Development Economics: Lecture 5

Climate Change, Environment and Development

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Structure of the course (days 1–5)

Topics 1-5 (Moneke)

- Topic 1 (Mon 09/09): Econ. Growth and Transformation
- Topic 2 (Tue 10/09): Poverty Traps and Policy Scale-up
- Topic 3 (Wed 11/09): Infrastructure and Spatial Development
- Topic 4 (Thu 12/09): Energy Access and Electrification Puzzle
- Topic 5 (Fri 13/09): Climate Change, Environment and Dev.

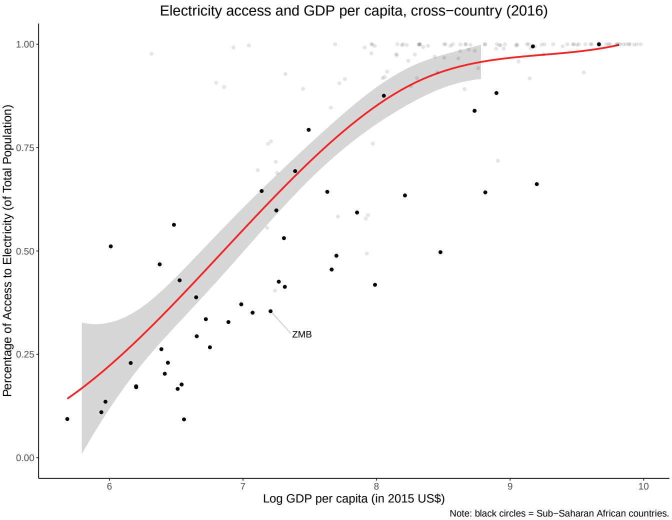
5. Climate change, Environment and Development

5.1 Climate change in low income countries

5.2 Climate change and mortality

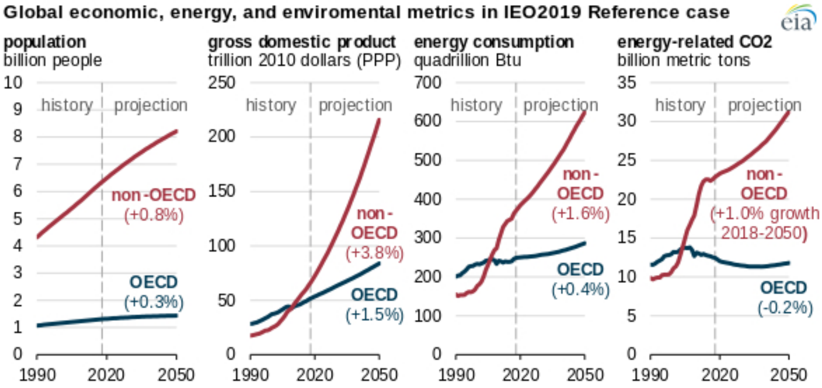
5.3 Climate change and dynamic misallocation

Recap: energy crucial for development



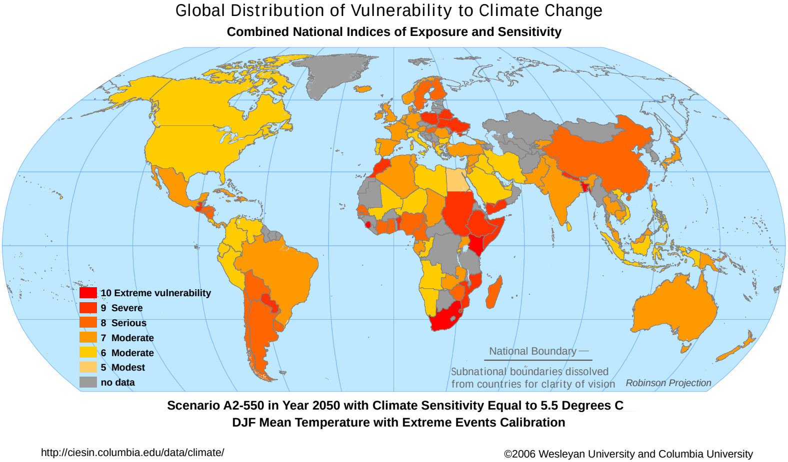
Source: Figueiredo Walter & Moneke (2022), using WDI data

Energy, growth and future emissions



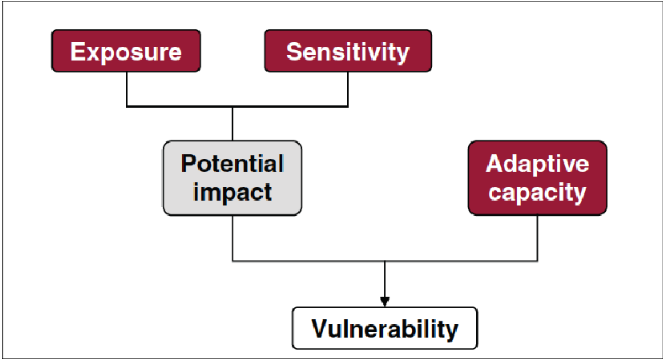
Source: EIA (2019), *International Energy Outlook, Chart 2.*

Climate change disproportionately affects LICs



Source: Yohe, G. et al. (2006), *A Synthetic Assessment of the Global Distribution of Vulnerability to Climate Change from the IPCC Perspective that Reflects Exposure and Adaptive Capacity, Map 17.3.* Palisades, New York: CIESIN (Center for International Earth Science Information Network), Columbia University.

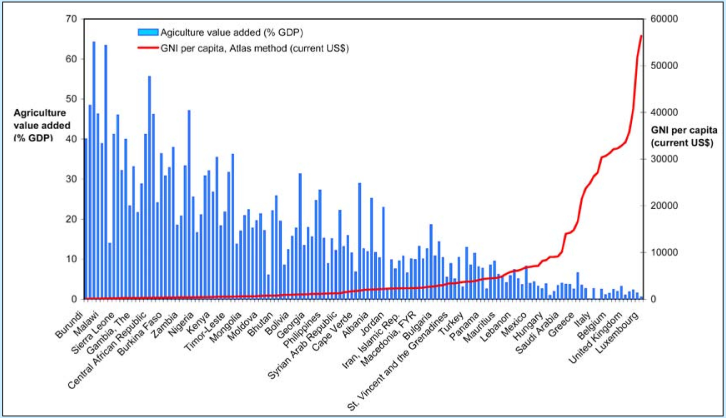
Why are LICs more vulnerable to climate change?



