# Online Appendix for
# In Harm's Way? Infrastructure Investments and the Persistence of Coastal Cities

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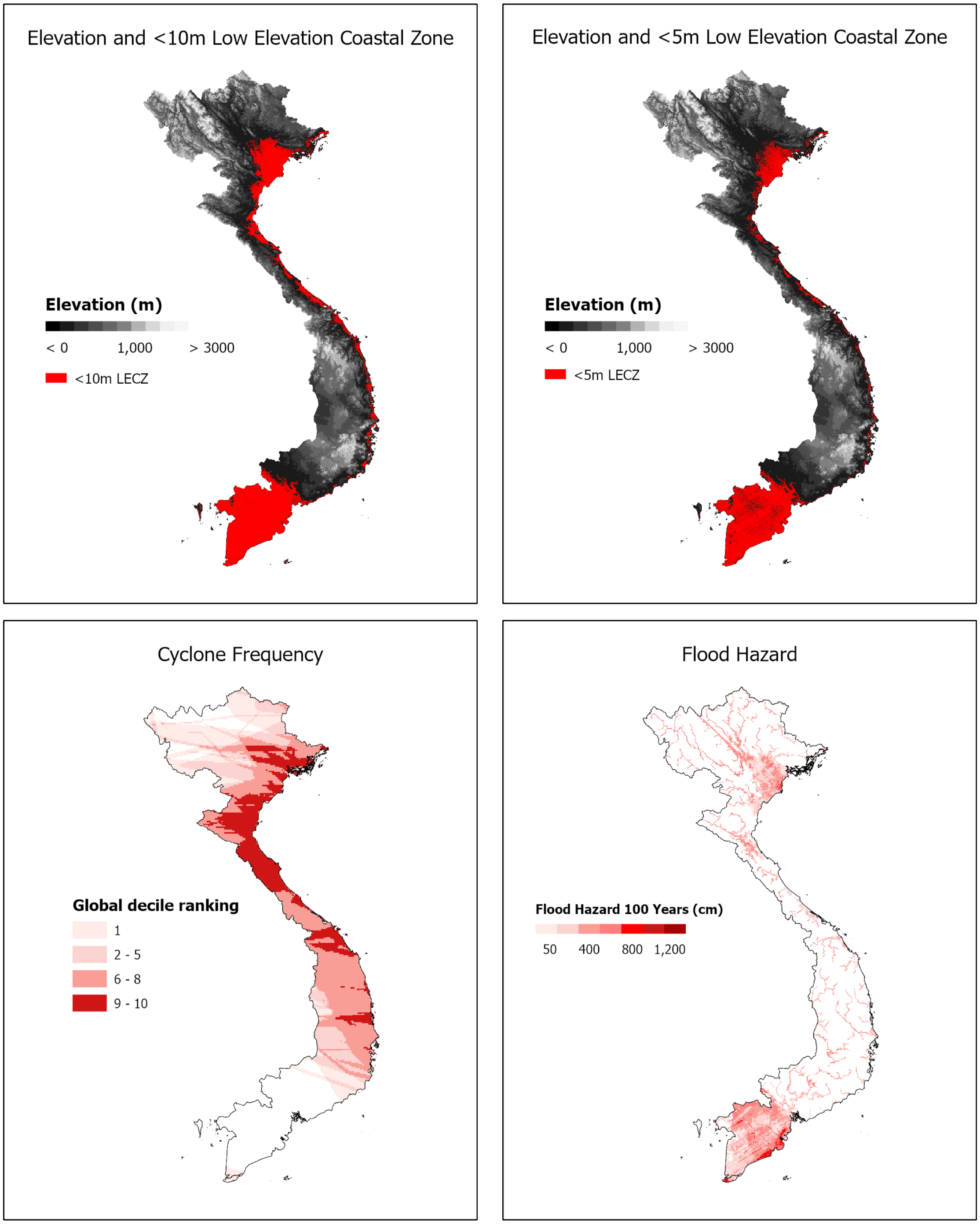
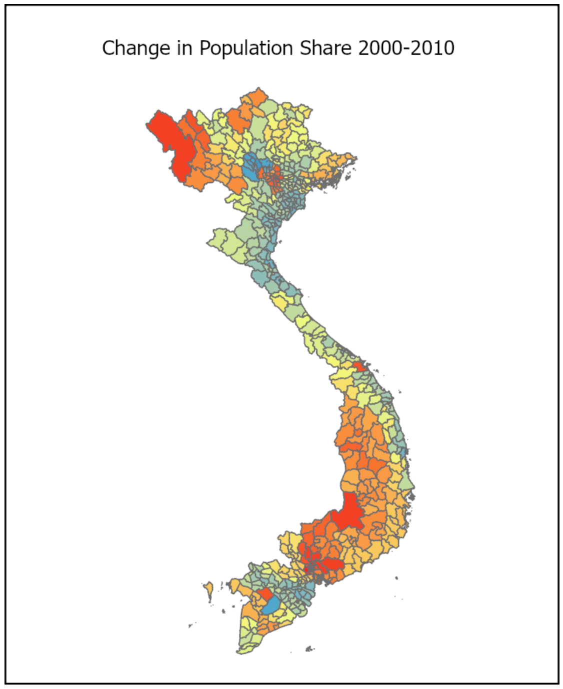
# I Supplementary Tables and Figures

Figure A1: Natural hazard vulnerability in Vietnam



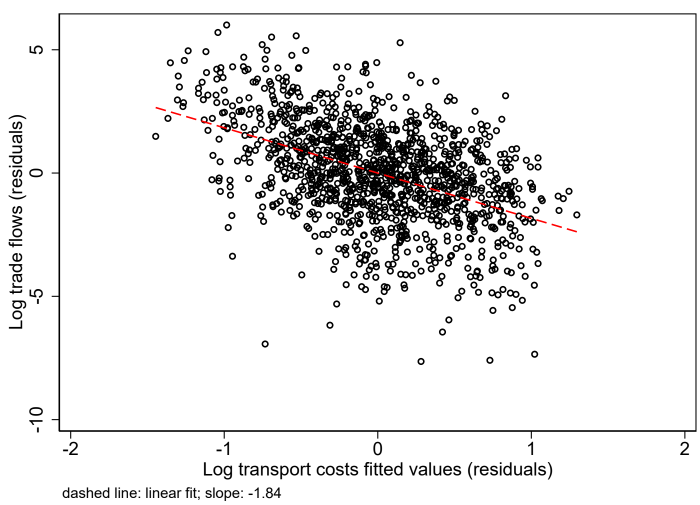

*Notes: Top left (right) panel shows elevation, with pixels at less than 10 (5) meters elevation in red, from Jarvis et al. (2008). Bottom left panel shows cyclone frequency measured using a global decile ranking across grid cells from the Global Cyclone Hazard Frequency and Distribution v1 dataset (Center for Hazards and Risk Research and CIESIN at Columbia University and IBRD, The World Bank (2005)). Bottom right panel shows flood hazard for riverine flooding (from McGlade et al. (2019)) and coastal flooding (from Muis et al. (2016)).*

Figure A2: District-level population share changes 2000-2010




*Notes: Data are reported at the level of district-based spatial units. Red (blue) units indicate higher (lower) values. Data sources and construction are described in Section II of the paper and Supplemental Appendix II.*

Figure A3: Inter-provincial gravity in goods trade



# II Data Appendix

## A Economic Data

### A.1 Vietnam Household Living Standards Survey (VHLSS)

The VHLSS has been conducted biennially by the General Statistics Office of Vietnam since 2002. These surveys collect information on demographics, education, health, employment, income, consumption, housing and participation in poverty alleviation programs. In each round, some respondents are administered the full survey questionnaire (29,530 households in 2002, 9,402 in 2010) and a larger number of respondents are administered a shorter version excluding the expenditure module (75,000 households in 2002, 69,360 in 2010). Responses to the former are representative at the level of Vietnam's six geographic regions and for rural/ urban areas, while those to the latter are representative at the provincial level (GSO (2010a), Lanjouw, Marra, and Nguyen Viet (2013)).

### A.2 Vietnam Enterprise Census (VEC)

The VEC has been conducted annually by the General Statistics Office of Vietnam since 2000 (GSO (2015)). The census provides firm-level data covering all economic units with their own legal status, independent business accounts and more than 10 employees. Primary, manufacturing and services industries are included, and the data collected includes firm ownership, industry, location, age, employees, employees' compensation and fixed capital. There are a total of 42,044 firm-level observations in 2000 and 287,853 observations in 2010. The total reported labor force employed by these firms represented 4% and 11% of the total population in 2000 and 2010 respectively. Each firm for which data is reported in the VEC is assigned to a spatial unit based on its province and district identifiers. For each firm, I calculate the average annual wage per worker as the sum of salaries and salary equivalents paid to all workers divided by the number of workers. Each spatial unit average wage is then obtained as the mean value across all firms in the spatial unit, excluding 1% outliers. Similar results are obtained using the median wage across all firms in the spatial unit.

## B Transport Network Data

This section describes how transport network data was constructed from manually digitized maps of Vietnam's road, inland waterway and coastal shipping networks in 2000 and 2010. I then describe the data used to assign to each segment of this network a direct economic cost of transportation per ton-km, a travel time cost associated with time spent in transit and a one-off mobilization charge per ton. Together, these datasets are used to calculate bilateral trade costs between any two locations on the network or from these locations to international markets.

### B.1 Roads

I obtain road network data from the 2000 and 2010 editions of ITMB Publishing's detailed International Travel Maps of Vietnam (ITMB Publishing (2000), ITMB Publishing (2010)), which show the location of freeways, dual carriageways, major, minor and other roads. I geo-referenced each map and manually traced the location of each road category to obtain a GIS shapefile of the entire road network in each road category in 2000 and 2010, shown in Figure 3. The total length of the road network captured in this exercise is 45,741km in 2000 and 45,770km in 2010. National transport studies in 2000 and 2010 (JICA (2000a), JICA (2010)) report the total lengths of roads at the national (15,250km in 2000/ 17,000km in 2010), provincial (17,449km/ 23,000km), district (36,372km/ 55,000km) and commune/village (131,455km/ 141,000km) level. As such, the road network data used in this analysis should cover the entire national and provincial road networks, and a sizable share of of the district network. Since the object of interest for my analysis is the road network that facilitates trade and migration between spatial units at a slightly more aggregated level that the district level, the coverage of my road data seems sensible.

Direct economic costs per ton-km and travel speed are allowed to vary with road type (freeway/ dual carriageway/ major road/ minor road/ other road), surface slope and surface condition.

To obtain speed data, I first assign each segment of road in 2000 and 2010 a designed speed based on its type and slope, and then adjust these downwards to obtain realized speeds based on a calibrated value for the average road surface condition across the network. I obtain road types from the mapped road networks. Surface slope is calculated using the elevation data described in Section II and the 'Slope' tool in ArcGIS Spatial Analyst, and discretized into three bins to denote flat, hilly and mountainous terrain[1]. JICA (2000a) presents data on the designed speed for different road types in flat, hilly and mountainous regions. For comparability with this data, I assume that the freeways mapped in my road transport network correspond to roads with 4 x 3.75m lanes, dual carriageways to 2 x 3.75m lanes, major roads to 2 x 3m lanes, minor roads to 1 x 3.5m lanes and other roads to 1 x 3m lanes.

I assume that the average road surface condition across the network is constant and calibrate this based on the average percentage of designed speed achieved on Vietnam's roads using data from JICA (2000a) and Blancas and El-Hifnawi (2013). JICA (2000a) estimates that, while 100% of the designed speed can be achieved on roads with good surface condition, this falls to 80%, 50% and 30% when the road condition is fair, poor and very poor respectively. I do not have data on the surface condition of all roads in Vietnam in 2000 and 2010, so I calibrate the average road surface condition across the network based on evidence in Blancas and El-Hifnawi (2013) that in 2010 an average truck speed of 40 km/hr is 'consistently corroborated in interviews with road transport carriers'. I therefore calculate the average road surface condition across the country (measured in percentage of designed speed achieved) such that the average travel speed on the network of roads used by truckers (assumed to exclude the category 'other roads', which corresponds to sub-national level roads) in 2010 is 40 km/hr. This calculation suggests that on average 72% of the designed speed is achieved, corresponding to fair road surface conditions according to the JICA (2000a) descriptions. This is

[1] The size of these bins is determined by ArcGIS's 'natural breaks' classification, which partitions data into a given number of classes based on the size of valleys in the data distribution. This gives gradient bins which correspond closely to those used to denote flat, hilly and mountainous terrain in studies of the geometric design of roads across countries (e.g. Tanzania Ministry of Works (2011), JICA (2014)).

consistent with evidence in JICA (2010) that 43% of national highways were in good condition, 37% average and 20% bad or very bad. To calculate realized travel speeds on each segment of the road network, I therefore assume that road surface conditions are such that 72% of the designed speed can be achieved in both 2000 and 2010 (average speeds still increase significantly due to substantial road upgrades). Based on this and the designed speed for roads of different types and slopes, I assign a travel speed to each segment of the road network in 2000 and 2010.

I use JICA (2000a) data on average truck mobilization costs and cargo transportation costs per ton-km in 2000. I assume that the mobilization cost is constant across the road network but that the average cost per ton-km applies at the average travel speed on the network of roads used by truckers (32km/hr in 2000). I then apply estimated adjustment factors to allow the cost per ton-km to vary at different road speeds[2]. To obtain 2010 figures, I use evidence from Blancas and El-Hifnawi (2013) that the cost per ton of cargo transport over the 4000km round trip along the North-South axis in 2010 was $110.5. I assume that the proportion of this attributable to mobilization charges is the same in 2010 as in 2000 and that the cost per ton-km again applies at the average travel speed across the road network used by truckers (40 km/hr in 2010), scaling by the adjustment factors to obtain costs per ton-km at different road speeds.

