
117	Aastveit, K. A., & Anundsen, A. K. (2022). Asymmetric Effects of Monetary Policy in Regional Housing Markets. <i>American Economic Journal: Macroeconomics</i> , 14(4), 499–529.	–	land unavailability derived from elevation changes (Saiz 2010)	housing prices	USA 1983-2007
118	Aastveit, K. A., Albuquerque, B., & Anundsen, A. K. (2023). Changing Supply Elasticities and Regional Housing Booms. <i>Journal of Money, Credit and Banking</i> , 55(7), 1749–1783.	–	land unavailability	housing supply	USA 1996-2019
119	Adamopoulos, T., & Restuccia, D. (2022). Geography and Agricultural Productivity: Cross-Country Evidence from Micro Plot-Level Data. <i>Review of Economic Studies</i> , 89(4), 1629–1653.	–	soil quality, climate conditions and <b>terrain topography</b>	agricultural output	globally, 2000
120	Ahlerup, P. & Olsson, O. (2012). The roots of ethnic diversity. <i>Journal of Economic Growth</i> , 17(2), 71-102.	–	altitude variation (elevation changes)	1. ethnolinguistic diversity 2. ethnic diversity	globally, since 1500 CE

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
121	Ali, D. A., Deininger, K., & Ronchi, L. (2019). Costs and benefits of land fragmentation: Evidence from Rwanda. <i>The World Bank Economic Review</i> , 33(3), 750-771.	–	land fragmentation, mountainous area	1. agricultural output 2. travel time	Rwanda 2010-2012
122	Alix-Garcia, J., & Sellars, E. A. (2020). Locational fundamentals, trade, and the changing urban landscape of Mexico. <i>Journal of Urban Economics</i> , 116, 103213.	–	ruggedness	urban development	Mexico 1900-2010
123	Bakker, J. D., Maurer, S., Pischke, J. S., & Rauch, F. (2021). Of mice and merchants: connectedness and the location of economic activity in the Iron Age. <i>Review of Economics and Statistics</i> , 103(4), 652-665.	–	agroclimatic factors, <b>ruggedness</b> , distance to river	urbanization	The Mediterranean 900 BC
124	Barjamovic, G., Chaney, T., Coşar, K., & Hortaçsu, A. (2019). Trade, merchants, and the lost cities of the bronze age. <i>The Quarterly Journal of Economics</i> , 134(3), 1455-1503.	–	ruggedness	city size	Northern Iraq, Northern Syria, central Turkey 2000-1650 BCE
125	Baten, J., & Hippe, R. (2018). Geography, land inequality and regional numeracy in Europe in historical perspective. <i>Journal of Economic Growth</i> , 23, 79-109.	–	soil quality, altitude, <b>ruggedness</b>	numeracy (Human Development Index)	Europe 1900
126	Berry, K., James, A., Smith, B., & Watson, B. (2022). Geography, geology, and regional economic development. <i>Journal of Environmental Economics and Management</i> , 115, 102715.	–	localized resources discoveries* <b>preexisting geographic properties (terrain ruggedness and water coverage)</b>	population growth	USA 1970-2010
127	Billings, S. B., Gallagher, E. A., & Ricketts, L. (2022). Let the rich be flooded: The distribution of financial aid and distress after hurricane harvey. <i>Journal of Financial Economics</i> , 146(2), 797-819.	–	topographic variation	disaster risk (flood risk)	USA 2015-2019
128	Boone, C. D., & Wilse-Samson, L. (2023). Structural change and internal labor migration: Evidence from the Great Depression. <i>The Review of Economics and Statistics</i> , 105(4), 962-981.	–	average slope, ruggedness	employment structure	USA 1900-1940

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
129	Bosker, M., & Buringh, E. (2017). City seeds: Geography and the origins of the European city system. <i>Journal of Urban Economics</i> , 98, 139-157.	–	elevation, ruggedness	urban growth	Europe 800-1800
130	Candau, F., Regnacq, C., & Schlick, J. (2022). Climate change, comparative advantage and the water capability to produce agricultural goods. <i>World Development</i> , 158, 105963.	–	topographic variation	agricultural land conversion	global coverage 1995-2017
131	Chen, Y. J., Li, L., & Xiao, Y. (2022). Early-Life Exposure to Tap Water and the Development of Cognitive Skills. <i>Journal of Human Resources</i> , 57(6), 2113–2149.	–	topographic characteristics in the village	piped water supply	China 2010
132	Christensen, P., & McCord, G. C. (2016). Geographic determinants of China's urbanization. <i>Regional Science and Urban Economics</i> , 59, 90-102.	–	terrain slope	urbanization	China 1990-1999
133	Colas, M., & Morehouse, J. M. (2022). The environmental cost of land-use restrictions. <i>Quantitative Economics</i> , 13(1), 179–223.	–	land unavailability derived from elevation changes (Saiz 2010)	housing prices	USA 1990-2000
134	Fajgelbaum, P. D., & Schaal, E. (2020). Optimal transport networks in spatial equilibrium. <i>Econometrica</i> , 88(4), 1411-1452.	–	ruggedness	road construction	Europe 2010s
135	Gendron-Carrier, N., Gonzalez-Navarro, M., Polloni, S., & Turner, M. A. (2022). Subways and Urban Air Pollution. <i>American Economic Journal: Applied Economics</i> , 14(1), 164–196.	–	effect of subway system openings* <b>above median elevation range in a 25 km disk centered around the city center</b>	(urban) air pollution	Global coverage 2000-2017
136	Giuliano, P., Spilimbergo, A., & Tonon, G. (2014). Genetic distance, transportation costs, and trade. <i>Journal of Economic Geography</i> , 14(1), 179-198.	–	terrain ruggedness, mountainous area	trade flows	Europe 1975-2000
137	Guedes, R., Iachan, F. S., & Sant'Anna, M. (2023). Housing supply in the presence of informality. <i>Regional Science and Urban Economics</i> , 99, 103875.	–	land unavailability	housing supply	Brazil 1991-2010
138	Gyourko, J., Mayer, C., & Sinai, T. (2013). Superstar cities. <i>American Economic Journal: Economic Policy</i> , 5(4), 167-199.	–	land unavailability derived from elevation changes (Saiz 2010)	income	USA 1975-2000