Source: Stern Review (2006), *The Economics of Climate Change (PART II): The Impacts of Climate Change on Growth and Development, Figure 4.1. (redrawn)*

High exposure: reliance on agriculture for income

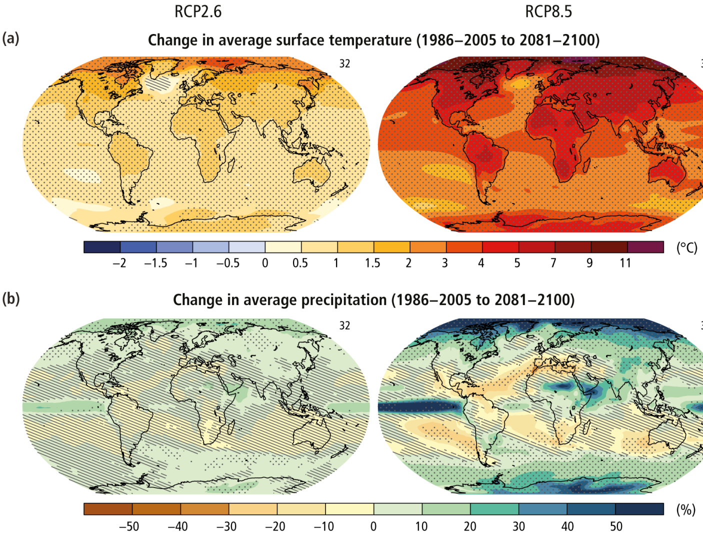
Figure 4.2 The share of agriculture in GDP and per capita income in 2004



Source: Updated from an earlier version by Tol et al (2004) using data from World Bank (World Development Indicators for 2004) for all countries for which such data are available. Countries are ranked by per capita income.

Source: Stern Review (2006), *The Economics of Climate Change (PART II): The Impacts of Climate Change on Growth and Development, Figure 4.2.*

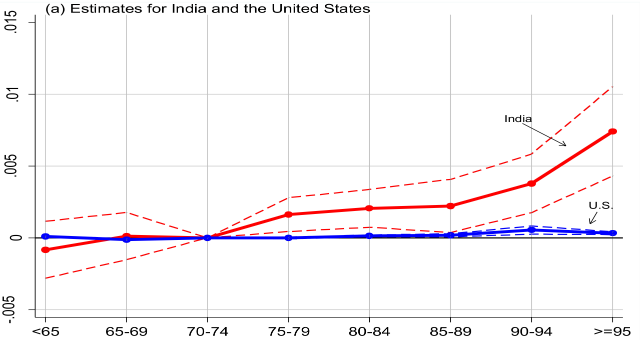
High sensitivity: elasticity of temperature wrt. emissions



Source: IPCC AR5 Synthesis Report (2006), *Topic 2: Future Climate Changes, Risks and Impacts, Figure 2.2.*

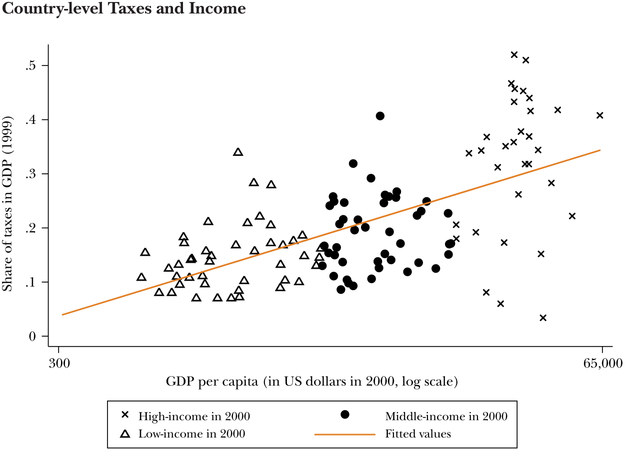
Impacts: temperature $\uparrow \rightarrow$ mortality $\uparrow$ for rural population

Figure 1: Impact of Daily Temperature on Log All-Age Mortality Rates in India and the United States.



Source: Burgess, R., Donaldson, D., Deschenes, O., & Greenstone, M. (2017). Weather, climate change and death in India. *London School of Economics mimeo*.

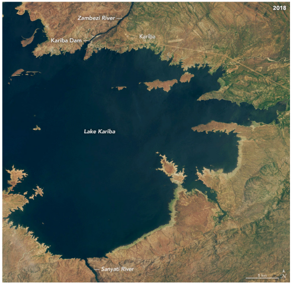
Low capacity: low income countries struggle to tax

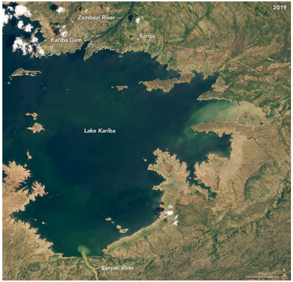


Notes and Sources: Figure 2 plots the total tax take as a share of GDP (from Baunsgaard and Keen 2005) against the log of GDP per capita (from the Penn World Tables), both measured around the year 2000. The outliers visible in the lower right corner are the three oil states of Bahrein, Kuwait, and Oman.