### B.2 Inland waterways

In contrast to the road network, the inland waterway network did not change significantly over the study period (JICA (2000a), JICA (2010))[3]. I therefore map only one version of the inland waterway network, and use this for both the 2000 and 2010 analyses. The inland waterway network was traced manually in GIS from maps of the network in the JICA (2000a) technical report on inland waterways (JICA (2000b)), which shows the location of inland waterways in each of six classes characterized by different dimensions and therefore vessel capacities. This network was also cross-referenced with dimensions for major inland waterway routes in 2009 reported in Blancas and El-Hifnawi (2013) to verify that the network and channel classifications remained broadly unchanged. The inland waterway network is shown in Figure A4.

Blancas and El-Hifnawi (2013) estimate that the average sailing speed of self-propelled barges of all sizes on the inland waterway network is 9 km/hr, slightly lower than the typical design speed of 10 km/hr. Given minimal changes in the inland waterway network between 2000 and 2010, this value is used in both years. Blancas and El-Hifnawi (2013) provide estimates of 2010 loading and unloading costs per ton for inland waterway transportation and cargo transport costs per ton-km for ships of varying capacities[4]. For 2010 calculations, I assign the former as the mobilization cost for all inland waterway journeys, and assign variable costs per ton-km based on the vessel capacities

[2]JICA (2000a) estimates adjustment factors of 1 for speeds of 60+ km/hr, 1.07 at 50 km/hr, 1.17 at 40 km/hr, 1.31 at 30 km/hr, 1.53 at 20 km/hr and 2.01 at 15 km/hr.

[3]Consistent with this, investment in the inland waterway sector over the period represented only 2% of transport sector funding between 1999 and 2007 (Blancas and El-Hifnawi (2013)).

[4]Blancas and El-Hifnawi (2013) also consider variation in cost per cargo ton-km by trip distance for each ship type. As the costs per ton-km vary much less significantly across trip distances than vessel capacities, I use the authors' baseline of costs per ton-km based on a 150 km trip for all ship types.

permissible on waterways of different classes. JICA (2000a) provides average estimates in 2000 for mobilization charges per ton (again assigned to all inland waterway journeys) and transport costs per ton-km. To calculate variable costs in 2000, I assume that the midpoint of the JICA (2000a) figures applies to Class 3 waterways, and obtain values for other waterway classes using the ratios of variable costs per ton-km across waterway classes from the 2010 data.

These calculations reveal that, while the slowest of the transport modes considered here, inland waterway transportation is characterized by lower direct costs per ton-km of cargo than road transport and lower mobilization charges per ton than coastal shipping.

### B.3 Coastal shipping

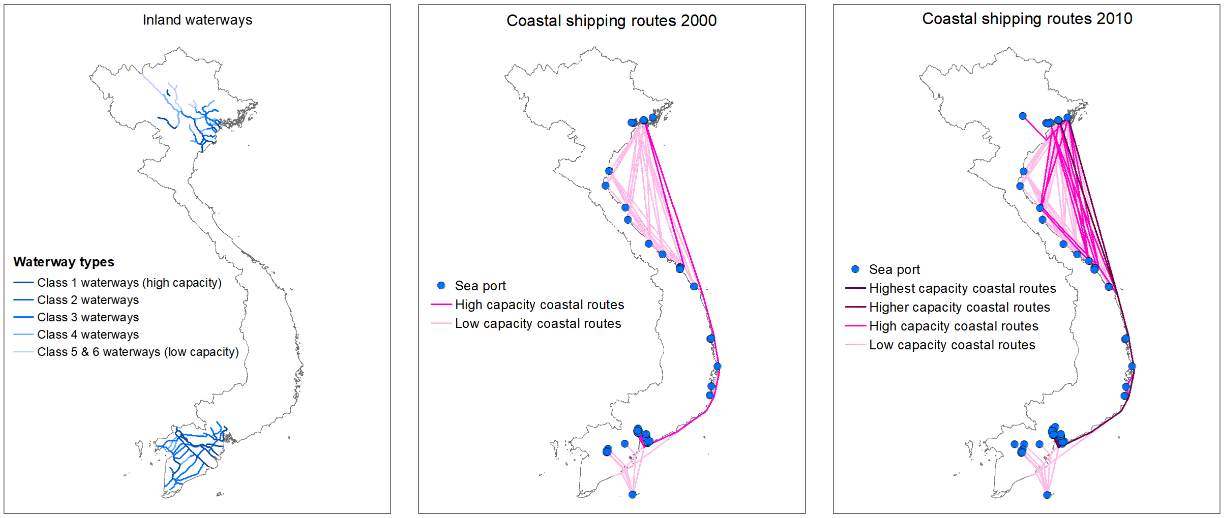
Coastal shipping routes are mapped based on the location of Vietnam's sea ports in 2000 and 2010. The locations of ports are taken from the website of the Vietnam Seaports Association (Vietnam Seaports Association (2016)). Data on which ports were operational and the maximum vessel sizes that were accepted in each port in 2000 and 2010 are based on the *'List of Seaports in the Master Plan on the Development of Vietnam's Seaport System till the Year 2010'*, *'List of Seaports in the Master Plan on Development of Vietnam's Seaport System through 2020'* and Blancas and El-Hifnawi (2013)[5]. The location of sea ports in 2000 and 2010 are shown in Figure A4, which also shows coastal shipping routes between them.

To map coastal shipping routes between these sea ports, I obtained the entire coastline of mainland Vietnam from Natural Earth (Natural Earth (2016)) and for both the 2000 and 2010 networks of seaports mapped the shortest route between neighboring ports. Estimates of coastal shipping speeds are based on data for the key shipping route between Haiphong and Ho Chi Minh City. The total time for the 3216 km round trip was estimated to be 7 days for all vessel sizes in 2010 (Blancas and El-Hifnawi (2013)), giving an average travel speed of 19km/hr. This is used as the average coastal shipping speed on all routes in both 2000 and 2010 calculations.

Direct economic costs of coastal shipping between each of Vietnam's seaports are allowed to vary with vessel size. In each year, I divide seaports into four bins based on their maximum vessel capacity and assign the average maximum vessel capacity of the ports in a bin to each port in that bin. I then choose the vessel size for journeys between each origin and destination port to be whichever is the lower of the assigned vessel capacities of the origin and destination ports in the relevant year. This allows me to subdivide the full network of coastal shipping routes in each year into four categories according to the vessel size that can be accommodated on each route; each of these categories is characterized by different economic costs of cargo transportation.

[5]For most ports, these three documents report whether the port was operational in 1999 and 2009 and their maximum vessel capacity in each of these years. For those ports where this data was not available from these documents, I used searches of other public sources to determine whether the port was operational in 2000 and 2010. For operational ports, I then estimated maximum vessel capacities in 2000 and 2010 based on current maximum vessel capacities for each port reported on the Vietnam Seaports Association website and average percentage growth rates in maximum vessel capacity across all ports with available data.

Figure A4: Inland waterway and coastal shipping networks




The key data sources for the economic cost calculations are again JICA (2000a), which reports average values for coastal shipping costs per ton-km and mobilization charges in 2000, and Blancas and El-Hifnawi (2013), which provides 2010 shipping costs per ton for the Haiphong - Ho Chi Minh City route for vessels of different sizes. For 2000 calculations, I assume that the JICA (2000a) figures for variable costs and mobilization charges are for a vessel of average size. I estimate these costs for vessels of other sizes by assuming that shipping costs per ton decrease with vessel size at the same rate as demonstrated in the 2010 data for the Haiphong - Ho Chi Minh City route, and that these decreases apply equally to mobilization charges and variable costs. For 2010 calculations, I use the Blancas and El-Hifnawi (2013) data on total shipping costs per ton for the Haiphong - Ho Chi Minh City route by vessel size, and the share of mobilization costs implied by the 2000 data[6]. The relevant variable transport cost per ton-km is assigned to each stretch, but the assigned mobilization cost on all routes is an average for the relevant year.

In terms of direct economic costs, coastal shipping incurs the lowest variable costs per ton-km of all modes, but the highest mobilization charges. Coastal shipping speeds are intermediate between those of road transport and inland waterways.

### B.4 International ports

The subset of seaports that are international seaports are obtained using data on domestic and international throughput at Vietnam's seaports in 2000 and 2010 from the Vietnam Seaports Association. In each year, I classify a seaport as an international seaport if it accounts for over 1%

[6]For vessel sizes outside the estimated range in both years, I assume the continuation of a linear trend in the relationship between vessel size and shipping cost from the nearest interval for which data is available.

of the country's entire international cargo throughput and/or over 50% of the port's throughput is international in the relevant year.

The international ports included in the analysis comprise these 26 international seaports together with fourteen international border road connections of the Asian Highway Network and Greater Mekong Subregion cross-border road network (geo-referenced from ADB (2010) and ERIA (2010)) and Vietnam's three major international airports (from https://www.naturalearthdata.com/).

### B.5 Connecting roads

Because the location of each spatial unit is assigned to the longitude and latitude of its centroid, it is not always the case that the assigned location of each spatial unit lies directly on the mapped transportation network. In order to calculate bilateral transport costs between all spatial units, each spatial unit centroid is connected to the nearest point on the road network (and the inland waterway network if this is closer). Similarly, where sea ports did not coincide exactly with a spatial unit centroid or a point on the road/ inland waterway network, I connected them to the nearest point on the road network (and the inland waterway network if closer). These 'feeder' roads are assigned a travel speed and cost equivalent to the most costly type of road ('other' road on mountainous terrain). The only exceptions are the few spatial units which are islands off Vietnam's coast: these are instead assigned a travel speed and cost equivalent to a Class 1 waterway.

I allow movement between different types of road and the inland waterway network wherever they connect (albeit incurring the relevant mobilization cost), but only allow switches on to or off coastal shipping routes at sea ports.

### B.6 Monetizing travel time costs

Travel time costs in 2000 are monetized using a weighted average of estimated cargo time costs by commodity type in 2000 from JICA (2000a), where the weights are the share of each commodity in 1999 inter-provincial freight traffic demand from the same source. 2010 figures are obtained by applying the commodity-specific price indices from 2000-2010 for each commodity from GSO (2005) and GSO (2010b), and averaging using weights given by the share of each commodity in 2008 inter-provincial freight traffic demand from JICA (2010).

### B.7 Intra spatial unit trade costs

Since the location of each spatial unit in Vietnam is assigned to its centroid, the Dijkstra algorithm would estimate that trade *within* each spatial unit is costless. Analyses that calibrate trade costs as a function of distance alone have addressed this problem by approximating intra-unit trade costs based on the average distance traveled to the center of a circular unit of the same area from evenly-distributed points within it, given by $\frac{2}{3}(area/\pi)^{1/2}$ (e.g. Redding and Venables (2004), Au and Henderson (2006)). Since my analysis focuses on changes in transport infrastructure, distance-based measures will not be appropriate. However, I use the same intuition that the average distance traveled from points inside a circular unit to its center will be two thirds of the unit's radius. I assume that intra-unit trade occurs via road given the comparative advantage of road transport over shorter distances. For each spatial unit, I calculate both the travel cost along the road network and the geodesic distance from the unit's centroid to the nearest point at which the road network intersects the unit's border. I then scale the travel cost (net of the road mobilization cost) by the ratio between the measured geodesic distance and the radius of a circle with the unit's total land area. I use two thirds of this value added to the road mobilization cost as my estimate of the intra-unit bilateral trade cost.[7]

Iceberg trade costs within the spatial unit that represents the rest of the world are based on the estimated tax-equivalent of representative trade costs for industrialized countries of 170% in Anderson and Van Wincoop (2004).

## C Road construction costs

This section uses data on the realized costs of individual road construction projects in Vietnam from 2000 to 2010 to validate the construction cost function in Equation (19) in this empirical setting. This construction cost function, based on the engineering literature, yields the relative road construction cost for area cells on different terrains and is used to ensure cost-neutrality of the counterfactual networks considered relative to the status quo upgrades.

Data was collected on the reported actual cost of road construction and upgrade projects in Vietnam from 2000 to 2010 from the World Bank's Road Costs Knowledge System dataset (Bosio et al. (2018)); reports of the Asian Development Bank (ADB (2001), ADB (2007), ADB (2009), ADB (2019)) and Japan International Cooperation Agency (Vietnam-Japan Joint Evaluation Team (2006), Vietnam-Japan Joint Evaluation Team (2007), Pham (2015), JICA (2013), Inazawa (2016)); and Vietnamese language sources from Logistics Vietnam (Logistics Viet Nam (2020)), Directorate for Roads Vietnam (Directorate for Roads of Vietnam (2020)) and local news reporting[8]. This yielded costs for 17 projects with sufficient geographic detail to be mapped to specific stretches of the road network. The cost per kilometer of new road lane construction projects was standardized relative to a single standard 3.7 meter lane upgrade, and the cost of lane upgrade projects to 50%

[7] For the seven districts that are groups of islands, I instead obtain the minimum bounding circle enclosing each group of islands, and estimate the intra-district trade cost as the cost of traversing two thirds of the radius of this circle, assuming the same travel costs as along class 1 waterways.