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
139	Henderson, J. V., Squires, T., Storeygard, A., & Weil, D. (2018). The global distribution of economic activity: nature, history, and the role of trade. <i>The Quarterly Journal of Economics</i> , 133(1), 357-406.	–	ruggedness, elevation	economic activity	globally 1950-2010
140	Huang, H., & Tang, Y. (2012). Residential land use regulation and the US housing price cycle between 2000 and 2009. <i>Journal of Urban Economics</i> , 71(1), 93-99.	–	water bodies, wetlands, <b>slope</b>	housing prices	USA 2000-2009
141	Jimenez-Ayora, P., & Ulubaşoğlu, M. A. (2015). What underlies weak states? The role of terrain ruggedness. <i>European Journal of Political Economy</i> , 39, 167-183.	–	terrain ruggedness	1. collectivism of societies 2. political institutions (rule of law) 3. tax income per capita 4. civil conflict 5. ethnic fractionalization	globally 1976-2006
142	Jackson, K. K. (2018). Regulation, land constraints, and California's boom and bust. <i>Regional Science and Urban Economics</i> , 68, 130-147.	–	land unavailability derived from elevation changes (Saiz 2010)	housing prices	California (USA) 2006-2010
143	Kitamura, S., & Lagerlöf, N. P. (2020). Geography and state fragmentation. <i>Journal of the European Economic Association</i> , 18(4), 1726-1769.	–	mountainous and rugged area	state fragmentation	Europe 2015
144	Kok, N., Monkkonen, P., & Quigley, J. M. (2014). Land use regulations and the value of land and housing: An intra-metropolitan analysis. <i>Journal of Urban Economics</i> , 81, 136-148.	–	topography, hills, elevation, slope	housing prices	San Francisco 1990-2010
145	Lang, C. (2018). Assessing the efficiency of local open space provision. <i>Journal of Public Economics</i> , 158, 12-24.	–	<b>land unavailability derived from elevation changes (Saiz 2010)*</b> authorized open space and other spending and proposed open space and other spending	housing prices	USA 2000s
146	Leonard, B., Parker, D., & Anderson, T. (2019). Land quality, land rights, and indigenous poverty. <i>Journal of Development Economics</i> , 143, 102435.	–	ruggedness	income	USA 1970-2010

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
147	Mann, M. L., Kaufmann, R. K., Bauer, D. M., Gopal, S., Nomack, M., Womack, J. Y., ... & Soares-Filho, B. S. (2014). Pasture conversion and competitive cattle rents in the Amazon. <i>Ecological Economics</i> , 97, 182-190.	–	slope	conversion to pasture land	Brazil 2000-2004
148	Michalopoulos, S. (2012). The origins of ethnolinguistic diversity. <i>American Economic Review</i> , 102(4), 1508–1539.	–	elevation changes (elevation, altitude, variation in land quality)	1. ethnic diversity 2. linguistic diversity	globally 1990-1995
149	Mitton, T. (2016). The wealth of subnations: Geography, institutions, and within-country development. <i>Journal of Development Economics</i> , 118, 88–111.	–	terrain ruggedness, elevation	GDP per capita (income)	globally 2005
150	Molloy, R., Nathanson, C. G., & Paciorek, A. (2022). Housing supply and affordability: Evidence from rents, housing consumption and household location. <i>Journal of Urban Economics</i> , 129, 103427.	–	land unavailability derived from elevation changes (Saiz 2010)	housing prices	USA 1970-2016
151	Motamed, M. J., Florax, R. J., & Masters, W. A. (2014). Agriculture, transportation and the timing of urbanization: Global analysis at the grid cell level. <i>Journal of Economic Growth</i> , 19, 339-368.	–	elevation	urbanization	globally 0-2000
152	Nunn, N., & Puga, D. (2012). Ruggedness: The blessing of bad geography in Africa. <i>Review of Economics and Statistics</i> , 94(1), 20-36.	–	ruggedness	1. GDP per capita (income) 2. slave trade 3. institutional qualities (rule of law)	Africa 1950-2000
153	Paciorek, A. (2013). Supply constraints and housing market dynamics. <i>Journal of Urban Economics</i> , 77, 11-26.	–	slope, gradient	housing prices	USA 1984-2008
154	Ploeckl, F. (2012). Endowments and market access; the size of towns in historical perspective: Saxony, 1550–1834. <i>Regional Science and Urban Economics</i> , 42(4), 607-618.	–	elevation, ruggedness	urban growth	Saxony 1550-1834
155	Robb, A. M., & Robinson, D. T. (2012). The capital structure decisions of new firms. <i>Review of Financial Studies</i> , 27(1), 153–179.	–	land unavailability derived from elevation changes (Saiz 2010)	credit availability (credit supply)	USA 2004-2007