Source: Besley & Persson (2014), *Why Do Developing Countries Tax so Little?, Figure 2.*

Vulnerability in practice (I): world’s largest reservoir drying



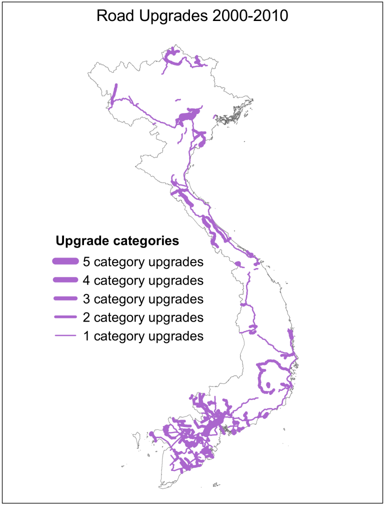


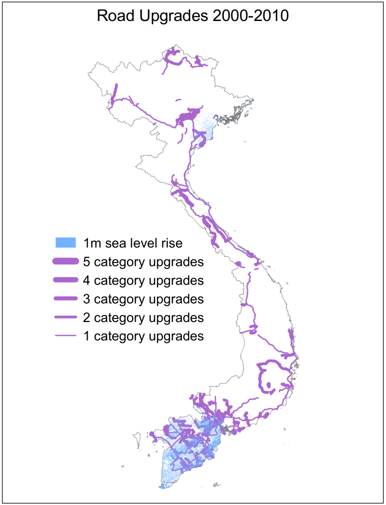
Source (left): NASA Earth Observatory (2019). *Water Levels Keep Falling at Lake Kariba, December 4th, 2018 vs December 23rd, 2019.*

Source (right): New York Times (2016). *Climate Change Hits Hard in Zambia, as of April 13th, 2016.*

Vulnerability in practice (II): new roads soon inundated

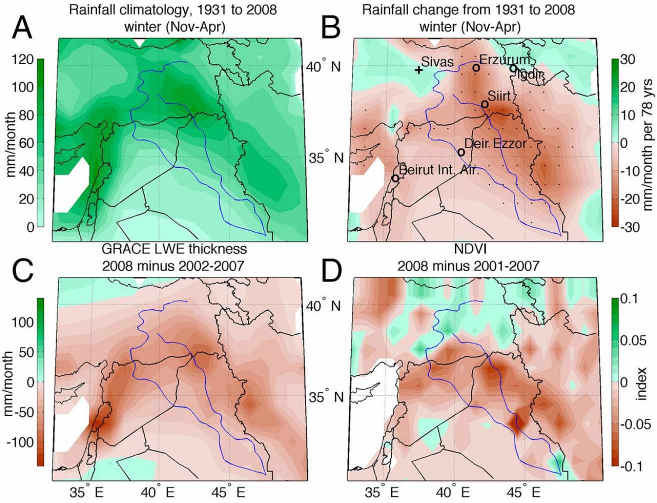
Figure 1: Road investments in Vietnam, 2000-2010





Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Vulnerability in practice (III): severe drought and conflict



Source: Kelley, Mohtadi, Cane, Seager & Kushnir (2015). *Climate change in the Fertile Crescent and implications of the recent Syrian drought, Figure 2.*

Burgess, R., Donaldson, D., Deschenes, O., & Greenstone, M. (2017). Weather, climate change and death in India. *London School of Economics mimeo*.

Weather and death: India vs US

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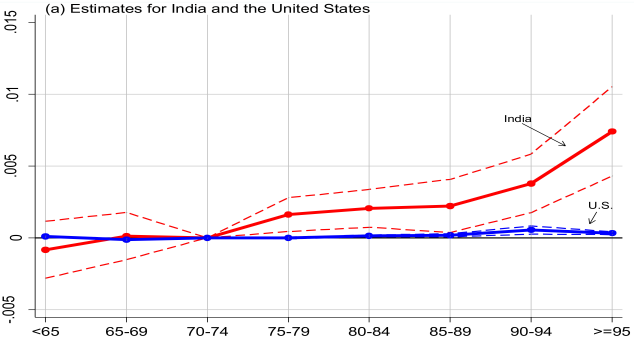
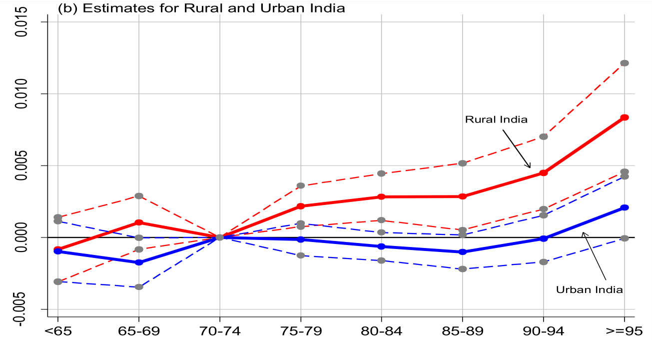


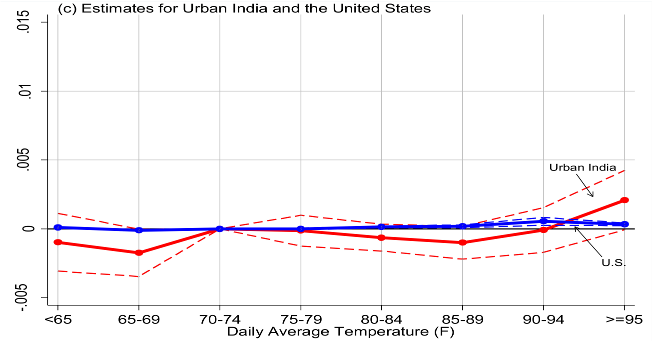
Source: Burgess, R., Donaldson, D., Deschenes, O., & Greenstone, M. (2017). Weather, climate change and death in India. *London School of Economics mimeo*.

Weather and death: rural vs urban India



Source: Burgess, R., Donaldson, D., Deschenes, O., & Greenstone, M. (2017). Weather, climate change and death in India. *London School of Economics mimeo*.

Weather and death: urban India vs US



Source: Burgess, R., Donaldson, D., Deschenes, O., & Greenstone, M. (2017). Weather, climate change and death in India. *London School of Economics mimeo*.

Mechanisms: Temperature$\uparrow \rightarrow$ Mortality

- Direct effect of temperature on mortality:
  - **heat stress:** extreme temperature directly increases morbidity due to physiological reactions
- Indirect effects of temperature on mortality:
  - **agricultural yields:** extreme temperature adversely affects agricultural yields and, thus incomes
  - **labour supply:** income-generating activities in general affected by making it harder to supply labour in outside activities, again decreasing income which could mitigate extreme temperature (e.g. by investing in heat-stress reducing health goods)

Mechanisms: effects worse in rural areas

Why should rural areas be worse affected by climate-change induced temperature increases than urban areas?

i agricultural incomes are more prone to weather disruption than non-agricultural incomes

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i. agricultural incomes are more prone to weather disruption than non-agricultural incomes
ii. agriculture more predominant in rural, less-developed areas
iii. access to health-improving "h" goods is generally worse in rural areas, independent of income (such as pharmaceuticals, air conditioning, etc.)