[8] http://mt.gov.vn/phunu/tin-tuc/5315/quang-ninh--chuan-bi-dau-tu-du-an-xay-dung-quoc-lo-4b.asp,http://baobariavungtau.com.vn/kinh-te/200808/Quy-iV-nam-2008-Khoi-cong-nang-cap-mo-rong-quoc-lo-51-264795/,https://vnexpress.net/khoi-cong-tuyen-cao-toc-dau-tien-o-mien-trung-2756877.html,https://baodautu.vn/dau-tu-18377-ty-dong-xay-dung-cao-toc-ninh-binh--thanh-hoa-d26477.html,http://mt.gov.vn/tk/tin-tuc/16200/du-an-duong-cao-toc-cau-gie---ninh-binh-(giai-doan-i).aspx,https://gkg.com.vn/thong-tin-moi-duong-cao-toc-thanh-pho-ho-chi-minh-trung-luong/,http://www.tapchigiaothong.vn/cao-toc-phap-van--cau-re-con-duong-dep-o-cua-ngo-phia-nam-thu-do-ha-noi-d85583.html,https://daklak.gov.vn/web/english/-/buon-ma-thuot-nha-trang-highway-has-four-lanes-total-investment-of-19-500-billion-vnd,https://mt.gov.vn/vn/tin-tuc/45211/cao-toc-tp-hcm---long-thanh---dau-giay-duoc-danh-gia-la-cong-trinh-co-chat-luong-la-vuot-troi-.aspx,http://mt.gov.vn/en/news/111/hn-thai-nguyen-new-national-highway-3-opens-to-traffic.aspx,https://sapaexpress.com/vn/tuyen-duong-cao-toc-noi-bai-lao-cai-chinh-thuc-hoat-dong.html,http://baochinhphu.vn/Doi-song/Cao-toc-Phap-VanCau-Gie-Tiep-tuc-cham-vi-vuong-mat-bang/336344.vgp,https://cafeland.vn/tin-tuc/nhung-cau-duong-bo-nao-sap-duoc-hoan-thanh-o-tphcm-76250.html.

of new lane construction.

The mapped road construction projects have good coverage across different regions and types of terrain across Vietnam, as shown in Figure A5. The routes corresponding to these projects were intersected with the relative road construction cost grid yielded by Equation (19). The average construction cost implied by Equation (19) across pixels traversed by each route was then plotted against the cost per kilometer for that route in millions of US dollars from the road construction projects data. The results are shown in Figure A6 and demonstrate that the construction cost estimates based on the engineering cost function fit reported road construction costs from these sources well. This provides reassurance that the construction cost at Equation (19) provides a sensible basis for ensuring cost-neutrality of the counterfactual networks considered.

Figure A5: Mapped road construction projects

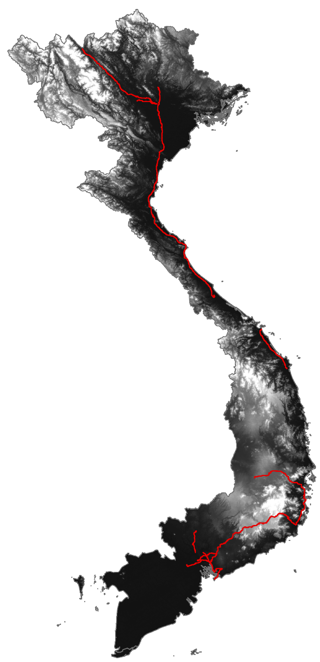
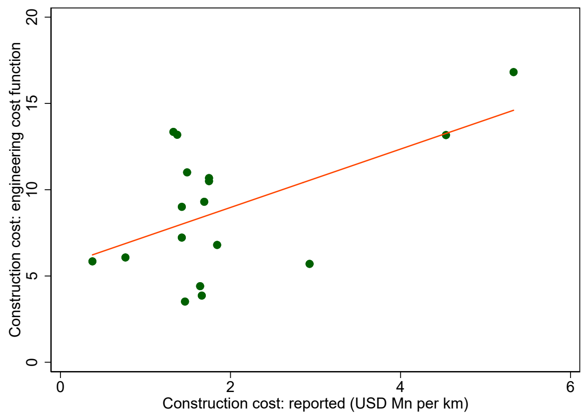


Figure A6: Road construction cost validation



## III Solution algorithm with unanticipated sea level rise

The central estimates assume that agents are perfectly foresighted about the future evolution of sea level rise. Under the alternative assumption of myopic agents, solving for the sequential equilibrium is more complex, since in each period the model must now be solved forward taking as given the set of initial conditions, an assumed path for the values of the model's parameters and the solution to the sequential equilibrium in the absence of any shock arriving that period. This Appendix outlines the method used to solve for the sequential equilibrium in the case where myopic agents expect that sea level rise will occur in line with climate projections 30 years into the future but that levels will stabilize thereafter.

In this case, the solution method uses agents' behavior before the arrival of the shock to construct differenced equations for $Y_{n,t+1}$, $\frac{m_{in,t+1}}{m_{in,t}}$ and $L_{n,t}$, which can be used together with equilibrium conditions (11) and (12) to solve for the sequential equilibrium. Let $X\left(\Theta^{s}\right)$ denote the variable $X$ according to the information available in period $s$. Recall that at $t=0$ (2010), agents expect gradual inundation over the periods $t=1$ to $t=5$, with sea levels maintained at their $t=5$ levels thereafter. At $t=6$ (2040), agents learn that the gradual inundation will instead continue. Take as given the initial conditions; an assumed time path for land areas, productivities and transport costs based on the information available during each time period; and the solution (computed previously) to the sequential equilibrium in the absence of any shocks. In this case, the equilibrium conditions for $Y_{n,t+1}$, $\frac{m_{in,t+1}}{m_{in,t}}$ and $L_{n,t}$ are derived at Appendix IV and summarized here.

The equilibrium conditions for expected lifetime utility and migration shares expressed in relative time differences in the absence of any shocks are as derived previously (Equations (A14) and (A15)), repeated here with the available information set made explicit:

$$\text{(A1)} \quad Y\left(\Theta^{0}\right)_{n,t+1} = \left[\frac{\left(\frac{w\left(\Theta^{0}\right)_{n,t+1}}{w\left(\Theta^{0}\right)_{n,t}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^{0}\right)_{n,t+1}}{P\left(\Theta^{0}\right)_{n,t}}\right)^{\alpha}\left(\frac{L\left(\Theta^{0}\right)_{n,t+1}/L\left(\Theta^{0}\right)_{n,t}}{H\left(\Theta^{0}\right)_{n,t+1}/H\left(\Theta^{0}\right)_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{k\in N} m\left(\Theta^{0}\right)_{kn,t}\left(Y\left(\Theta^{0}\right)_{k,t+2}\right)^{\beta} exp\left[\frac{1}{\nu}\left(B\left(\Theta^{0}\right)_{k,t+1}-B\left(\Theta^{0}\right)_{k,t}\right)\right]$$

$$\text{(A2)} \quad \frac{m\left(\Theta^{0}\right)_{in,t+1}}{m\left(\Theta^{0}\right)_{in,t}} = \frac{\left(Y\left(\Theta^{0}\right)_{i,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^{0}\right)_{i,t+1}-B\left(\Theta^{0}\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^{0}\right)_{kn,t}\left(Y\left(\Theta^{0}\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^{0}\right)_{k,t+1}-B\left(\Theta^{0}\right)_{k,t}\right]\right)^{\frac{1}{\nu}}}$$

In all periods after $t=6$, the period in which the unanticipated shock arrives and updated information on the path of the economy's fundamentals becomes available, define $Y\left(\Theta^{6}\right)_{n,6} = \left[exp\left(V\left(\Theta^{6}\right)_{n,6}-V\left(\Theta^{0}\right)_{n,5}\right)\right]^{\frac{1}{\nu}}$ and $Y\left(\Theta^{6}\right)_{n,t+1} = \left[exp\left(V\left(\Theta^{6}\right)_{n,t+1}-V\left(\Theta^{6}\right)_{n,t}\right)\right]^{\frac{1}{\nu}}$ for $t \geq 6$. It is shown in Appendix IV that this gives rise to the following system of equations:

$$(A3)\qquad Y\left(\Theta^6\right)_{n,6} = \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w\left(\Theta^0\right)_{n,5}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^6\right)_{n,6}}{P\left(\Theta^0\right)_{n,5}}\right)^{\alpha}\left(\frac{L\left(\Theta^6\right)_{n,6}/L\left(\Theta^0\right)_{n,5}}{H\left(\Theta^6\right)_{n,6}/H\left(\Theta^0\right)_{n,5}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{i\in N}\left(\frac{Y\left(\Theta^6\right)_{i,6}}{Y\left(\Theta^0\right)_{i,6}}\right)^{\beta} m\left(\Theta^0\right)_{in,5}\left(Y\left(\Theta^6\right)_{i,7}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,6} - B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}$$

$$(A4)\qquad Y\left(\Theta^6\right)_{n,t+1} = \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,t+1}}{w\left(\Theta^6\right)_{n,t}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^6\right)_{n,t+1}}{P\left(\Theta^6\right)_{n,t}}\right)^{\alpha}\left(\frac{L\left(\Theta^6\right)_{n,t+1}/L\left(\Theta^6\right)_{n,t}}{H\left(\Theta^6\right)_{n,t+1}/H\left(\Theta^6\right)_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{k\in N} m\left(\Theta^6\right)_{kn,t}\left(Y\left(\Theta^6\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,t+1} - B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}}, \quad t \geq 6$$

$$(A5)\qquad \frac{m(\Theta^6)_{in,6}}{m(\Theta^0)_{in,5}} = \frac{\left(Y(\Theta^6)_{i,7}\right)^{\beta}\left(\frac{Y\left(\Theta^6\right)_{i,6}}{Y\left(\Theta^0\right)_{i,6}}\right)^{\beta}\left(exp\left[B(\Theta^6)_{i,6} - B(\Theta^0)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m(\Theta^0)_{kn,5}\left(Y(\Theta^6)_{k,7}\right)^{\beta}\left(\frac{Y(\Theta^6)_{k,6}}{Y\left(\Theta^0\right)_{k,6}}\right)^{\beta}\left(exp\left[B(\Theta^6)_{k,6} - B(\Theta^0)_{k,5}\right]\right)^{\frac{1}{\nu}}}$$

$$(A6)\qquad \frac{m\left(\Theta^6\right)_{in,t+1}}{m\left(\Theta^6\right)_{in,t}} = \frac{\left(Y\left(\Theta^6\right)_{i,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,t+1} - B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^6\right)_{kn,t}\left(Y\left(\Theta^6\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{k,t+1} - B\left(\Theta^6\right)_{k,t}\right]\right)^{\frac{1}{\nu}}} \quad t \geq 6$$

$$(A7)\qquad L\left(\Theta^6\right)_{n,6} = \sum_{i\in N} m\left(\Theta^0\right)_{ni,5} L\left(\Theta^0\right)_{i,5}$$

$$(A8)\qquad L\left(\Theta^6\right)_{n,t+1} = \sum_{i\in N} m\left(\Theta^6\right)_{ni,t} L\left(\Theta^6\right)_{i,t}, \quad t \geq 6$$

This is the set of equilibrium conditions that are solved together with equilibrium conditions (11), (12) and (15) for the sequential equilibrium in the case where sea level rise arrives as an unanticipated shock.

# IV Theory Appendix

## A Derivation of expected lifetime utility (Equation (1))

1. Agents choose to remain in or move to the location $j$ that offers the largest expected benefits, net of moving costs. Let $v_{i,t}$ denote the lifetime utility of a worker in location $i$ at time $t$ and $V = \mathbb{E}(v)$ denote the expected lifetime utility of a representative agent with respect to the vector of idiosyncratic shocks $b$.

   (A9)
$$\begin{aligned} V_{n,t} &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \mathbb{E}\left\{max_{i\in N}\left[\beta\mathbb{E}\left(v_{i,t+1}\right) - \mu_{in} + B_{i,t} + b_{i,t}\right]\right\} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \mathbb{E}\{\textstyle\sum_{i\in N}\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \\ &\quad \times Pr\left[\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \geq \left(\beta V_{m,t+1} - \mu_{mn} + B_{m,t} + b_{m,t}\right), m = 1, ..., N\right]\} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) f\left(b_{i,t}\right) \\ &\quad \times \textstyle\prod_{m\neq i} F\left(\beta\left(V_{i,t+1} - V_{m,t+1}\right) - \left(\mu_{in} - \mu_{mn}\right) + \left(B_{i,t} - B_{m,t}\right) + b_{i,t}\right) db_{i,t} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) \\ &\quad + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) f\left(b_{i,t}\right) \prod_{m\neq i} F\left(\bar{b}_{im,t} + b_{i,t}\right) db_{i,t} \end{aligned}$$

   where $\bar{b}_{im,t} = \beta\left(V_{i,t+1} - V_{m,t+1}\right) - \left(\mu_{in} - \mu_{mn}\right) + \left(B_{i,t} - B_{m,t}\right)$.