	Results	Instruments and their components <sup>1</sup>	Treatment Variables <sup>2</sup>	Outcomes <sup>3</sup>	Context
156	Salvati, L., Sateriano, A., Grigoriadis, E., & Carlucci, M. (2017). New wine in old bottles: The (changing) socioeconomic attributes of sprawl during building boom and stagnation. <i>Ecological Economics</i> , 131, 361-372.	–	<b>topographic indicators for accessibility, elevation, proximity to the sea, distance from the central city</b>	urban growth	Italy 1970-2010
157	Sheldon, T. L., & Zhan, C. (2022). The impact of hurricanes and floods on domestic migration. <i>Journal of Environmental Economics and Management</i> , 115, 102726.	–	topographic variation	flood risk	USA 1998-2015
158	Wrenn, D. H., & Sam, A. G. (2014). Geographically and temporally weighted likelihood regression: Exploring the spatiotemporal determinants of land use change. <i>Regional Science and Urban Economics</i> , 44, 60-74.	–	slope	own land use change	USA 1989-2010
159	Wang, Y., Chen, S., & Araral, E. (2021). The mediated effects of urban proximity on collective action in the commons: Theory and evidence from China. <i>World Development</i> , 142, 105444.	–	topography, hills, elevation, slope	1. irrigation 2. collectivism of societies	China 2012-2017
160	Ye, V. Y., & Becker, C. M. (2018). The (literally) steepest slope: spatial, temporal, and elevation variance gradients in urban spatial modelling. <i>Journal of Economic Geography</i> , 18(2), 421-460.	–	slope, elevation changes	housing prices	Hong Kong 1997-2014
161	Ye, V. Y., & Becker, C. M. (2018). The Z-axis: Elevation gradient effects in Urban America. <i>Regional Science and Urban Economics</i> , 70, 312-329.	–	elevation, slope	1. population growth 2. income inequality 3. housing prices	USA 2009-2013

Notes: <sup>1</sup> For this column, “\*” indicates instrument-covariate interaction. Listing by commas indicates a multiple-component instrument (e.g. a ruggedness index). The extra notation “Multiple instruments” lists all instruments if a study uses more than one instrument. In case of multi-component instruments or multiple instruments with non-topographic components, topographic-variation variables are marked in bold; <sup>2,3</sup> If the treatment variable in the reduced-form studies includes multiple components, topographic-variation variables are again marked in bold. For both columns, brackets behind variables contain broader theoretical concepts into which the original variable of the study has been transcribed, e.g. “GDP per capita” into “income”. Alternatively, brackets indicate a more detailed description of the variable.



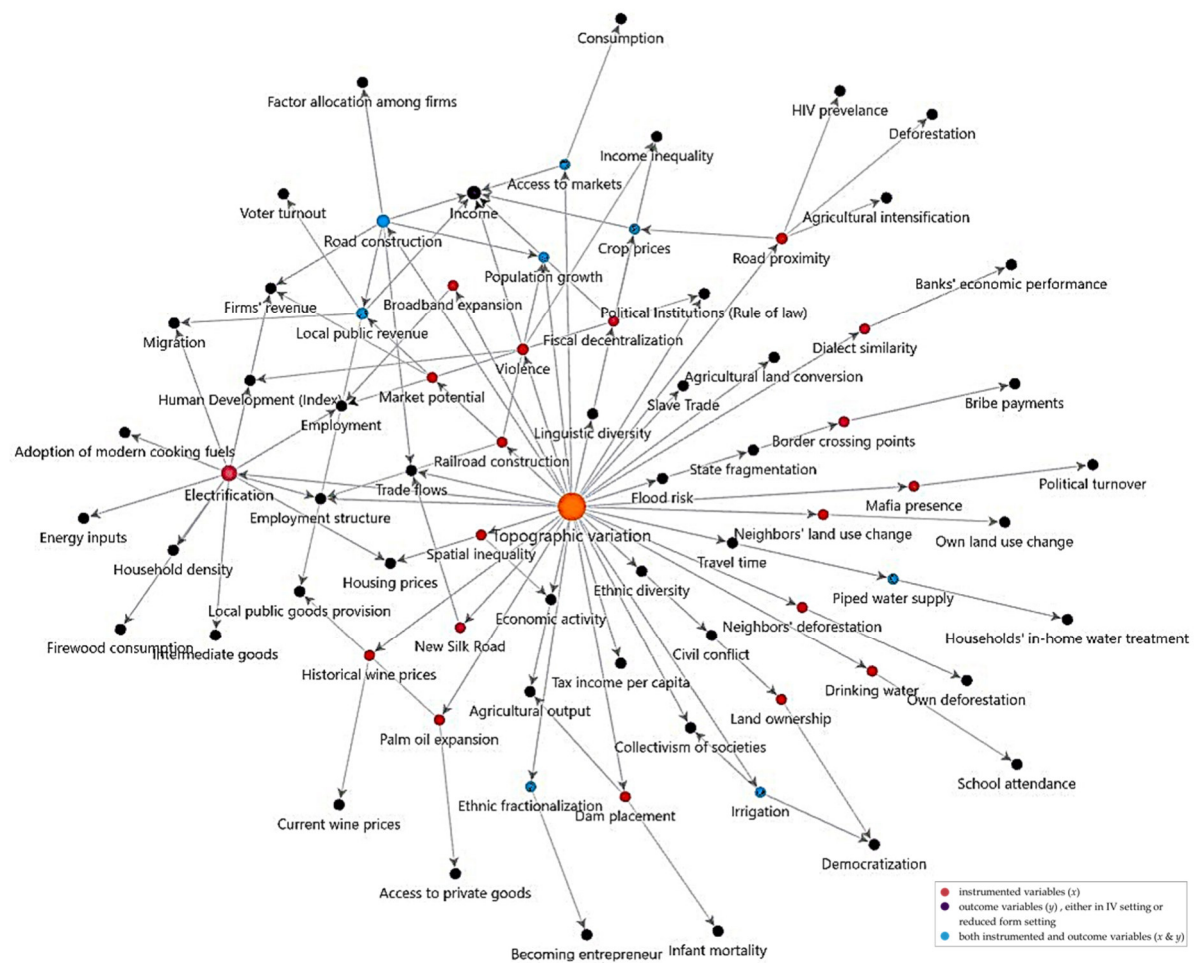
## Appendix B: Weak IV statistics and additional causal webs