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Following a similar logic, mortality effects of climate change should be worse in developing than developed countries (all five apply)

Identification: exogenous weather shocks

Assume weather shocks to be exogenous, conditional on location and time fixed effects:

- regress mortality on temperature over time and space

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- use spatial grid, not administrative units
- use temperature bins, not temperature values
  - to avoid low power for many temperature degree–district–year point estimates

Identification: exogenous weather shocks

Assume weather shocks to be exogenous, conditional on location and time fixed effects:

- regress mortality on temperature over time and space
- use spatial grid, not administrative units
- use temperature bins, not temperature values
  - to avoid low power for many temperature degree–district–year point estimates
- assumptions underlying temperature bins
  1. assumes that the impact of temperature on mortality is governed by the daily mean alone
  2. assumes that the impact of a day's mean temperature on the annual mortality rate is constant within 5 F degree intervals
  3. assumes that the sequence of relatively hot and cold days is irrelevant for how hot days affect the annual outcome variable

Key results: stark urban/rural difference

- **Burgess et al. (2017):**
  - see Figure 1, Panels (a)-(c) above
  - urban India has a similarly muted temperature–death relationship than the US, but rural India looks completely different
  - hence, climate change will affect agriculture-dependent, less-developed countries more adversely than urban and/or developed places
- **Barreca et al. (2016):**
  - provide interesting evidence on mechanisms how higher incomes allow adaptation to changing climate in long-run

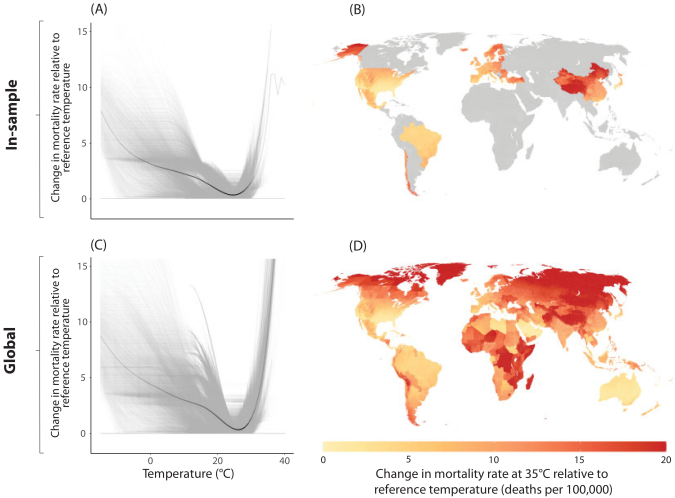
How about endogeneous adaptation to climate change?

- perfectly forward-looking agents should anticipate climate change-induced mortality ...
- ... and take adaptive countermeasures in line with expected costs and benefits

→ does endogenous adaptation exacerbate or limit the global mortality effects of climate change?

*** Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Mortality under endogeneous adaptation



Source: Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Mortality under endogeneous adaptation

FIGURE III

Using Income and Climate to Predict Current Response Functions Globally (Age > 64 Mortality Rate)

In Panels A and C, gray lines are predicted response functions for impact regions, each representing a population of 276,000 on average. Solid black lines are the unweighted average of the gray lines, where the opacity indicates the density of realized temperatures (Hsiang 2013). Panels B and D show each impact region's mortality sensitivity to a day at 35°C, relative to a location-specific minimum mortality temperature. The top row shows all impact regions in the estimating sample, and the bottom row shows extrapolation to all impact regions globally. Predictions shown are for 2015 using the SSP3 socioeconomic scenario and climate model CCSM4 under the RCP8.5 emissions scenario. Online Appendix Figure D.5 shows analogous results for other age groups.

Source: Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Mortality under endog. adaptation: distribution of effects

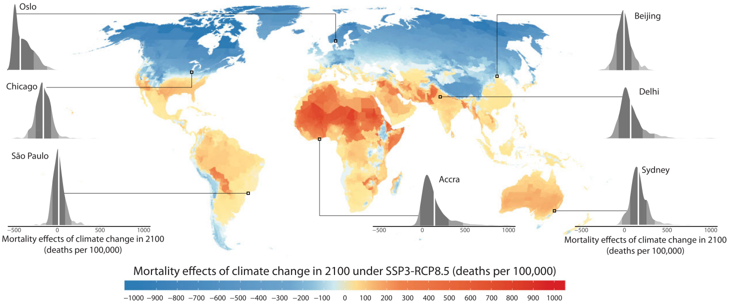


FIGURE IV

The Mortality Effects of Future Climate Change

The map indicates estimates of the mortality effects of climate change (equation (2′)), measured in units of deaths per 100,000 population, in 2100. Estimates come from a model accounting for the benefits of adaptation and income growth, and the map shows the climate model weighted mean estimate across Monte Carlo simulations conducted on 33 climate models; density plots for select regions indicate the full distribution of estimated effects across all Monte Carlo simulations. In each density plot, solid white lines indicate the mean estimate shown on the map, while shading indicates 1, 2, or 3 standard deviations from the mean. All values shown refer to the RCP8.5 emissions scenario and the SSP3 socioeconomic scenario. See Online Appendix Figure F.6 for an analogous map of effects for RCP4.5 and SSP3.

Source: Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Mortality under endog. adaptation: time series of effects

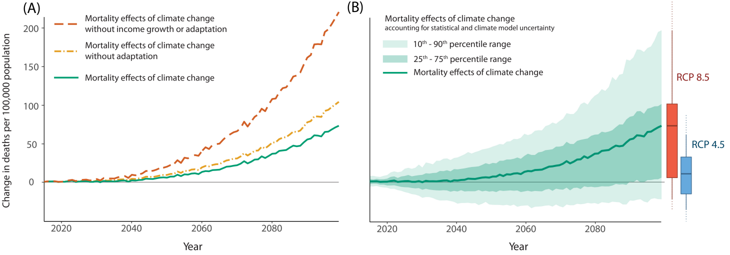


FIGURE V

Time Series of Projected Mortality Effects of Climate Change

All lines show projected mortality effects of climate change across all age categories and are represented by a mean estimate across a set of Monte Carlo simulations accounting for climate model and statistical uncertainty. In Panel A, each line represents one of three measures of the mortality effects of climate change. Dashed (equation (2a′)): mortality effects of climate change without income growth or adaptation. Dashed-dotted: (equation (2b′)): mortality effects of climate change without adaptation. Solid (equation (2′)): mortality effects of climate change. Panel B shows the 10th–90th percentile range of the Monte Carlo simulations for the mortality effects of climate change (equivalent to the solid line in Panel A), as well as the mean and interquartile range. The boxplots show the distribution of mortality effects of climate change in 2100 under both RCPs. All line estimates shown refer to the RCP8.5 emissions scenario and all line and boxplot estimates refer to the SSP3 socioeconomic scenario. Online Appendix Figure F.7 shows the equivalent for SSP3 and RCP4.5.