2. The Gumbel distribution with parameters $(-\gamma\nu, \nu)$ (where $\gamma$ is Euler's constant) has cumulative distribution function:
$$F(b) = exp\left(-exp\left(-\frac{b}{\nu} - \gamma\right)\right)$$
   and density function:
$$f(b) = \left(\frac{1}{\nu}\right) exp\left(-\frac{b}{\nu} - \gamma - exp\left(-\frac{b}{\nu} - \gamma\right)\right)$$

3. Substituting the cumulative distribution function and density function into Equation (A9) yields the following::
$$\begin{aligned} V_{n,t} &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \\ &\quad \times \left(\tfrac{1}{\nu}\right) exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma - exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma\right)\right) \textstyle\prod_{m\neq i} exp\left(-exp\left(-\tfrac{\bar{b}_{im,t}+b_{i,t}}{\nu} - \gamma\right)\right) db_{i,t} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \\ &\quad \times \left(\tfrac{1}{\nu}\right) exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma - exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma\right)\right) exp\left(-\textstyle\sum_{m\neq i} exp\left(-\tfrac{\bar{b}_{im,t}+b_{i,t}}{\nu} - \gamma\right)\right) db_{i,t} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \\ &\quad \times \left(\tfrac{1}{\nu}\right) exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma\right) exp\left(-exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma\right) - \textstyle\sum_{m\neq i} exp\left(-\tfrac{\bar{b}_{im,t}+b_{i,t}}{\nu} - \gamma\right)\right) db_{i,t} \\ &= \alpha ln\left(\tfrac{C_{n,t}}{\alpha}\right) + (1-\alpha) ln\left(\tfrac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + b_{i,t}\right) \\ &\quad \times \left(\tfrac{1}{\nu}\right) exp\left(-\tfrac{b_{i,t}}{\nu} - \gamma\right) exp\left(-\textstyle\sum_{m\in N} exp\left(-\tfrac{\bar{b}_{im,t}+b_{i,t}}{\nu} - \gamma\right)\right) db_{i,t} \end{aligned}$$

4. Define $\lambda_t = ln\sum_{m\in N} exp\left(-\frac{\bar{b_{im,t}}}{\nu}\right)$ and $x_t = \frac{b_{i,t}}{\nu} + \gamma$ and $y_t = x_t - \lambda_t$:

$$\begin{aligned}
V_{n,t} &= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + x_t\nu - \gamma\nu\right) \\
&\quad \times\left(\frac{1}{\nu}\right) exp\left(-x_t\right) exp\left(-\textstyle\sum_{m\in N} exp\left(-x_t\right) exp\left(-\frac{\bar{b_{im,t}}}{\nu}\right)\right)\nu dx_t \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(x_t - \gamma\right)\right) \\
&\quad \times exp\left(-x_t - exp\left(-\left(x_t - \lambda_t\right)\right)\right) dx_t \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N}\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(y_t + \lambda_t - \gamma\right)\right) \\
&\quad \times exp\left(-y_t - \lambda_t - exp\left(-y_t\right)\right) dy_t \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-\lambda_t\right) \\
&\quad \times\int\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(y_t + \lambda_t - \gamma\right)\right) exp\left(-y_t - exp\left(-y_t\right)\right) dy_t \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-\lambda_t\right)\left[\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(\lambda_t - \gamma\right)\right)\right. \\
&\quad \left.\times\int exp\left(-y_t - exp\left(-y_t\right)\right) dy_t + \nu\int y_t exp\left(-y_t - exp\left(-y_t\right)\right) dy_t\right]
\end{aligned}$$

5. The anti-derivative of $exp\left(-y - exp(-y)\right)$ is $exp\left(-exp(-y)\right)$, and $\int y\cdot exp\left(-y - exp(-y)\right) dy = \gamma$ (Patel, Kapadia, and Owen (1976)). Therefore:

$$\begin{aligned}
V_{n,t} &= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-\lambda_t\right)\left\{\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(\lambda_t - \gamma\right)\right)\right. \\
&\quad \left.\times\left[exp\left(-exp\left(-y_t\right)\right)\right]_{-\infty}^{+\infty} + \nu\gamma\right\} \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-\lambda_t\right)\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\left(\lambda_t - \gamma\right) + \nu\gamma\right] \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-\lambda_t\right)\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu\lambda_t\right] \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp\left(-ln\sum_{m\in N} exp\left(-\frac{\bar{b_{im,t}}}{\nu}\right)\right) \\
&\quad \times\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \nu ln\textstyle\sum_{m\in N} exp\left(-\frac{\bar{b_{im,t}}}{\nu}\right)\right] \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp[-ln\sum_{m\in N} exp(-\frac{1}{\nu}(\beta\left(V_{i,t+1} - V_{m,t+1}\right) \\
&\quad -\left(\mu_{in} - \mu_{mn}\right) + \left(B_{i,t} - B_{m,t}\right)))][\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \\
&\quad \nu ln\textstyle\sum_{m\in N} exp\left(-\frac{1}{\nu}\left(\beta\left(V_{i,t+1} - V_{m,t+1}\right) - \left(\mu_{in} - \mu_{mn}\right) + \left(B_{i,t} - B_{m,t}\right)\right)\right)] \\
&= \alpha ln\left(\frac{C_{n,t}}{\alpha}\right) + (1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right) + \textstyle\sum_{i\in N} exp(-ln[exp\left(-\frac{1}{\nu}\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right)\right) \\
&\quad \textstyle\sum_{m\in N} exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1} + \mu_{mn} - B_{m,t}\right)\right)])[\beta V_{i,t+1} - \mu_{in} + B_{i,t} + \\
&\quad \nu ln\left[exp\left(-\frac{1}{\nu}\left(\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right)\right)\textstyle\sum_{m\in N} exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1} + \mu_{mn} - B_{m,t}\right)\right)\right]]
\end{aligned}$$

$$\begin{aligned}
= \quad & \alpha ln\left(\frac{C_{n,t}}{\alpha}\right)+(1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right)+\textstyle\sum_{i\in N}\{exp[(\frac{1}{\nu}\left(\beta V_{i,t+1}-\mu_{in}+B_{i,t}\right)- \\
& ln\textstyle\sum_{m\in N}exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1}+\mu_{mn}-B_{m,t}\right)\right))][\beta V_{i,t+1}-\mu_{in}+B_{i,t}+ \\
& \nu\left[-\frac{1}{\nu}\left(\beta V_{i,t+1}-\mu_{in}+B_{i,t}\right)+ln\textstyle\sum_{m\in N}exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1}+\mu_{mn}-B_{m,t}\right)\right)\right]]\} \\
= \quad & \alpha ln\left(\frac{C_{n,t}}{\alpha}\right)+(1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right)+\textstyle\sum_{i\in N}\{\frac{exp\left[\frac{1}{\nu}\left(\beta V_{i,t+1}-\mu_{in}+B_{i,t}\right)\right]}{\sum_{m\in N}exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1}+\mu_{mn}-B_{m,t}\right)\right)} \\
& \times\left[\nu ln\textstyle\sum_{m\in N}exp\left(-\frac{1}{\nu}\left(-\beta V_{m,t+1}+\mu_{mn}-B_{m,t}\right)\right)\right]\} \\
= \quad & \alpha ln\left(\frac{C_{n,t}}{\alpha}\right)+(1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right)+\nu ln\textstyle\sum_{m\in N}\left(exp\left(\beta V_{m,t+1}-\mu_{mn}+B_{m,t}\right)\right)^{\frac{1}{\nu}} \\
& \times\left\{\frac{\sum_{i\in N}\left(exp(\beta V_{i,t+1}-\mu_{in}+B_{i,t})\right)^{\frac{1}{\nu}}}{\sum_{m\in N}\left(exp(\beta V_{m,t+1}-\mu_{mn}+B_{m,t})\right)^{\frac{1}{\nu}}}\right\} \\
= \quad & \alpha ln\left(\frac{C_{n,t}}{\alpha}\right)+(1-\alpha)ln\left(\frac{H_{n,t}}{1-\alpha}\right)+\nu ln\textstyle\sum_{m\in N}\left(exp\left(\beta V_{m,t+1}-\mu_{mn}+B_{m,t}\right)\right)^{\frac{1}{\nu}}
\end{aligned}$$

# B Derivation of migration shares (Equation (2))

1. Of agents that start period $t$ in location $n$, the fraction that migrate to region $i$ is given by the probability that location $i$ offers the highest expected utility for agents from region $n$ of all possible destination regions (including the region of origin):

$$\begin{aligned}
m_{in,t} &= Pr\left[\left(\beta V_{i,t+1}-\mu_{in}+B_{i,t}+b_{i,t}\right)\geq\left(\beta V_{m,t+1}-\mu_{mn}+B_{m,t}+b_{m,t}\right), m=1,...,N\right] \\
&= \textstyle\int f\left(b_{i,t}\right)\prod_{m\neq i}F\left(\beta\left(V_{i,t+1}-V_{m,t+1}\right)-\left(\mu_{in}-\mu_{mn}\right)+\left(B_{i,t}-B_{m,t}\right)+b_{i,t}\right)db_{i,t}
\end{aligned}$$

2. Again substituting $\bar{b_{im,t}}=\beta\left(V_{i,t+1}-V_{m,t+1}\right)-\left(\mu_{in}-\mu_{mn}\right)+\left(B_{i,t}-B_{m,t}\right)$ and the cumulative distribution function and density function of the distribution of the idiosyncratic preference draws:

$$\begin{aligned}
m_{in,t} &= \textstyle\int\left(\frac{1}{\nu}\right)exp\left(-\frac{b_{i,t}}{\nu}-\gamma-exp\left(-\frac{b_{i,t}}{\nu}-\gamma\right)\right)\prod_{m\neq i}exp\left(-exp\left(-\frac{\bar{b_{im,t}}}{\nu}-\frac{b_{i,t}}{\nu}-\gamma\right)\right)db_{i,t} \\
&= \textstyle\int\left(\frac{1}{\nu}\right)exp\left(-\frac{b_{i,t}}{\nu}-\gamma\right)exp\left(-\sum_{m\in N}exp\left(-\frac{\bar{b_{im,t}}}{\nu}-\frac{b_{i,t}}{\nu}-\gamma\right)\right)db_{i,t}
\end{aligned}$$

3. As in the previous derivation, define $\lambda_t=ln\sum_{m\in N}exp\left(-\frac{\bar{b_{im,t}}}{\nu}\right)$ and $x_t=\frac{b_{i,t}}{\nu}+\gamma$ and $y_t=x_t-\lambda_t$ and use the fact that the anti-derivative of $exp\left(-y-exp(-y)\right)$ is $exp\left(-exp(-y)\right)$:

$$\begin{aligned}
m_{in,t} &= \textstyle\int\left(\frac{1}{\nu}\right)exp\left(-x_t\right)exp\left(-exp\left(\lambda_t\right)exp\left(-x_t\right)\right)\nu dx_t \\
&= \textstyle\int exp\left(-y_t-\lambda_t\right)exp\left(-exp\left(\lambda_t\right)exp\left(-y_t-\lambda_t\right)\right)dy_t \\
&= exp\left(-\lambda_t\right)\textstyle\int exp\left(-y_t-exp\left(-y_t\right)\right)dy_t \\
&= exp\left(-\lambda_t\right) \\
&= \frac{1}{\sum_{m\in N}exp\left(\frac{1}{\nu}\left[-\beta(V_{i,t+1}-V_{m,t+1})+(\mu_{in}-\mu_{mn})-(B_{i,t}-B_{m,t})\right]\right)} \\
&= \frac{\left(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}]\right)^{\frac{1}{\nu}}}{\sum_{m\in N}\left(exp[\beta V_{m,t+1}-\mu_{mn}+B_{m,t}]\right)^{\frac{1}{\nu}}}
\end{aligned}$$

## C Derivation of consumption goods price index and the share of location $n$'s expenditure on goods produced in location $i$ at time $t$ (Equations (4) and (5))

Firms set the price of their variety to maximize profits, which yields the result that the equilibrium price at $n$ of a good produced at $i$ at time $t$ is a constant mark-up over marginal cost:

$$p_{ni,t}(j) = \left(\frac{\sigma}{\sigma - 1}\right) \frac{d_{ni,t} w_{i,t}}{A_{i,t}} \tag{A10}$$

where $w_{i,t}$ is the wage at $i$ at time $t$.

Combining Equation (A10) with the zero profit condition, equilibrium employment of effective labor units for each variety is equal to a constant, $l_{i,t}(j) = \bar{l} = \sigma F$. Combining this in turn with the labor market clearing condition in each location, $\int_0^{M_{i,t}} l_{i,t}(j)dj = L_{i,t}$, the measure of varieties supplied in each location at time $t$ is proportional to the endogenous supply of labor units in that location: $M_{i,t} = \frac{L_{i,t}}{\sigma F}$.