**Table B1: Share of weak IVs according to specific benchmarks**

Benchmark F-value	Share of IVs classified as weak (%)				
	All articles (1)	Top-30 journals (2)	Published 2018-2023 (3)	IV only geographic (4)	IV in main specification (5)
Staiger–Stock ( $F \leq 10$ )	15	14	17	18	15
Borderline weak ( $10 < F \leq 15$ )	18	20	11	16	20
Olea–Pflueger ( $F < 23.11$ )	50	53	43	49	52
Keane & Neal ( $F < 50$ )	77	81	76	80	78
Lee et al. ( $F < 104.7$ )	86	88	87	88	83
<b>Median F-value</b>	23.4	21.7	24.32	23.4	22.0
<b>F-statistics included</b>	<b>119</b>	<b>59</b>	<b>75</b>	<b>51</b>	<b>94</b>

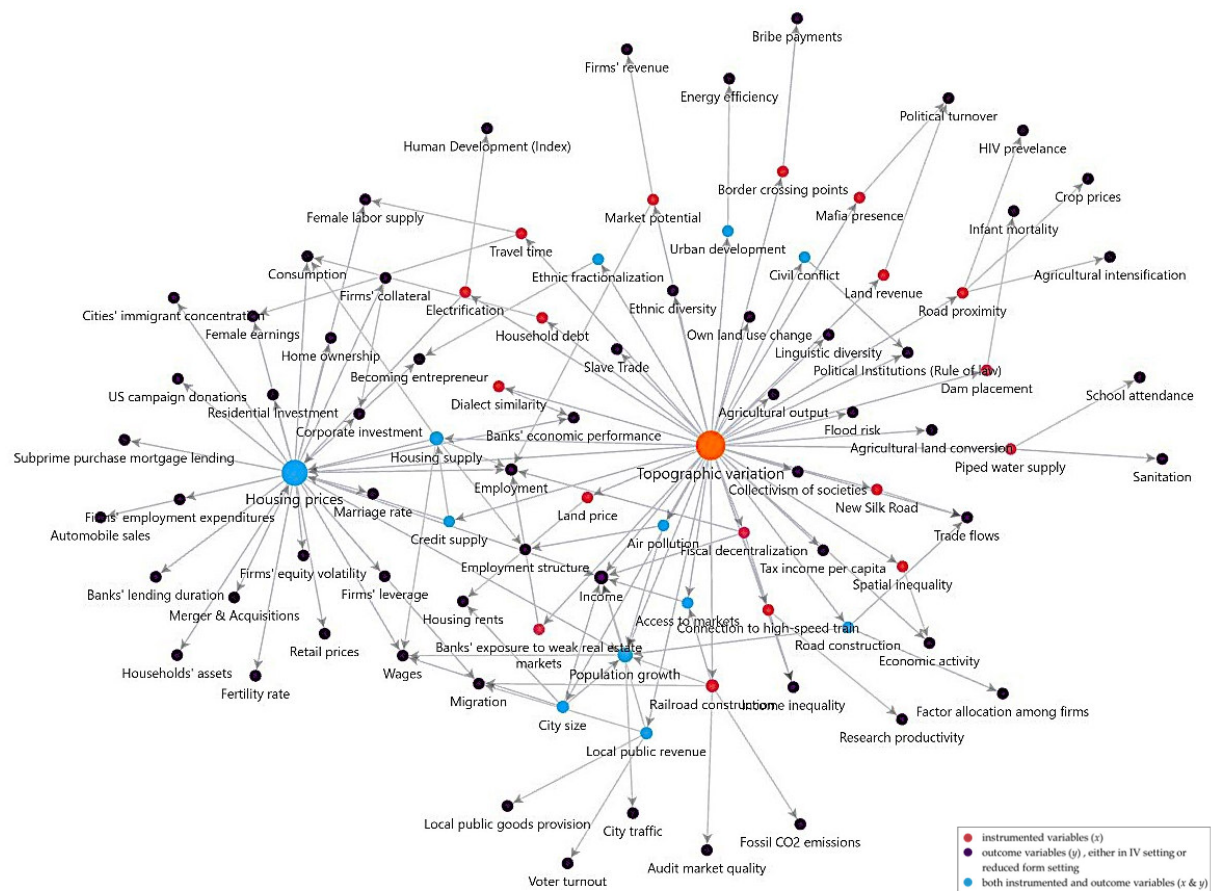
*Note: The shares in column 1 are calculated based on all reported F-statistics ( $N = 119$ ) from the main specifications of IV papers for which this information was available. Column 2 includes only F-statistics from articles published in the Top 30 economics journals according to the Simple IDEAS/RePEc Impact Factor Ranking (June 2022). Column 3 is restricted to articles published after 2017, while column 4 includes only F-statistics from IVs with geographic components only and column 5 includes IVs that are used in main specifications, and not only as part of robustness checks.*