Source: Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Mortality under endog. adaptation: adaptation costs

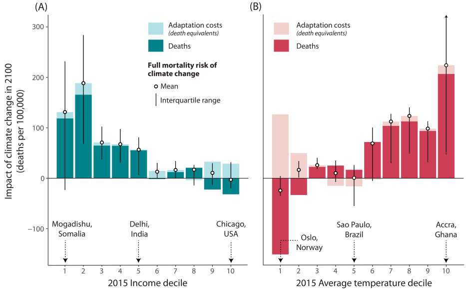


FIGURE VI

Climate Change Effects and Adaptation Costs are Correlated with Present-Day Income and Climate

Figure shows mortality effects of climate change in 2100 (RCP8.5, SSP3) against deciles of 2015 per capita income (Panel A) and average annual temperature (Panel B). Dark bars indicate mean estimates of the mortality effects of climate change (following equation (2′)), and light shading indicates mean estimates of changes in adaptation costs, measured in death equivalents (equation (7) divided by the VSL). For all bars, means are taken across impact regions falling into the corresponding decile of income or climate and across Monte Carlo simulations that account for econometric and climate model uncertainty. Black outlined circles indicate the mean estimate of the full mortality risk of climate change (following equation (3′)), which is the sum of deaths and adaptation costs, and black vertical lines indicate the interquartile range of the distribution across impact regions in each decile. The income and average temperature deciles are calculated across 24,378 global impact regions and are population weighted using 2015 population values.

Source: Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*.

Key findings from Carleton et al. (2022)

- uncover U-shaped temperature – mortality relationship
  - extreme cold and hot temperatures increase mortality rates
  - especially so for the elderly (> 64)
  - relationship flattened by higher incomes and/or adaptation

Key findings from Carleton et al. (2022)

- uncover U-shaped temperature – mortality relationship
  - extreme cold and hot temperatures increase mortality rates
  - especially so for the elderly (> 64)
  - relationship flattened by higher incomes and/or adaptation
- mean global increase in mortality risk due to climate change valued at roughly 3.2% of global GDP in 2100
  - accounting for adaptation benefits/costs
  - use revealed-preference to recover unobserved adaptation costs
  - here: high emissions scenario

Conclusions from Carleton et al. (2022)

Takeaways:

i today's cold locations projected to benefit

ii today's poor and hot locations see large projected damages

iii central estimates: additional ton of CO2 released today will cause mortality-related damages of USD36.6

iv estimates exceed literature by **an order of magnitude**

Big picture: low income countries' situation

How does the situation present itself for low income country governments and policymakers?

- mitigation not possible since not emitting much carbon in the first place
- adaptation investments expensive, compete with alternative infrastructure investments over scarce resources

→ low life expectancy and high child mortality today vs probability of climate calamities in future decades

→ would have to place extremely high utility weight on future generations' welfare to focus on tackling climate change today (instead of tackling high present mortality)

Climate change & coastal advantage: reversal of fortunes?

- throughout human history, settlements and economic activity centred on coastal locations:
  - historical advantages for transport and agriculture
  - 5m elevation coastal zone contains 5% of global population on 1% of global land mass
- coastal advantage becoming less relevant with improved inland infrastructure and structural transformation
- climate change may even reverse coastal advantage once sea level rises

*** Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Balboni (2019): infrastructure under climate change

Research question:

Should infrastructure investments continue to favour coasts?

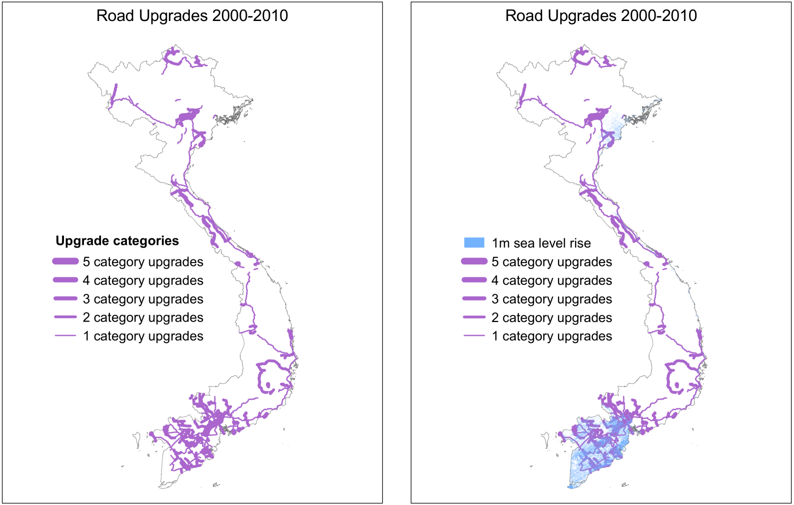
To what extent will infrastructure investments be misallocated once dynamics from future sea level rises taken into account?