The consumption goods price index can then be expressed as:

$$P_{n,t}^{1-\eta} = \sum_{i \in N} P_{ni,t}^{1-\eta} = \sum_{i \in N} \left(\frac{L_{i,t}}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} \left(\left(\frac{\sigma}{\sigma - 1}\right) \frac{d_{ni,t} w_{i,t}}{A_{i,t}}\right)^{1-\eta} \tag{A11}$$

This yields an expression for trade shares:

$$\begin{aligned} \pi_{ni} &= \left(\frac{P_{ni}}{P_n}\right)^{1-\eta} = \frac{\left(\frac{L_{i,t}}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} \left[\left(\frac{\sigma}{\sigma-1}\right) \frac{d_{ni,t} w_{i,t}}{A_{i,t}}\right]^{1-\eta}}{\sum_{l \in N} \left(\frac{L_{l,t}}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} \left[\left(\frac{\sigma}{\sigma-1}\right) \frac{d_{nl,t} w_{l,t}}{A_{l,t}}\right]^{1-\eta}} \\ &= \frac{A_{i,t}^{\eta-1} L_{i,t}^{\frac{1-\eta}{1-\sigma}} \left[d_{ni,t} w_{i,t}\right]^{1-\eta}}{\sum_{l \in N} A_{l,t}^{\eta-1} L_{l,t}^{\frac{1-\eta}{1-\sigma}} \left[d_{nl,t} w_{l,t}\right]^{1-\eta}} \\ &= \frac{A_{i,t}^{\eta-1} L_{i,t}^{\frac{\eta-1}{\sigma-1}} \left[d_{ni,t} w_{i,t}\right]^{1-\eta}}{\sum_{l \in N} A_{l,t}^{\eta-1} L_{l,t}^{\frac{\eta-1}{\sigma-1}} \left[d_{nl,t} w_{l,t}\right]^{1-\eta}} \end{aligned} \tag{A12}$$

Summing the total value of bilateral trade flows $X_{ni,t}$ over all destinations, and substituting from the expressions for $P_{n,t}$ and $\pi_{ni,t}$, yields:

$$\begin{aligned} X_{i,t} &= \sum_n X_{ni,t} \\ &= \sum_n \frac{L_{i,t}^{\frac{1-\eta}{1-\sigma}} \left[\frac{d_{ni,t} w_{i,t}}{A_{i,t}}\right]^{1-\eta}}{\sum_{l \in N} L_{l,t}^{\frac{1-\eta}{1-\sigma}} \left[\frac{d_{nl,t} w_{l,t}}{A_{l,t}}\right]^{1-\eta}} X_{n,t} \\ &= \sum_n \frac{L_{i,t}^{\frac{1-\eta}{1-\sigma}} \left[\frac{d_{ni,t} w_{i,t}}{A_{i,t}}\right]^{1-\eta}}{P_{n,t}^{1-\eta} (\sigma F)^{\frac{1-\eta}{1-\sigma}} \left(\frac{\sigma}{\sigma-1}\right)^{\eta-1}} X_{n,t} \\ &= \left(\frac{\sigma}{\sigma-1}\right)^{1-\eta} \left(\frac{1}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} L_{i,t}^{\frac{1-\eta}{1-\sigma}} \left(\frac{w_{i,t}}{A_{i,t}}\right)^{1-\eta} FMA_{i,t} \end{aligned}$$

Combining this with the definition of $CMA_{i,t}$ yields:

$$\begin{aligned} CMA_{n,t} &= P_{n,t}^{1-\eta} \\ &= \sum_{i\in N} d_{ni,t}^{1-\eta} \left(\frac{\sigma}{\sigma-1}\right)^{1-\eta} \left(\frac{1}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} L_{i,t}^{\frac{1-\eta}{1-\sigma}} \left(\frac{w_{i,t}}{A_{i,t}}\right)^{1-\eta} \\ &= \sum_{i\in N} d_{ni,t}^{1-\eta} \frac{X_{i,t}}{FMA_{i,t}} \end{aligned}$$

# D Derivation of expected lifetime utility of workers residing at location $n$ at time $t$ (Equation (16))

1. From Equation (2), the share of the population who start period $t$ in location $n$ that choose to stay in the same location next period is given by:

$$m_{nn,t} = \frac{\left(exp\left[\beta V_{n,t+1} + B_{n,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{m\in N} \left(exp\left[\beta V_{m,t+1} - \mu_{mn} + B_{m,t}\right]\right)^{\frac{1}{\nu}}}$$

which implies that:

$$ln\left(m_{nn,t}\right) = \frac{1}{\nu}\left(\beta V_{n,t+1} + B_{n,t}\right) - ln \sum_{m\in N} \left(exp\left[\beta V_{m,t+1} - \mu_{mn} + B_{m,t}\right]\right)^{\frac{1}{\nu}}$$

2. Substituting this into Equation (10) gives:

$$\begin{aligned} V_{n,t} &= \alpha ln w_{n,t} - \alpha ln P_{n,t} - (1-\alpha) ln\left(\frac{(1-\alpha)L_{n,t}}{H_{n,t}}\right) + \nu ln \sum_{i\in N}\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}} \\ &= \alpha ln w_{n,t} - \alpha ln P_{n,t} - (1-\alpha) ln\left(\frac{(1-\alpha)L_{n,t}}{H_{n,t}}\right) + \nu\left[\frac{1}{\nu}\left(\beta V_{n,t+1} + B_{n,t}\right) - ln\left(m_{nn,t}\right)\right] \\ &= \alpha ln w_{n,t} - \alpha ln P_{n,t} - (1-\alpha) ln\left(\frac{(1-\alpha)L_{n,t}}{H_{n,t}}\right) + \beta V_{n,t+1} + B_{n,t} - \nu ln\left(m_{nn,t}\right) \end{aligned}$$

3. Iterating this equation forward yields:

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

4. Simplifying yields:

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

# E Derivation of equilibrium condition for lifetime utilities expressed in relative differences

1. From the equilibrium condition for expected lifetime utility in Equation (13):
   (A13)
$$\begin{aligned}
[exp\left(V_{n,t+1}-V_{n,t}\right)]^{\frac{1}{\nu}} &= [exp\{\alpha ln w_{n,t+1}-\alpha ln P_{n,t+1}-(1-\alpha)ln\left(\frac{(1-\alpha)L_{n,t+1}}{H_{n,t+1}}\right) \\
&\quad +\nu ln \textstyle\sum_{i\in N}\left(exp\left[\beta V_{i,t+2}-\mu_{in}+B_{i,t+1}\right]\right)^{\frac{1}{\nu}} \\
&\quad -\left(\alpha ln w_{n,t}-\alpha ln P_{n,t}-(1-\alpha)ln\left(\frac{(1-\alpha)L_{n,t}}{H_{n,t}}\right)\right) \\
&\quad -\nu ln \textstyle\sum_{i\in N}\left(exp\left[\beta V_{i,t+1}-\mu_{in}+B_{i,t}\right]\right)^{\frac{1}{\nu}}\}]^{\frac{1}{\nu}} \\
&= \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)^{\alpha}}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)^{\alpha}\left(\frac{L_{n,t+1}/L_{n,t}}{H_{n,t+1}/H_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}}\left(\frac{\sum_{i\in N}(exp[\beta V_{i,t+2}-\mu_{in}+B_{i,t+1}])^{\frac{1}{\nu}}}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}}\right)
\end{aligned}$$

2. Multiplying and dividing each term in the sum $\sum_{i\in N}\left(exp\left[\beta V_{i,t+2}-\mu_{in}+B_{i,t+1}\right]\right)^{\frac{1}{\nu}}$ by $\left(exp\left[\beta V_{i,t+1}-\mu_{in}+B_{i,t}\right]\right)^{\frac{1}{\nu}}$ gives:
$$\begin{aligned}
\frac{\sum_{i\in N}(exp[\beta V_{i,t+2}-\mu_{in}+B_{i,t+1}])^{\frac{1}{\nu}}}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}} &= \frac{(exp[\beta V_{1,t+2}-\mu_{1n}+B_{1,t+1}])^{\frac{1}{\nu}}+(exp[\beta V_{2,t+2}-\mu_{2n}+B_{2,t+1}])^{\frac{1}{\nu}}+...}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}} \\
&= \frac{(exp[\beta V_{1,t+2}-\mu_{1n}+B_{1,t+1}])^{\frac{1}{\nu}}\frac{\left(exp\left[\beta V_{1,t+1}-\mu_{1n}+B_{1,t}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[\beta V_{1,t+1}-\mu_{1n}+B_{1,t}\right]\right)^{\frac{1}{\nu}}}}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}} \\
&\quad +\frac{(exp[\beta V_{2,t+2}-\mu_{2n}+B_{2,t+1}])^{\frac{1}{\nu}}\frac{\left(exp\left[\beta V_{2,t+1}-\mu_{2n}+B_{2,t}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[\beta V_{2,t+1}-\mu_{2n}+B_{2,t}\right]\right)^{\frac{1}{\nu}}}}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}}+...
\end{aligned}$$

3. Substituting the migration shares equation $m_{in,t}=\frac{(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}}{\sum_{m\in N}(exp[\beta V_{m,t+1}-\mu_{mn}+B_{m,t}])^{\frac{1}{\nu}}}$ gives:
$$\begin{aligned}
\frac{\sum_{i\in N}(exp[\beta V_{i,t+2}-\mu_{in}+B_{i,t+1}])^{\frac{1}{\nu}}}{\sum_{i\in N}(exp[\beta V_{i,t+1}-\mu_{in}+B_{i,t}])^{\frac{1}{\nu}}} &= m_{1n,t}\frac{(exp[\beta V_{1,t+2}-\mu_{1n}+B_{1,t+1}])^{\frac{1}{\nu}}}{(exp[\beta V_{1,t+1}-\mu_{1n}+B_{1,t}])^{\frac{1}{\nu}}}+m_{2n,t}\frac{(exp[\beta V_{2,t+2}-\mu_{2n}+B_{2,t+1}])^{\frac{1}{\nu}}}{(exp[\beta V_{2,t+1}-\mu_{2n}+B_{2,t}])^{\frac{1}{\nu}}}+... \\
&= \textstyle\sum_{k\in N} m_{kn,t}\frac{\left(exp\left[\beta V_{k,t+2}-\mu_{kn}+B_{k,t+1}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[\beta V_{k,t+1}-\mu_{kn}+B_{k,t}\right]\right)^{\frac{1}{\nu}}} \\
&= \textstyle\sum_{k\in N} m_{kn,t}\left(exp\left[\beta\left(V_{k,t+2}-V_{k,t+1}\right)+B_{k,t+1}-B_{k,t}\right]\right)^{\frac{1}{\nu}} \\
&= \textstyle\sum_{k\in N} m_{kn,t}exp\left[\frac{\beta}{\nu}\left(V_{k,t+2}-V_{k,t+1}\right)\right]exp\left[\frac{1}{\nu}\left(B_{k,t+1}-B_{k,t}\right)\right]
\end{aligned}$$

4. Substituting this back into Equation (A13) gives:
$$\begin{aligned}
[exp\left(V_{n,t+1}-V_{n,t}\right)]^{\frac{1}{\nu}} &= \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)^{\alpha}}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)^{\alpha}\left(\frac{L_{n,t+1}/L_{n,t}}{H_{n,t+1}/H_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \\
&\quad \times\textstyle\sum_{k\in N} m_{kn,t}exp\left[\frac{\beta}{\nu}\left(V_{k,t+2}-V_{k,t+1}\right)\right]exp\left[\frac{1}{\nu}\left(B_{k,t+1}-B_{k,t}\right)\right]
\end{aligned}$$

5. Defining $Y_{n,t+1} = \left[exp\left(V_{n,t+1} - V_{n,t}\right)\right]^{\frac{1}{\nu}}$ and substituting gives:

$$Y_{n,t+1} = \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)^{\alpha}}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)^{\alpha}\left(\frac{L_{n,t+1}/L_{n,t}}{H_{n,t+1}/H_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \sum_{k\in N} m_{kn,t}\left(Y_{k,t+2}\right)^{\beta} exp\left[\frac{1}{\nu}\left(B_{k,t+1} - B_{k,t}\right)\right]$$

6. The central estimates assume that local amenities are exogenous and time-invariant, $B_{n,t} = B_n$, so this equation reduces to:

(A14)
$$Y_{n,t+1} = \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)^{\alpha}}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)^{\alpha}\left(\frac{L_{n,t+1}/L_{n,t}}{H_{n,t+1}/H_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \sum_{k\in N} m_{kn,t}\left(Y_{k,t+2}\right)^{\beta}$$

# F Derivation of equilibrium condition for migration shares expressed in relative differences

1. From the equilibrium condition for migration shares in Equation (14):

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

2. Defining $Y_{n,t+1} = \left[exp\left(V_{n,t+1} - V_{n,t}\right)\right]^{\frac{1}{\nu}}$ and substituting gives:

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

3. The central estimates assume that local amenities are exogenous and time-invariant, $B_{n,t} = B_n$, so this equation reduces to:

(A15)
$$\frac{m_{in,t+1}}{m_{in,t}} = \frac{\left(Y_{i,t+2}\right)^{\beta}}{\sum_{k\in N} m_{kn,t}\left(Y_{k,t+2}\right)^{\beta}}$$

## G Derivation of welfare change induced by changes in the economy's fundamentals (Equation (18))

Denoting by $\widehat{x}$ the value of a variable $x$ under an alternative scenario for the economy's fundamentals, the expected lifetime utilities in location $n$ at time $t$ with and without the change in fundamentals are given by, respectively:

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

and:

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

The compensating variation in consumption for location $n$ at time $t$ is given by $\delta_{n,t}$ such that:

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

Following Caliendo et al. (2019), this yields an expression for the consumption equivalent change in welfare:

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

The aggregate welfare change is obtained by taking the mean value across locations, weighted by their respective initial population shares:

$$\text{(A16)} \quad \triangle Welfare_t = \sum_{n \in N} \frac{L_{n,t}}{\sum_{i \in N} L_{i,t}} \left\{ (1-\beta) \sum_{s=t}^{\infty} \beta^{s-t} ln \left( \frac{\left(\frac{\widehat{w_{n,s}}}{w_{n,s}}\right)^{\alpha} \frac{exp\left(\widehat{B_{n,s}}\right)}{exp\left(B_{n,s}\right)}}{\left(\frac{\widehat{P_{n,s}}}{P_{n,s}}\right)^{\alpha} \left(\frac{\widehat{L_{n,s}}/L_{n,s}}{\widehat{H_{n,s}}/H_{n,s}}\right)^{1-\alpha} \left(\frac{\widehat{m_{nn,s}}}{m_{nn,s}}\right)^{\nu}} \right) \right\}$$

## H Derivation of equilibrium conditions for lifetime utilities, migration shares and population with unanticipated sea level rise (Equations (A3) to (A6))

1. The assumption made about how agents anticipate the evolution of the future path of sea level rise is as follows. At $t = 0$ (2010), agents expect gradual inundation over the periods $t = 1$ to $t = 5$, with sea levels maintained at their $t = 5$ levels thereafter. At $t = 6$, agents learn that the gradual inundation will continue until $t = 20$ (2110), after which sea levels remain constant. Let $X\left(\Theta^{s}\right)$ denote the variable $X$ according to the information available in period $s$.