**Figure B1: Causal web for studies from rural areas**

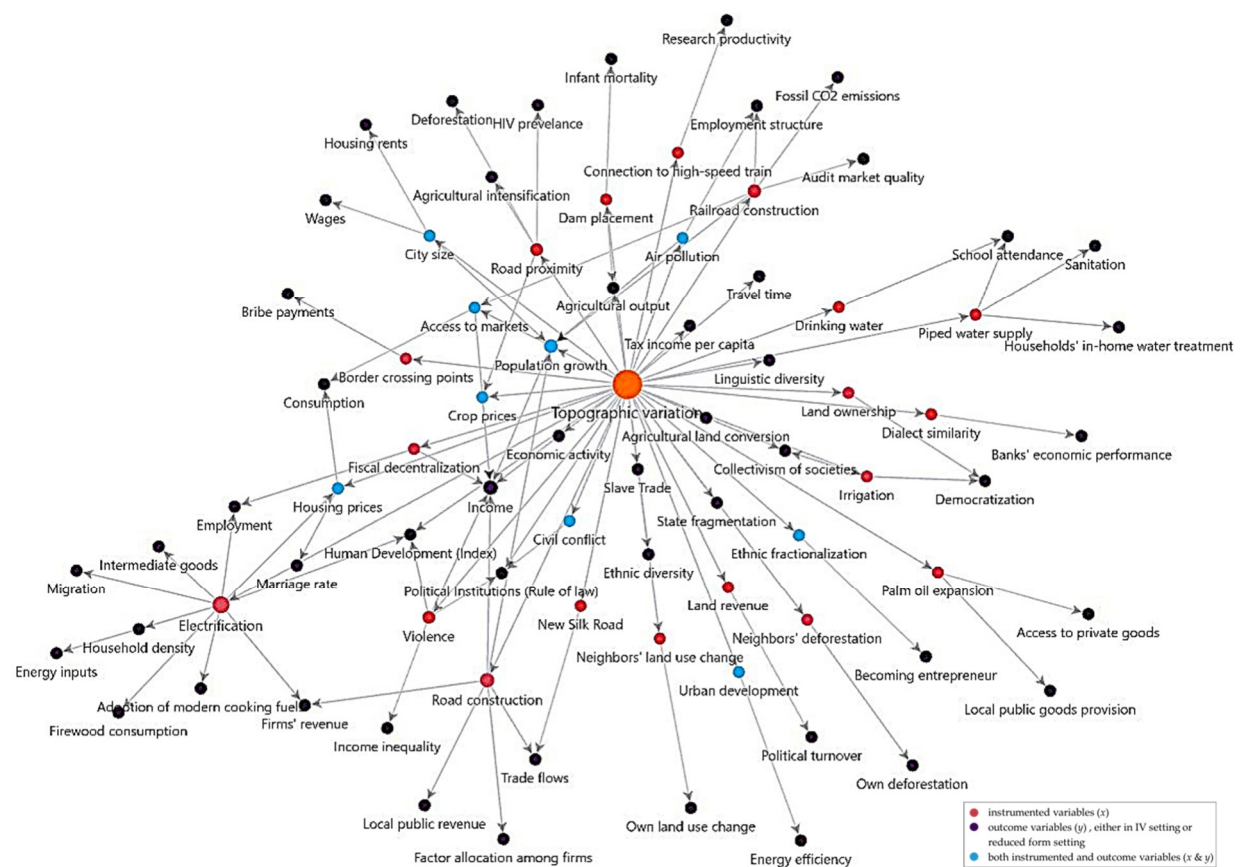


*Note: The causal web includes all studies conducted in rural areas (n= 69). Some studies cover both rural and urban contexts and are therefore also included. The direction of the arrows indicates the causal order, and the size of the nodes is proportional to the frequency of the variable in the systematic review. Outcome variables can be outcomes in IV or in reduced-form articles.*