Setting:

- coastal regions globally still attract large (and growing) share of investments, e.g. twice average global road density
- optimality of new investments doubtful given climate change
- empirical focus on Vietnam (2000-2010)
  - historically strong coastal focus
  - coastal regions highly and increasingly vulnerable
  - major infrastructure investments continue to favour coast
- develop **dynamic** QSE model with role for future sea level rise
  - structurally estimate impact of realised and counterfactual road investments ...
  - ... both with and without future climate change

Recent major road upgrades in Vietnam soon inundated

Figure 1: Road investments in Vietnam, 2000-2010



Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

. . . but still seems optimal given today's population density

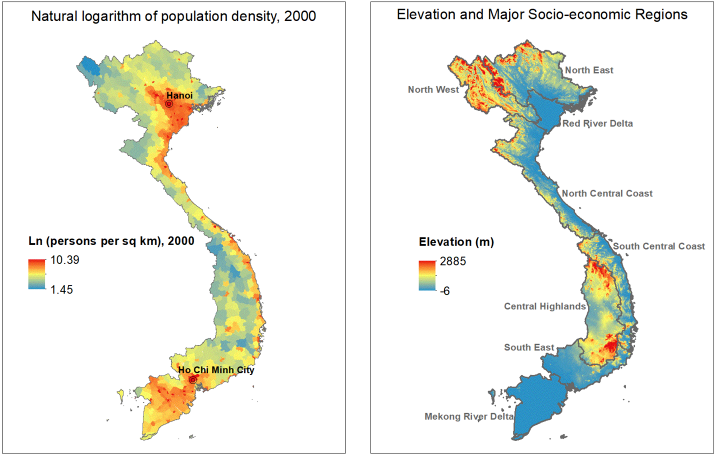
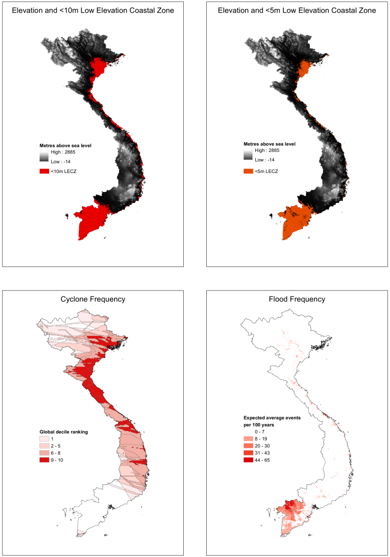


Figure 2: 2000 population density, elevation and major socio-economic regions of Vietnam

Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

How about optimality in light of future climate risks?

Figure 4: Vietnam natural hazard vulnerability



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Key model features

- locations differ in productivity, geography and trade links
  $\rightarrow$ multi-region economic geography setup [Helpman (1998), Eaton & Kortum (2002), Redding (2016)]
- roads have general equilibrium effects and lead to reallocation
  $\rightarrow$ spatial general eq. [Allen & Arkolakis (2014), Redding (2016)]
- roads durable and affected by future changes in fundamentals
  $\rightarrow$ dynamic setup [Artuc et al. (2010), Caliendo et al. (2018)]
- trade and mobility frictions matter empirically
  $\rightarrow$ allow for imperfect mobility of goods and workers [Fujita, Krugman & Venables (1999), Bryan & Morten (2019)]

Model components

- workers choose residential location, consumption of goods and consumption of land
- firms choose prices of (tradeable) goods varieties
- utility maximisation + profit maximisation + market clearing

  $\Rightarrow$ three spatial equilibrium conditions:

  1. expected lifetime utility of rep. agent in each location
  2. gravity equation for goods flows in each period
  3. gravity equation for migration flows between periods

Setup: geography

- locations $n \in \{1, .., N\}$ in time periods $t \in \{1, ..., T\}$ endowed with:
  - innate productivity $A_{n,t}$
  - innate amenities $B_{n,t}$
  - land supply $H_{n,t}$
- trade and mobility frictions:
  - trade cost between locations i and n: $d_{ni,t} \geq 1$
  - mobility cost between locations i and n: $\mu_{ni,t} \geq 1$
- initial exogenous allocation of population across locations: $L_{n,0}$

Setup: geography and road investments

- locations $n \in \{1, .., N\}$ in time periods $t \in \{1, ..., T\}$ endowed with:
  - innate productivity $A_{n,t}$
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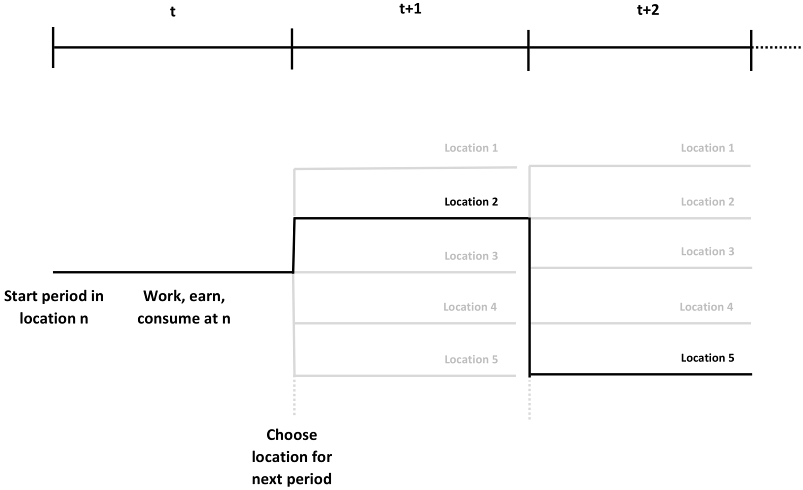
  - land supply $H_{n,t}$
- trade and mobility frictions between locations i and n:
  - trade cost $d_{ni,t} \geq 1 \leftarrow$ road investments
  - mobility cost $\mu_{ni,t} \geq 1$
- initial exogenous allocation of population across locations $L_{n,0}$

Setup: geography and sea level rises

- locations $n \in \{1, .., N\}$ in time periods $t \in \{1, ..., T\}$ endowed with:
  - innate productivity $A_{n,t}$
  - innate amenities $B_{n,t}$
  - land supply $H_{n,t} \leftarrow$ sea level rises
- trade and mobility frictions between locations i and n:
  - trade cost $d_{ni,t} \geq 1 \leftarrow$ sea level rises
  - mobility cost $\mu_{ni,t} \geq 1$
- initial exogenous allocation of population across locations $L_{n,0}$

Setup: forward-looking location choices ('dynamics')



Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Setup: preferences and amenities

Lifetime utility of worker in location n at time t:

$$v_{n,t} = \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\frac{H_{n,t}}{1-\alpha}\right) + max_{i \in N}\left[\beta E(v_{i,t+1}) - \mu_{in} + B_{i,t} + b_{i,t}\right]$$