2. Using the equilibrium conditions in relative time differences for expected lifetime utility in Equation (A14) and for migration shares in Equation (A15), the evolution of $\left\{m\left(\Theta^0\right)_{ni,t}, Y\left(\Theta^0\right)_{n,t+1}\right\}_{t=0}^{\infty}$ in the absence of any shocks can be obtained from:

$$\begin{aligned} Y\left(\Theta^0\right)_{n,t+1} &= \left[\frac{\left(\frac{w\left(\Theta^0\right)_{n,t+1}}{w\left(\Theta^0\right)_{n,t}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^0\right)_{n,t+1}}{P\left(\Theta^0\right)_{n,t}}\right)^{\alpha}\left(\frac{L\left(\Theta^0\right)_{n,t+1}/L\left(\Theta^0\right)_{n,t}}{H\left(\Theta^0\right)_{n,t+1}/H\left(\Theta^0\right)_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \\ &\quad \times \sum_{k\in N} m\left(\Theta^0\right)_{kn,t}\left(Y\left(\Theta^0\right)_{k,t+2}\right)^{\beta} exp\left[\frac{1}{\nu}\left(B\left(\Theta^0\right)_{k,t+1} - B\left(\Theta^0\right)_{k,t}\right)\right] \end{aligned}$$

$$\frac{m\left(\Theta^0\right)_{in,t+1}}{m\left(\Theta^0\right)_{in,t}} = \frac{\left(Y\left(\Theta^0\right)_{i,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^0\right)_{i,t+1} - B\left(\Theta^0\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^0\right)_{kn,t}\left(Y\left(\Theta^0\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^0\right)_{k,t+1} - B\left(\Theta^0\right)_{k,t}\right]\right)^{\frac{1}{\nu}}}$$

3. No shocks occur during $0 \leq t \leq 5$. At $t = 6$, the shock is received and the information set $\left(\Theta^6\right)$ becomes available. Adding and subtracting $\beta V\left(\Theta^6\right)_{i,6}$ in the equations for $V\left(\Theta^0\right)_{i,5}$ and $m\left(\Theta^0\right)_{in,5}$ yields:

$$\begin{aligned} V\left(\Theta^0\right)_{n,5} &= \alpha lnw\left(\Theta^0\right)_{n,5} - \alpha lnP\left(\Theta^0\right)_{n,5} - (1-\alpha)ln\left(\frac{(1-\alpha)L\left(\Theta^0\right)_{n,5}}{H\left(\Theta^0\right)_{n,5}}\right) + \\ &\quad \nu ln\sum_{i\in N}\left(exp\left[V\left(\Theta^0\right)_{i,6} - V\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V\left(\Theta^6\right)_{i,6} - \mu_{in} + B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}} \end{aligned}$$

$$\text{(A17)}\quad m\left(\Theta^0\right)_{in,5} = \frac{\left(exp\left[V\left(\Theta^0\right)_{i,6} - V\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V\left(\Theta^6\right)_{i,6} - \mu_{in} + B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N}\left(exp\left[V\left(\Theta^0\right)_{k,6} - V\left(\Theta^6\right)_{k,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V\left(\Theta^6\right)_{k,6} - \mu_{kn} + B\left(\Theta^0\right)_{k,5}\right]\right)^{\frac{1}{\nu}}}$$

4. Based on the new information that becomes available with the shock at $t = 6$, in periods thereafter:

$$\begin{aligned} V\left(\Theta^6\right)_{n,t} &= \alpha lnw\left(\Theta^6\right)_{n,t} - \alpha lnP\left(\Theta^6\right)_{n,t} - (1-\alpha)ln\left(\frac{(1-\alpha)L\left(\Theta^6\right)_{n,t}}{H\left(\Theta^6\right)_{n,t}}\right) \\ &\quad + \nu ln\sum_{i\in N}\left(exp\left[\beta V\left(\Theta^6\right)_{i,t+1} - \mu_{in} + B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}} \end{aligned}$$

$$\text{(A18)}\qquad m\left(\Theta^6\right)_{in,t} = \frac{\left(exp\left[\beta V\left(\Theta^6\right)_{i,t+1} - \mu_{in} + B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N}\left(exp\left[\beta V\left(\Theta^6\right)_{k,t+1} - \mu_{kn} + B\left(\Theta^6\right)_{k,t}\right]\right)^{\frac{1}{\nu}}}$$

5. Taking the difference between $V\left(\Theta^6\right)_{n,6}$ and $V\left(\Theta^0\right)_{n,5}$ gives:

$$\begin{aligned}
V\left(\Theta^6\right)_{n,6} - V\left(\Theta^0\right)_{n,5} \quad = \quad & \alpha lnw\left(\Theta^6\right)_{n,6} - \alpha lnP\left(\Theta^6\right)_{n,6} - (1-\alpha)ln\left(\frac{(1-\alpha)L\left(\Theta^6\right)_{n,6}}{H(\Theta^6)_{n,6}}\right) \\
& - \left[\alpha lnw\left(\Theta^0\right)_{n,5} - \alpha lnP\left(\Theta^0\right)_{n,5} - (1-\alpha)ln\left(\frac{(1-\alpha)L\left(\Theta^0\right)_{n,5}}{H(\Theta^0)_{n,5}}\right)\right] \\
& +\nu ln\textstyle\sum_{i\in N}\left(exp\left[\beta V\left(\Theta^6\right)_{i,7} - \mu_{in} + B\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{1}{\nu}} \\
& -\nu ln\textstyle\sum_{i\in N}\left(exp\left[V\left(\Theta^0\right)_{i,6} - V\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{\beta}{\nu}} \\
& \times\left(exp\left[\beta V\left(\Theta^6\right)_{i,6} - \mu_{in} + B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}} \\
= \quad & ln\left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w(\Theta^0)_{n,5}}\right)^{\alpha}}{\left(\frac{P(\Theta^6)_{n,6}}{P(\Theta^0)_{n,5}}\right)^{\alpha}\left(\frac{L(\Theta^6)_{n,6}/L(\Theta^0)_{n,5}}{H(\Theta^6)_{n,6}/H(\Theta^0)_{n,5}}\right)^{1-\alpha}}\right] \\
& +\nu ln\left(\frac{\sum_{i\in N}\left(exp\left[\beta V\left(\Theta^6\right)_{i,7} - \mu_{in} + B\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{1}{\nu}}}{\sum_{i\in N}\left(exp\left[V(\Theta^0)_{i,6} - V(\Theta^6)_{i,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V(\Theta^6)_{i,6} - \mu_{in} + B(\Theta^0)_{i,5}\right]\right)^{\frac{1}{\nu}}}\right) \\
= \quad & ln\left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w(\Theta^0)_{n,5}}\right)^{\alpha}}{\left(\frac{P(\Theta^6)_{n,6}}{P(\Theta^0)_{n,5}}\right)^{\alpha}\left(\frac{L(\Theta^6)_{n,6}/L(\Theta^0)_{n,5}}{H(\Theta^6)_{n,6}/H(\Theta^0)_{n,5}}\right)^{1-\alpha}}\right] \\
& +ln\left(\textstyle\sum_{i\in N}\frac{m\left(\Theta^0\right)_{in,5}\left(exp\left[\beta V\left(\Theta^6\right)_{i,7} - \beta V\left(\Theta^6\right)_{i,6} + B\left(\Theta^6\right)_{i,6} - B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[V(\Theta^0)_{i,6} - V(\Theta^6)_{i,6}\right]\right)^{\frac{\beta}{\nu}}}\right)^{\nu}
\end{aligned}$$

6. Exponentiating and substituting $Y\left(\Theta^6\right)_{n,6} = \left[exp\left(V\left(\Theta^6\right)_{n,6} - V\left(\Theta^0\right)_{n,5}\right)\right]^{\frac{1}{\nu}}$, $Y\left(\Theta^0\right)_{n,6} = \left[exp\left(V\left(\Theta^0\right)_{n,6} - V\left(\Theta^0\right)_{n,5}\right)\right]^{\frac{1}{\nu}}$ and $Y\left(\Theta^6\right)_{n,t+1} = \left[exp\left(V\left(\Theta^6\right)_{n,t+1} - V\left(\Theta^6\right)_{n,t}\right)\right]^{\frac{1}{\nu}}$:

$$\begin{aligned}
Y\left(\Theta^6\right)_{n,6} \quad = \quad & \left[exp\left(V\left(\Theta^6\right)_{n,6} - V\left(\Theta^0\right)_{n,5}\right)\right]^{\frac{1}{\nu}} \\
= \quad & \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w(\Theta^0)_{n,5}}\right)^{\alpha}}{\left(\frac{P(\Theta^6)_{n,6}}{P(\Theta^0)_{n,5}}\right)^{\alpha}\left(\frac{L(\Theta^6)_{n,6}/L(\Theta^0)_{n,5}}{H(\Theta^6)_{n,6}/H(\Theta^0)_{n,5}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \\
& \times\textstyle\sum_{i\in N}\frac{m\left(\Theta^0\right)_{in,5}\left(exp\left[V\left(\Theta^6\right)_{i,7} - V\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[B\left(\Theta^6\right)_{i,6} - B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[V(\Theta^0)_{i,6} - V(\Theta^6)_{i,6}\right]\right)^{\frac{\beta}{\nu}}} \\
= \quad & \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w(\Theta^0)_{n,5}}\right)^{\alpha}}{\left(\frac{P(\Theta^6)_{n,6}}{P(\Theta^0)_{n,5}}\right)^{\alpha}\left(\frac{L(\Theta^6)_{n,6}/L(\Theta^0)_{n,5}}{H(\Theta^6)_{n,6}/H(\Theta^0)_{n,5}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \\
& \times\textstyle\sum_{i\in N}\frac{m\left(\Theta^0\right)_{in,5}\left(Y\left(\Theta^6\right)_{i,7}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,6} - B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[V(\Theta^0)_{i,6} - V(\Theta^0)_{i,5} + V(\Theta^0)_{i,5} - V(\Theta^6)_{i,6}\right]\right)^{\frac{\beta}{\nu}}} \\
= \quad & \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,6}}{w(\Theta^0)_{n,5}}\right)^{\alpha}}{\left(\frac{P(\Theta^6)_{n,6}}{P(\Theta^0)_{n,5}}\right)^{\alpha}\left(\frac{L(\Theta^6)_{n,6}/L(\Theta^0)_{n,5}}{H(\Theta^6)_{n,6}/H(\Theta^0)_{n,5}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \\
& \times\textstyle\sum_{i\in N}\left(\frac{Y(\Theta^6)_{i,6}}{Y(\Theta^0)_{i,6}}\right)^{\beta} m\left(\Theta^0\right)_{in,5}\left(Y\left(\Theta^6\right)_{i,7}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,6} - B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}
\end{aligned}$$

7. Taking Equation (A18) for $m\left(\Theta^6\right)_{in,6}$ and dividing by the expression for $m\left(\Theta^0\right)_{in,5}$ in Equation (A17) yields:

$$\frac{m\left(\Theta^6\right)_{in,6}}{m\left(\Theta^0\right)_{in,5}} = \frac{\frac{\left(exp\left[\beta V\left(\Theta^6\right)_{i,7}-\mu_{in}+B\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N}\left(exp\left[\beta V\left(\Theta^6\right)_{k,7}-\mu_{kn}+B\left(\Theta^6\right)_{k,6}\right]\right)^{\frac{1}{\nu}}}}{\frac{\left(exp\left[V\left(\Theta^0\right)_{i,6}-V\left(\Theta^6\right)_{i,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V\left(\Theta^6\right)_{i,6}-\mu_{in}+B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N}\left(exp\left[V\left(\Theta^0\right)_{k,6}-V\left(\Theta^6\right)_{k,6}\right]\right)^{\frac{\beta}{\nu}}\left(exp\left[\beta V\left(\Theta^6\right)_{k,6}-\mu_{kn}+B\left(\Theta^0\right)_{k,5}\right]\right)^{\frac{1}{\nu}}}}$$

$$= \frac{\left(Y\left(\Theta^6\right)_{i,7}\right)^{\beta}\left(\frac{Y\left(\Theta^6\right)_{i,6}}{Y\left(\Theta^0\right)_{i,6}}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,6}-B\left(\Theta^0\right)_{i,5}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^0\right)_{kn,5}\left(Y\left(\Theta^6\right)_{k,7}\right)^{\beta}\left(\frac{Y\left(\Theta^6\right)_{k,6}}{Y\left(\Theta^0\right)_{k,6}}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{k,6}-B\left(\Theta^0\right)_{k,5}\right]\right)^{\frac{1}{\nu}}}$$

8. In time periods after $t = 6$, the same method as was used to prove Equations (A14) and (A15) can be used to show that:

$$Y\left(\Theta^6\right)_{n,t+1} = \left[\frac{\left(\frac{w\left(\Theta^6\right)_{n,t+1}}{w\left(\Theta^6\right)_{n,t}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^6\right)_{n,t+1}}{P\left(\Theta^6\right)_{n,t}}\right)^{\alpha}\left(\frac{L\left(\Theta^6\right)_{n,t+1}/L\left(\Theta^6\right)_{n,t}}{H\left(\Theta^6\right)_{n,t+1}/H\left(\Theta^6\right)_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{k\in N} m\left(\Theta^6\right)_{kn,t}\left(Y\left(\Theta^6\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,t+1}-B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}}, \quad t\geq 6$$

and:

$$\frac{m\left(\Theta^6\right)_{in,t+1}}{m\left(\Theta^6\right)_{in,t}} = \frac{\left(Y\left(\Theta^6\right)_{i,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{i,t+1}-B\left(\Theta^6\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^6\right)_{kn,t}\left(Y\left(\Theta^6\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^6\right)_{k,t+1}-B\left(\Theta^6\right)_{k,t}\right]\right)^{\frac{1}{\nu}}}$$