**Figure B2: Causal web for studies from urban areas**

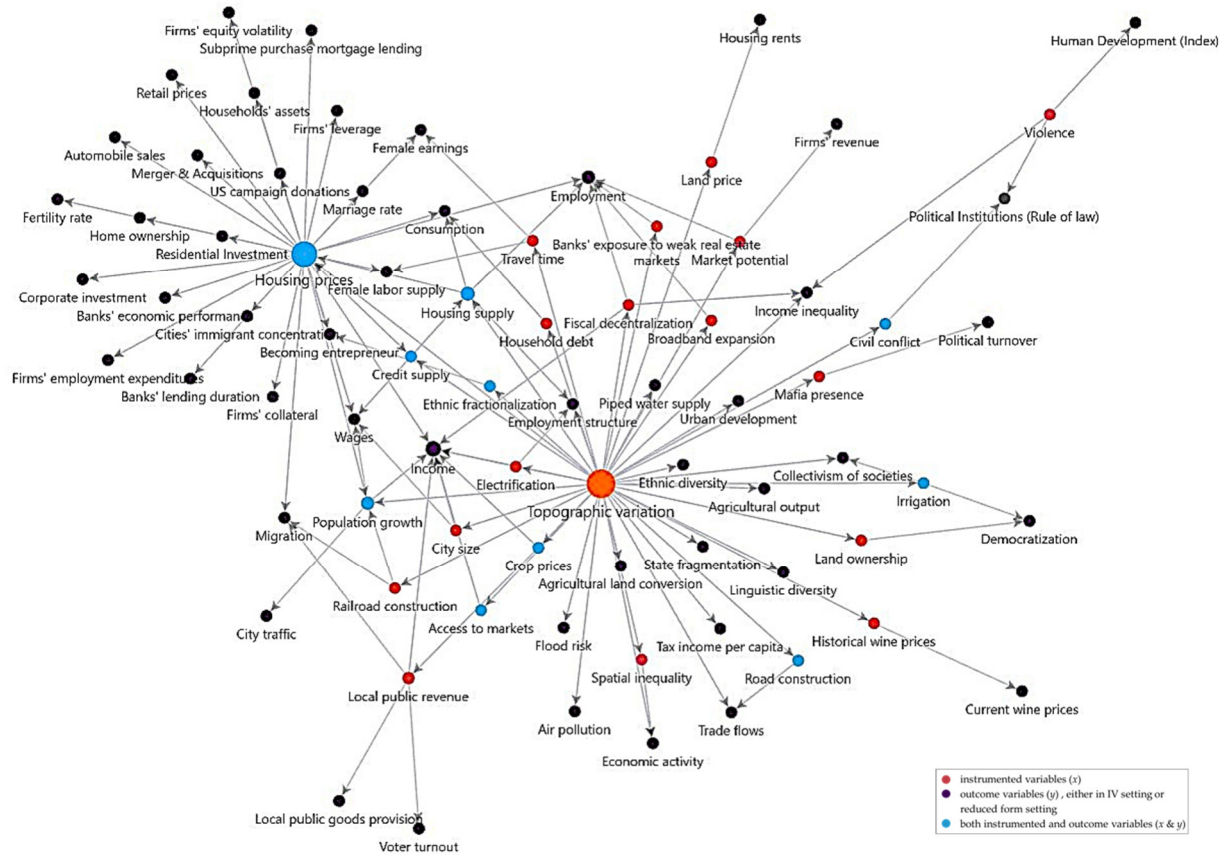


*Note: The causal web includes all studies conducted in urban areas (n= 128). Some studies cover both rural and urban contexts and are therefore also included. The direction of the arrows indicates the causal order, and the size of the nodes is proportional to the frequency of the variable in the systematic review. Outcome variables can be outcomes in IV or in reduced-form articles.*

**Figure B3: Causal web for studies from low-income countries**

*Note: The causal web includes all studies conducted in low and lower-income countries ( $n=64$ ). Some studies cover both low- and high-income countries and are therefore also included. The direction of the arrows indicates the causal order, and the size of the nodes is proportional to the frequency of the variable in the systematic review. Outcome variables can be outcomes in IV or in reduced-form articles.*

**Figure B4: Causal web for studies from high-income countries**



*Note: The causal web includes all studies conducted in high- and upper-income countries (n= 113). Some studies cover both low- and high-income countries and are therefore also included. The direction of the arrows indicates the causal order, and the size of the nodes is proportional to the frequency of the variable in the systematic review. Outcome variables can be outcomes in IV or in reduced-form articles.*

## Appendix C: Results for additional tests applied to Dinkelman (2011)

**Table C1: Placebo tests for effect of gradient on the female employment rate**

Dependent variable Estimation method Sample	$\Delta$ female employment rate			
	OLS			
	Areas electrified before 1996		Non-electrified communities (no Eskom project)	
	(1)	(2)	(3)	(4)
Land gradient x 10	-0.01 (0.01) [0.36]	-0.01 (0.01) [0.42]	-0.007* (0.004) [0.07]	-0.007** (0.004) [0.05]
Baseline controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Controls for other services <sup>#</sup>	No	Yes	No	Yes
R <sup>2</sup>	0.068	0.106	0.078	0.095
N communities	373	373	1,451	1,451

Note: Column (2) reproduces column (1) of table 6 in Dinkelman (2011), and column (4) differs from that specification only in that the analysis is conducted in the sub-sample of non-electrified villages. Robust standard errors clustered at community level in parentheses and p-values in square brackets. <sup>#</sup> Other services refer to water and sanitation access in the communities. \*\* significant at the 5% level; \* significant at the 10% level