- Cobb-Douglas prefs. for goods C and housing H, $\alpha \in (0,1)$
- CES varieties demand: $C_{n,t} = \left[\sum_{i \in N} \int_0^{M_{i,t}} c_{ni,t}(j)^{\frac{\sigma-1}{\sigma}} dj\right]^{\frac{\sigma}{\sigma-1}}$
- residential land / housing demand: $H_{n,t}$
- utility cost of relocating from n to i, μ_{in}
- innate amenity shifter $B_{i,t}$
- idiosyncratic preference shocks: $b_{i,t} \sim Gumbel(-\gamma\nu, \nu)$
  - heterogeneous, time-varying location preference draws
  - allows model to replicate bi-directional migration flows
  - Gumbel distribution with tractable aggregation properties

Setup: NEG tradeable goods production

- monopolistic competition and IRS in production of tradeable goods varieties (cf. Helpman (1998) and Krugman (1991))
- endogenous number of heterogeneous varieties $M_{i,t}$ (one firm = one variety, different location = diff. varieties)
- IRS via fixed cost (in terms of labour) to set up production, labour requirement per unit $x_{i,t}$: $l_{i,t}(j) = \bar{l} = F + \frac{x_{i,t}}{A_{i,t}}$
- classic new economic geography-style **agglomeration force**: $\rightarrow$ IRS + love of variety + transport cost

Setup: land markets

- land rents redistributed lump-sum to local workers
  (cf. Redding (2016) and Redding and Rossi-Hansberg (2017))
- land market clearing yields solution for land rental rate $r_{n,t}$:

$$r_{n,t} = \frac{\alpha}{1-\alpha} \frac{w_{n,t} L_{n,t}}{H_{n,t}}$$

- classic Helpman-style **dispersion force**: $L_{n,t} \uparrow \rightarrow r_{n,t} \uparrow$

Equilibrium condition 1: expected lifetime utility

Taking expectation over preference shocks yields **expected lifetime utility** for representative worker residing in location *n*:

$$V_{n,t} = \alpha ln\left(\frac{w_{n,t}}{\alpha}\right) - \alpha lnP_{n,t} - (1-\alpha)ln\left(\frac{(1-\alpha)L_{n,t}}{H_{n,t}}\right) + \nu ln\sum_{i\in N}\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}} \tag{1}$$

- first line of RHS: current period utility
- second line of RHS: option value to move elsewhere next period

Equilibrium condition 2: migration flows gravity equation

Migration shares given by probability that location i offers highest expected utility of all possible destinations for agents from n:

$$m_{in,t} = \frac{\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k \in N}\left(exp\left[\beta V_{k,t+1} - \mu_{kn} + B_{k,t}\right]\right)^{\frac{1}{\nu}}} \tag{2}$$

- higher expected lifetime utility in destination: $m \uparrow$
- higher destination amenities: $m \uparrow$
- higher moving cost between residence and destination: $m \downarrow$

Equilibrium condition 2: migration flows gravity equation

Migration shares given by probability that location i offers highest expected utility of all possible destinations for agents from n:

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- higher expected lifetime utility in destination: $m \uparrow$
- higher destination amenities: $m \uparrow$
- higher moving cost between residence and destination: $m \downarrow$

Evolution of each location's population over time

- combines $L_{i,0}$ and $m_{ni,t}$ to trace history of population changes

$$L_{n,t+1} = \sum_{i \in N} m_{ni,t} L_{i,t}$$

Equilibrium condition 3: goods flows gravity equation

Profit maximisation, zero profit condition, labour market clearing and trade balance imply:

$$\pi_{ni,t} = \frac{X_{ni,t}}{X_{n,t}} = \frac{L_{i,t}\left(\frac{d_{ni,t}w_{i,t}}{A_{i,t}}\right)^{1-\sigma}}{\sum_{k\in N} L_{k,t}\left(\frac{d_{nk,t}w_{k,t}}{A_{k,t}}\right)^{1-\sigma}} \tag{3}$$

- can also incorporate international trade: $L_{x,t}\left(\frac{d_{nx,t}w_{x,t}}{A_{x,t}}\right)^{1-\sigma}$
  - see Balboni (2019), Section 4.5, Equations (13)-(19)

Equilibrium condition 3: testing gravity equation empirically

Implement log-linear gravity equation (in MA terms) as regression specification:

$\rightarrow$ Ho-Chi-Minh Trail IV approach:
market access $+1\%$ $\rightarrow$ expenditure pc $+0.595\%$

$\rightarrow$ similar to comparable estimates from literature
(e.g. Donaldson and Hornbeck (2016))

$\rightarrow$ IV estimate well in line with model prediction:
market access $+1\%$ $\rightarrow$ expenditure pc $[+0.143\%, +0.792\%]$

Welfare effects of road investments ↑ and sea levels ↑

Welfare at location n in period t (from iterating expected lifetime utility forward):

$$V_{n,t} = \sum_{s=t}^{\infty} \beta^{s-t} ln \left(\frac{\left(\frac{w_{n,s}}{\alpha}\right)^{\alpha} exp(B_{n,s})}{(P_{n,s})^{\alpha} \left(\frac{(1-\alpha)L_{n,s}}{H_{n,s}}\right)^{1-\alpha} (m_{nn,s})^{\nu}} \right)$$

Welfare effects of road investments ↑ and sea levels ↑

Welfare at location n in period t (from iterating expected lifetime utility forward):

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Road investments affect welfare via:

- → real wage effects: $d_{ni} \downarrow \rightarrow MA_n \uparrow \rightarrow P_n \downarrow, w_n \uparrow \rightarrow V_n \uparrow$
- → endogenous migration: location choice function of real wages

Welfare effects of road investments ↑ and sea levels ↑

Welfare at location n in period t (from iterating expected lifetime utility forward):

$$V_{n,t} = \sum_{s=t}^{\infty} \beta^{s-t} ln \left(\frac{\left(\frac{w_{n,s}}{\alpha}\right)^{\alpha} exp(B_{n,s})}{(P_{n,s})^{\alpha} \left(\frac{(1-\alpha)L_{n,s}}{H_{n,s}}\right)^{1-\alpha} (m_{nn,s})^{\nu}} \right)$$