9. In the general case, for time periods $\tilde{t}$ in which shocks arrive:

$$Y\left(\Theta^{\tilde{t}}\right)_{n,\tilde{t}} = \left[\frac{\left(\frac{w\left(\Theta^{\tilde{t}}\right)_{n,\tilde{t}}}{w\left(\Theta^{\tilde{t}-1}\right)_{n,\tilde{t}-1}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^{\tilde{t}}\right)_{n,\tilde{t}}}{P\left(\Theta^{\tilde{t}-1}\right)_{n,\tilde{t}-1}}\right)^{\alpha}\left(\frac{L\left(\Theta^{\tilde{t}}\right)_{n,\tilde{t}}/L\left(\Theta^{\tilde{t}-1}\right)_{n,\tilde{t}-1}}{H\left(\Theta^{\tilde{t}}\right)_{n,\tilde{t}}/H\left(\Theta^{\tilde{t}-1}\right)_{n,\tilde{t}-1}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{i\in N}\left(\frac{Y\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}}}{Y\left(\Theta^{\tilde{t}-1}\right)_{i,\tilde{t}}}\right)^{\beta} m\left(\Theta^{\tilde{t}-1}\right)_{in,\tilde{t}-1}\left(Y\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}+1}\right)^{\beta} \times\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}}-B\left(\Theta^{\tilde{t}-1}\right)_{i,\tilde{t}-1}\right]\right)^{\frac{1}{\nu}}$$

$$Y\left(\Theta^{\tilde{t}}\right)_{n,t+1} = \left[\frac{\left(\frac{w\left(\Theta^{\tilde{t}}\right)_{n,t+1}}{w\left(\Theta^{\tilde{t}}\right)_{n,t}}\right)^{\alpha}}{\left(\frac{P\left(\Theta^{\tilde{t}}\right)_{n,t+1}}{P\left(\Theta^{\tilde{t}}\right)_{n,t}}\right)^{\alpha}\left(\frac{L\left(\Theta^{\tilde{t}}\right)_{n,t+1}/L\left(\Theta^{\tilde{t}}\right)_{n,t}}{H\left(\Theta^{\tilde{t}}\right)_{n,t+1}/H\left(\Theta^{\tilde{t}}\right)_{n,t}}\right)^{1-\alpha}}\right]^{\frac{1}{\nu}} \times \sum_{k\in N} m\left(\Theta^{\tilde{t}}\right)_{kn,t}\left(Y\left(\Theta^{\tilde{t}}\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{i,t+1}-B\left(\Theta^{\tilde{t}}\right)_{i,t}\right]\right)^{\frac{1}{\nu}}, \quad t\geq\tilde{t}$$

and:

$$\frac{m\left(\Theta^{\tilde{t}}\right)_{in,\tilde{t}}}{m\left(\Theta^{\tilde{t}-1}\right)_{in,\tilde{t}-1}} = \frac{\left(Y\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}+1}\right)^{\beta}\left(\frac{Y\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}}}{Y\left(\Theta^{\tilde{t}-1}\right)_{i,\tilde{t}}}\right)^{\beta}\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{i,\tilde{t}}-B\left(\Theta^{\tilde{t}-1}\right)_{i,\tilde{t}-1}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^{\tilde{t}-1}\right)_{kn,\tilde{t}-1}\left(Y\left(\Theta^{\tilde{t}}\right)_{k,\tilde{t}+1}\right)^{\beta}\left(\frac{Y\left(\Theta^{\tilde{t}}\right)_{k,\tilde{t}}}{Y\left(\Theta^{\tilde{t}-1}\right)_{k,\tilde{t}}}\right)^{\beta}\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{k,\tilde{t}}-B\left(\Theta^{\tilde{t}-1}\right)_{k,\tilde{t}-1}\right]\right)^{\frac{1}{\nu}}}$$

$$\frac{m\left(\Theta^{\tilde{t}}\right)_{in,t+1}}{m\left(\Theta^{\tilde{t}}\right)_{in,t}} = \frac{\left(Y\left(\Theta^{\tilde{t}}\right)_{i,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{i,t+1}-B\left(\Theta^{\tilde{t}}\right)_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{k\in N} m\left(\Theta^{\tilde{t}}\right)_{kn,t}\left(Y\left(\Theta^{\tilde{t}}\right)_{k,t+2}\right)^{\beta}\left(exp\left[B\left(\Theta^{\tilde{t}}\right)_{k,t+1}-B\left(\Theta^{\tilde{t}}\right)_{k,t}\right]\right)^{\frac{1}{\nu}}}, \quad t \geq \tilde{t}$$

# V Land used in production

The baseline model assumes that residential land is used in consumption. This Appendix considers the alternative case where land is instead used in production.

## A Model setup

As in the baseline model, the economy consists of several locations indexed by $i, n \in N$ over discrete time periods $t = 0, 1, 2, ....$ Locations differ in terms of their productivity $A_{n,t}$, amenity value $B_{n,t}$, supply of (immobile) land $H_{n,t}$ and initial endowment of (imperfectly mobile) workers $L_{n,0}$.

## B Consumer preferences

Workers are each endowed with one unit of labor each period, which they supply inelastically with zero disutility in the region in which they start the period. During each period $t$, agents work, earn the market wage and consume consumption goods $C_{n,t}$ in the location $n$ in which they start the period. They have idiosyncratic preference shocks $b_{n,t}$ for each location which are independently and identically distributed across individuals, locations and time.

Workers are forward looking and discount the future with discount factor $\beta \in (0, 1)$. At the end of each period, they may relocate to another location, whose amenity value they will enjoy and where they will work next period. However, migration across space is subject to an additive migration cost, which depends on the locations of origin and destination according to the bilateral cost matrix $\mu_{ni}$, which is assumed time-invariant. This migration cost contributes to persistence in location choice, since workers incur a utility cost of relocating to any location other than their location of origin. Labor is immobile across countries.

The dynamic lifetime utility maximization problem of a worker in location $n$ at time $t$ is therefore:

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

The goods consumption index $C_{n,t}$ is defined over an endogenously-determined measure $M_{i,t}$ of horizontally differentiated varieties supplied by each location. Preferences are CES across location bundles with an elasticity of substitution $\eta$ and CES across varieties within a location bundle with elasticity of substitution $\sigma$.

Following Artuç, Chaudhuri, and McLaren (2010), the idiosyncratic preference shocks $b_{n,t}$ are assumed to follow a Gumbel distribution with parameters $(-\gamma\nu, \nu)$, where $\gamma$ is Euler's constant. Based on this assumption, the expected lifetime utility of a representative agent at location $n$ is given by the sum of the current period utility and the option value to move into any other market for the next period, where the expectation is over preference shocks:

$$V_{n,t} = \mathbb{E}\left(v_{n,t}\right) = ln\left(C_{n,t}\right) + \nu ln \sum_{i \in N}\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}} \tag{A19}$$

The distribution of the idiosyncratic preference shocks also yields an equation (derived in Appendix IV) for the share of workers who start period $t$ in region $n$ that migrate to region $i$:

$$m_{in,t} = \frac{\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}}}{\sum_{m\in N}\left(exp\left[\beta V_{m,t+1} - \mu_{mn} + B_{m,t}\right]\right)^{\frac{1}{\nu}}} \tag{A20}$$

As such, *ceteris paribus*, higher expected lifetime utilities and local amenities attract migrants while higher migration costs deter them, with a migration elasticity equal to $\frac{1}{\nu}$. The evolution of the population in each location across time can be obtained using these migration shares and the distribution of the population across regions in an initial period, $L_{i,0}$, according to:

$$L_{n,t+1} = \sum_{i\in N} m_{ni,t} L_{i,t} \tag{A21}$$

## C Production, prices and trade

Production is characterized by a static optimization problem that can be solved for equilibrium wages and prices given the supply of labor available in each location at every time period $t$.

Different varieties of goods are produced under conditions of monopolistic competition and increasing returns to scale, in line with the new economic geography literature. Increasing returns arise from the requirement that, in order to produce a variety $j$ in a location $i$, a firm must incur a fixed cost of $F$ units of labor as well as a variable cost that depends on productivity $A_{i,t}$ in the location. In the baseline model, the number of labor units required to produce $x_{i,t}(j)$ units of variety $j$ in location $i$ at time $t$ is $l_{i,t}(j) = F + \frac{x_{i,t}(j)}{A_{i,t}}$; or, equivalently, $l_{i,t}(j)$ units of labor produce $x_{i,t}(j) = A_{i,t}l_{i,t}(j) - A_{i,t}F$ units of output. In the alternative model considered here, the part of the production function that is linear in labor is replaced with a two-input Cobb-Douglas production function (following Allen and Arkolakis (2014) and Ahlfeldt et al. (2015)Appendix A2), such that $l_{i,t}(j)$ units of labor and $h_{i,t}(j)$ units of land produce $x_{i,t}(j) = A_{i,t}l_{i,t}(j)^{\chi}h_{i,t}(j)^{1-\chi} - A_{i,t}F$ units of output. The Cobb-Douglas share of land in the modified production function is set at $1-\chi = \frac{1}{3}$ following, for example, Córdoba and Ripoll (2009). Goods produced are imperfectly mobile across locations, with bilateral goods trade costs taking the iceberg form such that $d_{ni,t}$ units of a good must be shipped from location $i$ for one unit to arrive in location $n$, where $d_{ni,t} \geq 1$ for $\forall i, n, t$. Trade costs are assumed to be symmetric such that $d_{ni,t} = d_{in,t}$. Increasing returns to scale in production and costly trade, combined with consumer love of variety, result in agglomeration economies in the form of pecuniary externalities.

Firms set the price of their variety to maximize profits, which yields the result that the equilibrium price at $n$ of a good produced at $i$ at time $t$ is a constant mark-up over marginal cost:

$$p_{ni,t}(j) = \left(\frac{\sigma}{\sigma-1}\right)\frac{d_{ni,t}w_{i,t}^{\chi}r_{i,t}^{1-\chi}}{A_{i,t}}\left(\left(\frac{\chi}{1-\chi}\right)^{1-\chi} + \left(\frac{1-\chi}{\chi}\right)^{\chi}\right) \tag{A22}$$

where $w_{i,t}$ is the wage and $r_{i,t}$ is the land rental rate at $i$ at time $t$.

Combining Equation (A22) with the zero profit condition, in equilibrium, firms will demand $l_{i,t}(j) = \bar{l_{i,t}} = \sigma F \left(\frac{r_{i,t}}{w_{i,t}} \frac{\chi}{1-\chi}\right)^{1-\chi}$ units of labor and $h_{i,t}(j) = \bar{h_{i,t}} = \sigma F \left(\frac{w_{i,t}}{r_{i,t}} \frac{1-\chi}{\chi}\right)^{\chi}$ units of land. Combining this in turn with the market clearing conditions in the market for inputs in each location implies $\frac{w_{i,t}}{r_{i,t}} = \frac{\chi}{1-\chi} \frac{H_{i,t}}{L_{i,t}}$ and hence that the measure of varieties supplied in each location at time $t$ in location $i$ is: $M_{i,t} = \frac{L_{i,t}^{\chi} H_{i,t}^{1-\chi}}{\sigma F}$.The consumption goods price index can then be expressed as:

(A23)

$$P_{n,t}^{1-\eta} = \sum_{i \in N} P_{ni,t}^{1-\eta} = \sum_{i \in N} \left(\frac{L_{i,t}^{\chi} H_{i,t}^{1-\chi}}{\sigma F}\right)^{\frac{1-\eta}{1-\sigma}} \left(\left(\frac{\sigma}{\sigma - 1}\right) \left(\left(\frac{\chi}{1-\chi}\right)^{1-\chi} + \left(\frac{1-\chi}{\chi}\right)^{\chi}\right) \frac{d_{ni,t} w_{i,t}^{\chi} r_{i,t}^{1-\chi}}{A_{i,t}}\right)^{1-\eta}$$

This yields an expression for trade shares:

(A24)
$$\pi_{ni,t} = \left(\frac{P_{ni}}{P_n}\right)^{1-\eta} = \frac{X_{ni,t}}{X_{n,t}} = \frac{\left(L_{i,t}^{\chi} H_{i,t}^{1-\chi}\right)^{\frac{1-\eta}{1-\sigma}} \left[\frac{d_{ni,t} w_{i,t}^{\chi} r_{i,t}^{1-\chi}}{A_{i,t}}\right]^{1-\eta}}{\sum_{l \in N} \left(L_{l,t}^{\chi} H_{l,t}^{1-\chi}\right)^{\frac{1-\eta}{1-\sigma}} \left[\frac{d_{nl,t} w_{l,t}^{\chi} r_{l,t}^{1-\chi}}{A_{l,t}}\right]^{1-\eta}}$$

where $X_{ni,t}$ is the total value of bilateral trade flows from location $i$ to location $n$ and $X_{n,t}$ is aggregate expenditure at $n$ at time $t$.