**Table C2: Land gradient as IV for electrification vs. IV for road access**

Dependent variable Estimation method Treatment definition	$\Delta$ female employment rate			
	IV (gradient)			
	Access to roads within 5 km distance		Electrification (Dinkelman 2011)	
	(1)	(2)	(3)	(4)
Treatment	0.104* (0.059) [0.080]	0.106* (0.058) [0.069]	0.090* (0.054) [0.097]	0.095* (0.055) [0.083]
AR 90% Confidence Interval	{0.03; 0.29}	{0.03; 0.28}	{0.02; 0.25}	{0.02; 0.26}
Baseline controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Controls for other services <sup>#</sup>	No	Yes	No	Yes
First-stage results				
Gradient x 10 coefficient	-0.068*** (0.026)	-0.071*** (0.025)	-0.078*** (0.027)	-0.077*** (0.027)
R-Squared	0.15	0.16	0.19	0.20
F-statistic (Kleibergen-Paap)	7.11	7.77	8.34	8.26
N communities	1,816	1,816	1,816	1,816

Note: All model specifications are equal to columns 7 and 8 of table 4 from the original study with the only difference in columns (1) and (2) that the instrumented variable is access to roads instead of electrification and that we excluded binary road access from the control variables while adding electrification status; robust standard errors clustered at village level in parentheses and p-values in square brackets. <sup>#</sup> Other services refer to water and sanitation access in the communities. \*\*\* significant at the 1% level; \* significant at the 10% level

## Appendix D: Land gradient as an IV for road access

In order to use the land gradient as an IV for road access instead of electricity access, we take Dinkelman's model and only swap the roles of electrification and road access. Dinkelman's model looks as follows:

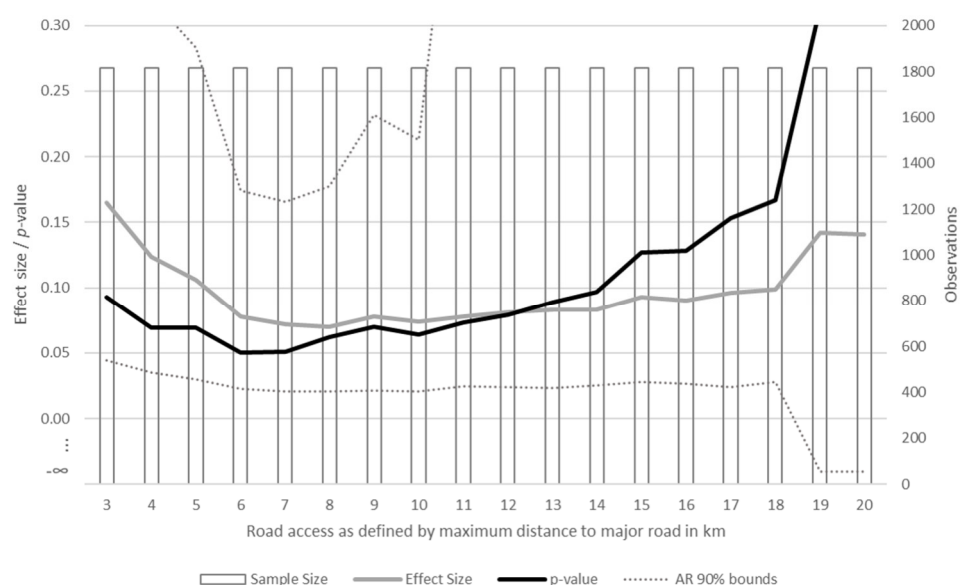
$$\Delta y_{jdt} = \alpha_1 + \alpha_2 \Delta T_{jdt} + X_{jdo} \beta + \lambda_d + (\delta_j + \Delta \varepsilon_{jdt}), \quad [D1]$$

which estimates the impact of an electricity project (the dummy  $T_{jdt}$ ), occurring in community  $j$  in district  $d$  at time  $t$ , on the growth in labour market outcomes over time  $\Delta y_{jdt}$  in that community, with  $\delta_j$  and  $\Delta \varepsilon_{jdt}$  being part of the unobserved error term. We now replace the electrification treatment by baseline main road access,  $RoadAccess_{jdo}$ , remove baseline main road access from the set of control variables,  $X_{jdo}$ , and add the electrification status in the respective year to the revised set of control variables,  $\tilde{X}_{jdt}$ . In the absence of data on over-time variation in road access, we estimate the effect of time-invariant differences in road access, while the original analysis also benefits from over-time variation in electricity access. District fixed effects capture this community-specific effect insufficiently given that there are on average 200 communities per district with different proximities to roads. Our estimation equation thus becomes