Road investments affect welfare via:

→ real wage effects: $d_{ni} \downarrow \rightarrow MA_n \uparrow \rightarrow P_n \downarrow, w_n \uparrow \rightarrow V_n \uparrow$

→ endogenous migration: location choice function of real wages

Sea level rises affect welfare via:

→ inundated land: $H_n \downarrow \rightarrow r_n \uparrow \rightarrow V_n \downarrow$

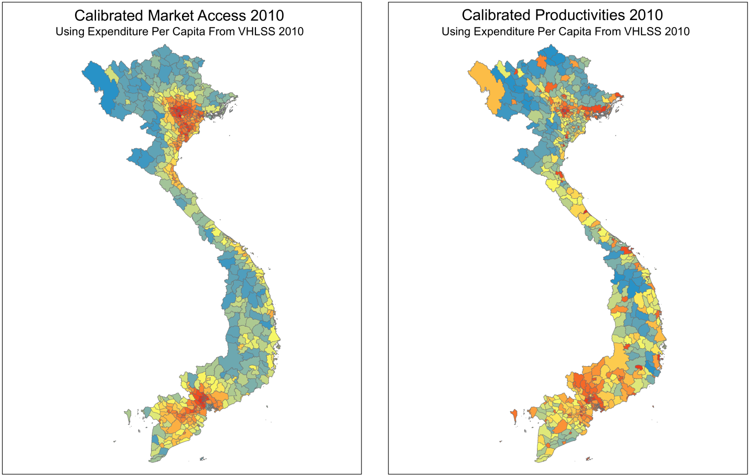
→ inundated roads: $d_{ni} \downarrow \rightarrow MA_n \downarrow \rightarrow V_n \downarrow$

Solving the model to estimate counterfactuals

1. choose values for the model's parameters
2. numerically solve static production problem at baseline (2010) (i.e. invert static part of model using baseline data)
   → obtain initial period's relative productivities and market access
3. parameterise sea level rise shocks, i.e. how sea level rise will affect land areas and trading costs in inundated locations
4. simulate model forward from 2010 in 5-year intervals
   → solve for sequential equilibrium path $\{L_{n,t}, m_{ni,t}, w_{n,t}, MA_{n,t}\}_{t=0}^{\infty}$ in each location
5. re-simulate model under counterfactual distributions of future road investments
   → compare welfare gains relative to the status quo

Recovered fundamental productivities (via model inversion)

Figure 7: Calibrated market access and productivities in 2010



Data are reported at the level of district-based spatial units.
Red (blue) spatial units indicate higher (lower) values.

Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Recovered fundamental productivities match proxy data

Table 9: Correlation between calibrated productivities and TFP measures, district-level estimates

Dependent variable: Calibrated relative productivity level by district, 2010		
TFP estimated using $Y = AK^{\frac{1}{3}}L^{\frac{2}{3}}$	0.182***	
	(0.0207)	
TFP estimated using $Y = AL$		0.0386***
		(0.00438)
Observations	540	540
R-squared	0.126	0.126

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Reallocation of population from alternative roads

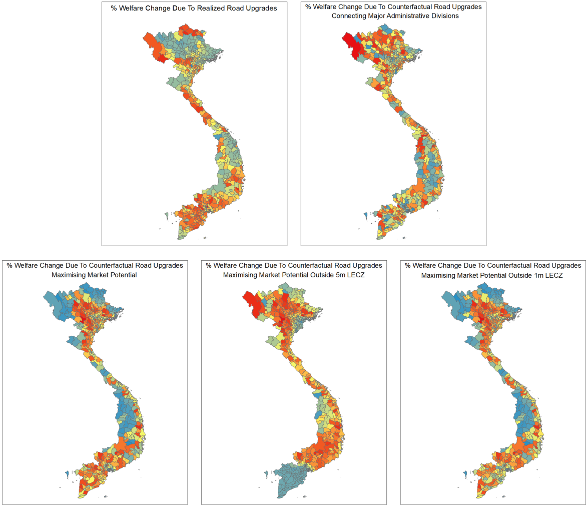
Figure 8: Population changes induced by road investment scenarios, relative to baseline scenario of no investments in road upgrades (scenario with no future sea level rise)

Data are reported at the level of district-based spatial units.
Red (blue) spatial units indicate higher (lower) values.

Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Spatial distribution of welfare gains from alternative roads

Figure 9: Welfare changes induced by road investment scenarios, relative to baseline scenario of no investments in road upgrades (scenario with no future sea level rise)

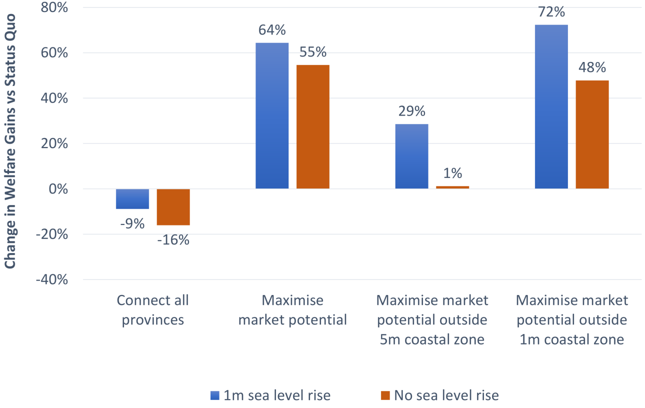


Data are reported at the level of district-based spatial units.
Red (blue) spatial units indicate higher (lower) values.

Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Welfare gains from counterfactual road investments

Figure 17: Relative welfare gains from counterfactual road investments versus status quo



Source: Balboni, C. (2019). In harm's way? Infrastructure investments and the persistence of coastal cities. *London School of Economics mimeo*.

Takeaways from Balboni (2019)

1. reversal of coastal fortune has important implications for where to place infrastructure today
   - coastal fortune decreasing already
     (e.g. via better infrastructure, structural transformation)
   - reversal of fortune reinforced/accelerated by climate change
2. allocating road investments further inland increases welfare even without inundation
3. sea level rise amplifies welfare gains from avoiding vulnerable coastal locations
4. infrastructure allocations may need to change dramatically: 180m people live on land below sea level by 2100

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