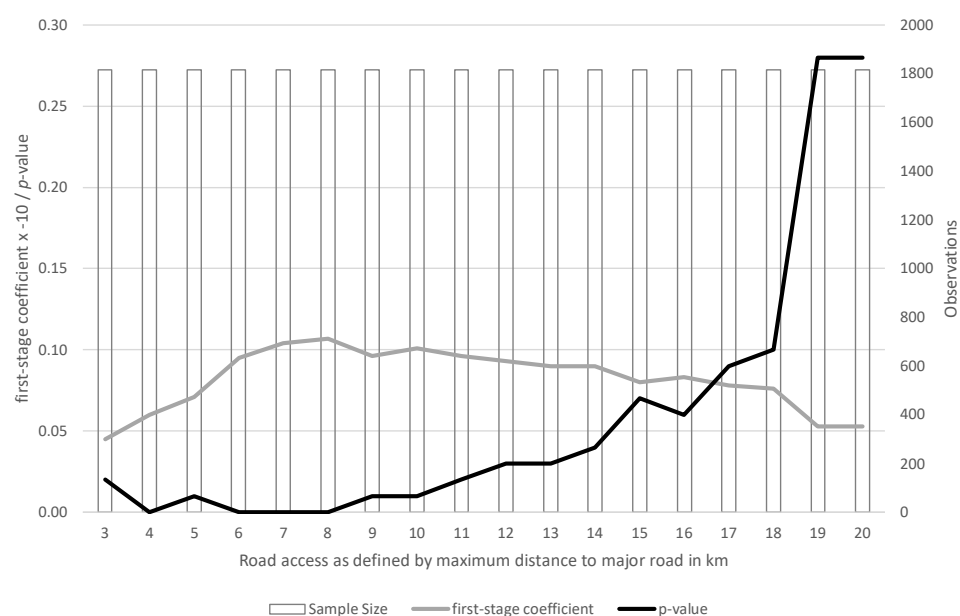
$$\Delta y_{jdt} = \alpha_1 + \alpha_2 RoadAccess_{jdo} + \tilde{X}_{jdt} \beta + \lambda_d + (\delta_j + \Delta \varepsilon_{jdt}) \quad [D2].$$

As can be taken from Figure D1, results are statistically significant at the 10% level and of similar magnitude for any choice of the cutoff between three and 14 km. Similarly, first-stage coefficients are statistically significant at the 5% level in this range of road distances (Figure D2). Results remain qualitatively unchanged for continuous, non-linear (convex downward) measures of road access across a range of reasonable cut-off distances (e.g. 20km and 50km). If we include road distance in a linear functional form, the effect becomes insignificant. Yet, it is more plausible to assume that benefits of infrastructure diminish over distance and level off at some cut-off distance.

In another test, we use Dinkelman's main analysis and make two modifications: first, we replace the continuous road distance variable used by Dinkelman by a binary road access variable, and, second, we include the interaction of this road access variable with the electrification treatment variable. Figure D3 shows results when varying the road access corridor between 3km and 20km.

**Figure D1: IV estimates of road access effect on employment, by road access definition**

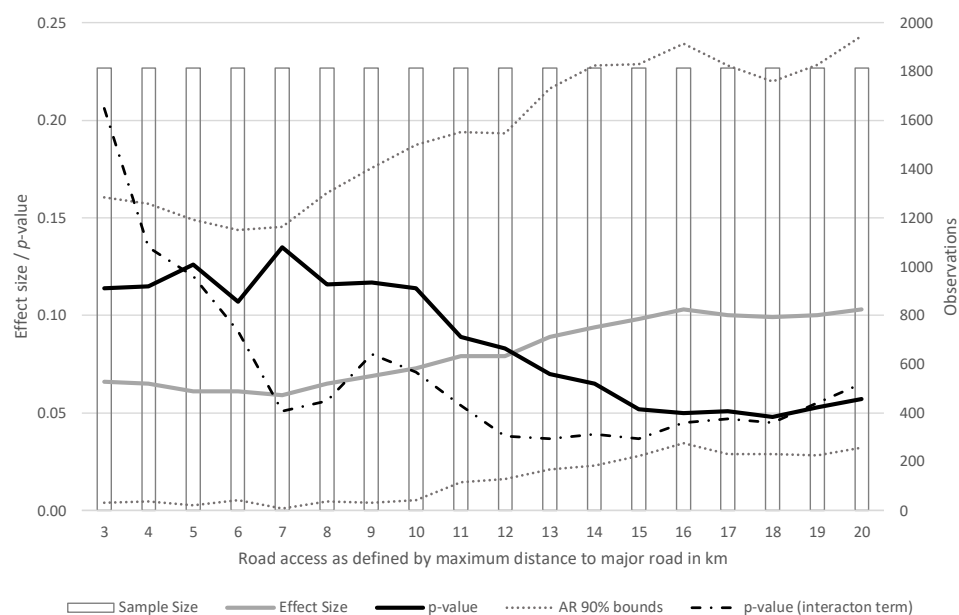
*Note: This figure shows results for estimations where we plug into equation [B2] different definitions of road access, ranging from 3 to 20 km distance between the centroid of the community and the main road. Since we do not exclude any communities as in Figure 5 in the main text, the sample size remains identical across all estimations. The results presented for 5 km are identical to those shown in Section 4.3 in the main text.*

**Figure D2: First-stage coefficients for the road access effect on employment, by road access definition**

*Note: This figure shows first-stage coefficients for the estimations results presented in Figure D1. For simplicity of presentation, first-stage coefficients are multiplied by -10.*



**Figure D3: IV estimates of electrification effect on employment and its interaction with road access, by road access definition**



*Note: This figure shows results for Dinkelman's main estimations from the original study with the only difference that the control set includes the binary road access variable and its interaction with the electrification treatment variable, separately for different road access definitions, ranging from 3 to 20 km distance between the centroid of the community and the main road.*