In each location, standard expressions define consumer market access as $CMA_{i,t} = P_{i,t}^{1-\eta}$ and firm market access as $FMA_{i,t} = \sum_{n \in N} \frac{X_{n,t}}{P_{n,t}^{1-\eta}} d_{ni,t}^{1-\eta}$. Following Anderson and Van Wincoop (2003), this system of equations is satisfied by[9]:

(A25)
$$CMA_{i,t} = FMA_{i,t} = MA_{i,t} = \sum_{n \in N} \frac{d_{ni,t}^{1-\eta} X_{n,t}}{MA_{n,t}}$$

## D Income

Let $y_{n,t}$ be the nominal income per labor unit. A worker who starts the period at $n$ will then receive real income:

(A26)
$$Y_{n,t} = \frac{y_{n,t}}{P_{n,t}}$$

Following Monte, Redding, and Rossi-Hansberg (2018), I assume that land in each location is owned by immobile landlords who receive worker expenditure on residential land as income and only consume goods in the location in which they live. As a result, workers' nominal income consists of

[9] As discussed in Anderson and Van Wincoop (2003) and Allen and Arkolakis (2022), the market access terms are equal up to scale and the general solution is $CMA_{i,t} = \lambda MA_{i,t}$ and $FMA_{i,t} = \frac{1}{\lambda} MA_{i,t}$ for any nonzero $\lambda$. The constant terms $\lambda$ cancel in and therefore do not affect estimation of the model.

their wage income only:

$$y_{n,t} L_{n,t} = w_{n,t} L_{n,t} \tag{A27}$$

This implies that the expected lifetime utility of a representative worker in location $n$ at time $t$ can be expressed as:

$$V_{n,t} = lnw_{n,t} - lnP_{n,t} + \nu ln \sum_{i \in N} \left( exp\left[ \beta V_{i,t+1} - \mu_{in} + B_{i,t} \right] \right)^{\frac{1}{\nu}} \tag{A28}$$

## E General equilibrium

The sequential equilibrium of the model is the set of labor units $\{L_{n,t}\}$, migration shares $\{m_{ni,t}\}$, wages $\{w_{n,t}\}$, market access terms $\{FMA_{n,t}, CMA_{n,t}\}$ and expected lifetime utilities $\{V_{n,t}\}$, that solve the following system of equations for all locations $i, n \in N$ and all time periods $t$:

1. Each location's income equals expenditure on goods produced in that location:

$$w_{i,t} L_{i,t} + r_{i,t} H_{i,t} = \frac{w_{i,t} L_{i,t}}{\chi} = \frac{\left( L_{i,t}^{\chi} H_{i,t}^{1-\chi} \right)^{\frac{1-\eta}{1-\sigma}} \left[ \frac{w_{i,t}^{\chi} \left( \frac{w_{i,t} L_{i,t}}{H_{i,t}} \left( \frac{1-\chi}{\chi} \right) \right)^{1-\chi}}{A_{i,t}} \right]^{1-\eta}}{(\sigma F)^{\frac{1-\eta}{1-\sigma}} \left( \left( \frac{\sigma}{\sigma-1} \right) \left( \left( \frac{\chi}{1-\chi} \right)^{1-\chi} + \left( \frac{1-\chi}{\chi} \right)^{\chi} \right) \right)^{\eta-1}} FMA_{i,t} \tag{A29}$$

2. Market access is given by:

$$FMA_{i,t} = \sum_{n \in N} \frac{d_{ni,t}^{1-\eta} X_{n,t}}{CMA_{n,t}}, \ CMA_{n,t} = \sum_{i \in N} \frac{d_{ni,t}^{1-\eta} X_{i,t}}{FMA_{i,t}} \tag{A30}$$

3. Expected lifetime utilities satisfy:

$$V_{n,t} = lnw_{n,t} - ln\left( (CMA_{n,t})^{\frac{1}{1-\eta}} \right) + \nu ln \sum_{i \in N} \left( exp\left[ \beta V_{i,t+1} - \mu_{in} + B_{i,t} \right] \right)^{\frac{1}{\nu}} \tag{A31}$$

4. Migration shares satisfy:

$$m_{in,t} = \frac{\left( exp\left[ \beta V_{i,t+1} - \mu_{in} + B_{i,t} \right] \right)^{\frac{1}{\nu}}}{\sum_{k \in N} \left( exp\left[ \beta V_{k,t+1} - \mu_{kn} + B_{k,t} \right] \right)^{\frac{1}{\nu}}} \tag{A32}$$

5. The evolution of labor units is given by:

$$L_{n,t+1} = \sum_{i \in N} m_{ni,t} L_{i,t} \tag{A33}$$

Following Caliendo, Dvorkin, and Parro (2019), a stationary equilibrium of the model is a sequential equilibrium such that the endogenous variables are constant for all $t$.

## F Aggregate welfare

The expected lifetime utility of workers residing in location $n$ at time $t$ is given by:

$$V_{n,t} = \sum_{s=t}^{\infty} \beta^{s-t} ln \left( \frac{w_{n,s} exp\left(B_{n,s}\right)}{P_{n,s}\left(m_{nn,s}\right)^{\nu}} \right) \tag{A34}$$

The consumption equivalent change in welfare from a change in the economy's fundamentals, aggregated using the mean value across all locations weighted by their respective initial population shares, is given by:

$$\triangle Welfare_t = \sum_{n \in N} \frac{L_{n,t}}{\sum_{i \in N} L_{i,t}} \left\{ (1-\beta) \sum_{s=t}^{\infty} \beta^{s-t} ln \left( \frac{\left(\frac{\widehat{w_{n,s}}}{w_{n,s}}\right) \frac{exp\left(\widehat{B_{n,s}}\right)}{exp\left(B_{n,s}\right)}}{\left(\frac{\widehat{P_{n,s}}}{P_{n,s}}\right)\left(\frac{\widehat{m_{nn,s}}}{m_{nn,s}}\right)^{\nu}} \right) \right\} \tag{A35}$$

## G Derivation of equilibrium condition for lifetime utilities expressed in relative differences

1. From the equilibrium condition for expected lifetime utility in Equation (13):

$$\begin{aligned} \left[exp\left(V_{n,t+1} - V_{n,t}\right)\right]^{\frac{1}{\nu}} &= \Big[exp\{lnw_{n,t+1} - lnP_{n,t+1} \\ &\quad + \nu ln \textstyle\sum_{i \in N} \left(exp\left[\beta V_{i,t+2} - \mu_{in} + B_{i,t+1}\right]\right)^{\frac{1}{\nu}} \\ &\quad - \left(lnw_{n,t} - lnP_{n,t}\right) \\ &\quad - \nu ln \textstyle\sum_{i \in N} \left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}} \}\Big]^{\frac{1}{\nu}} \\ &= \left[ \frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)} \right]^{\frac{1}{\nu}} \left( \frac{\sum_{i \in N}\left(exp[\beta V_{i,t+2} - \mu_{in} + B_{i,t+1}]\right)^{\frac{1}{\nu}}}{\sum_{i \in N}\left(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}]\right)^{\frac{1}{\nu}}} \right) \end{aligned} \tag{A36}$$

2. Multiplying and dividing each term in the sum $\sum_{i \in N} \left(exp\left[\beta V_{i,t+2} - \mu_{in} + B_{i,t+1}\right]\right)^{\frac{1}{\nu}}$ by $\left(exp\left[\beta V_{i,t+1} - \mu_{in} + B_{i,t}\right]\right)^{\frac{1}{\nu}}$ gives:

$$\begin{aligned} \frac{\sum_{i \in N}\left(exp[\beta V_{i,t+2} - \mu_{in} + B_{i,t+1}]\right)^{\frac{1}{\nu}}}{\sum_{i \in N}\left(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}]\right)^{\frac{1}{\nu}}} &= \frac{\left(exp[\beta V_{1,t+2} - \mu_{1n} + B_{1,t+1}]\right)^{\frac{1}{\nu}} + \left(exp[\beta V_{2,t+2} - \mu_{2n} + B_{2,t+1}]\right)^{\frac{1}{\nu}} + \dots}{\sum_{i \in N}\left(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}]\right)^{\frac{1}{\nu}}} \\ &= \frac{\left(exp[\beta V_{1,t+2} - \mu_{1n} + B_{1,t+1}]\right)^{\frac{1}{\nu}} \frac{\left(exp\left[\beta V_{1,t+1} - \mu_{1n} + B_{1,t}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[\beta V_{1,t+1} - \mu_{1n} + B_{1,t}\right]\right)^{\frac{1}{\nu}}}}{\sum_{i \in N}\left(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}]\right)^{\frac{1}{\nu}}} \\ &\quad + \frac{\left(exp[\beta V_{2,t+2} - \mu_{2n} + B_{2,t+1}]\right)^{\frac{1}{\nu}} \frac{\left(exp\left[\beta V_{2,t+1} - \mu_{2n} + B_{2,t}\right]\right)^{\frac{1}{\nu}}}{\left(exp\left[\beta V_{2,t+1} - \mu_{2n} + B_{2,t}\right]\right)^{\frac{1}{\nu}}}}{\sum_{i \in N}\left(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}]\right)^{\frac{1}{\nu}}} + \dots \end{aligned}$$

3. Substituting the migration shares equation $m_{in,t} = \frac{(exp[\beta V_{i,t+1} - \mu_{in} + B_{i,t}])^{\frac{1}{\nu}}}{\sum_{m \in N}(exp[\beta V_{m,t+1} - \mu_{mn} + B_{m,t}])^{\frac{1}{\nu}}}$ gives:

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

4. Substituting this back into Equation (A36) gives:

$$\begin{aligned}
\left[exp\left(V_{n,t+1} - V_{n,t}\right)\right]^{\frac{1}{\nu}} &= \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)}\right]^{\frac{1}{\nu}} \\
&\quad \times \sum_{k \in N} m_{kn,t} exp\left[\frac{\beta}{\nu}\left(V_{k,t+2} - V_{k,t+1}\right)\right] exp\left[\frac{1}{\nu}\left(B_{k,t+1} - B_{k,t}\right)\right]
\end{aligned}$$

5. Defining $Y_{n,t+1} = \left[exp\left(V_{n,t+1} - V_{n,t}\right)\right]^{\frac{1}{\nu}}$ and substituting gives:

$$Y_{n,t+1} = \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)}\right]^{\frac{1}{\nu}} \sum_{k \in N} m_{kn,t}\left(Y_{k,t+2}\right)^{\beta} exp\left[\frac{1}{\nu}\left(B_{k,t+1} - B_{k,t}\right)\right]$$

6. The central estimates assume that local amenities are exogenous and time-invariant, $B_{n,t} = B_n$, so this equation reduces to:

(A37)
$$Y_{n,t+1} = \left[\frac{\left(\frac{w_{n,t+1}}{w_{n,t}}\right)}{\left(\frac{P_{n,t+1}}{P_{n,t}}\right)}\right]^{\frac{1}{\nu}} \sum_{k \in N} m_{kn,t}\left(Y_{k,t+2}\right)^{\beta}$$

# H Derivation of welfare change induced by changes in the economy's fundamentals

Denoting by $\widehat{x}$ the value of a variable $x$ under an alternative scenario for the economy's fundamentals, the expected lifetime utilities in location $n$ at time $t$ with and without the change in fundamentals are given by, respectively:

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

and:

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

The compensating variation in consumption for location $n$ at time $t$ is given by $\delta_{n,t}$ such that:

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

This yields an expression for the consumption equivalent change in welfare:

$$\triangle Welfare_{n,t} = ln\left(\delta_{n,t}\right) = (1-\beta) \sum_{s=t}^{\infty} \beta^{s-t} ln \left( \frac{\left(\frac{\widehat{w_{n,s}}}{w_{n,s}}\right) \frac{exp\left(\widehat{B_{n,s}}\right)}{exp\left(B_{n,s}\right)}}{\left(\frac{\widehat{P_{n,s}}}{P_{n,s}}\right) \left(\frac{\widehat{m_{nn,s}}}{m_{nn,s}}\right)^{\nu}} \right)$$

The aggregate welfare change is obtained by taking the mean value across locations, weighted by their respective initial population shares:

$$\triangle Welfare_{t} = \sum_{n \in N} \frac{L_{n,t}}{\sum_{i \in N} L_{i,t}} \left\{ (1-\beta) \sum_{s=t}^{\infty} \beta^{s-t} ln \left( \frac{\left(\frac{\widehat{w_{n,s}}}{w_{n,s}}\right) \frac{exp\left(\widehat{B_{n,s}}\right)}{exp\left(B_{n,s}\right)}}{\left(\frac{\widehat{P_{n,s}}}{P_{n,s}}\right) \left(\frac{\widehat{m_{nn,s}}}{m_{nn,s}}\right)^{\nu}} \right) \right\} \tag{A38}$$

## VI Approximation of optimal infrastructure problem

The second set of counterfactual allocation rules considered aim to approximate an efficient network more closely than the simple rule-of-thumb allocations based on maximizing pairwise market potential. The allocation of investments is subject to the constraint that all counterfactuals considered have the same total cost as the status quo network upgrades. This Appendix sets out the simplified optimal infrastructure allocation problem on which these counterfactual allocations are based.

Suppose that the Government of Vietnam ('the planner') can choose a continuous level of road investment $I_{ni}$ to lower trade costs $d_{ni}$ between locations $i$ and $n$. We assume that $I_{ni} = I_{in}$. The social planner faces a budget constraint $\sum_{n\in N}\sum_{i\neq n} c_{ni}I_{ni} \leq K$, where $c_{ni}$ is the cost of one unit of investment in the connection between $i$ and $n$. The planner maximizes a weighted average of the expected lifetime utilities across different locations in Vietnam, where the weights are given by initial population shares:

$$\begin{aligned} W_0 &= \sum_{n\in VN} \frac{L_{n,0}}{\sum_{i\in VN} L_{i,0}} \sum_{t=0}^{\infty} \beta^t V_{n,t} \\ &= \sum_{n\in VN} \frac{L_{n,0}}{\sum_{i\in VN} L_{i,0}} \sum_{t=0}^{\infty} \beta^t \left\{\alpha \ln w_{n,t} - \alpha \ln P_{n,t} - (1-\alpha)\ln \frac{(1-\alpha)L_{n,t}}{H_{n,t}} + B_{n,t} - \nu \ln m_{nn,t}\right\} \end{aligned}$$

subject to the equilibrium conditions (Equations (11) to (15)) and budget constraint.

This yields the following Kuhn-Tucker first order conditions, where $P_K$ is the Lagrange multiplier on the infrastructure budget constraint (the shadow price of asphalt):

$$\text{(A39)} \qquad \sum_{n\in VN} \frac{L_{n,0}}{\sum_{i\in VN} L_{i,0}} \sum_{t=0}^{\infty} \beta^t \frac{\partial V_{n,t}}{\partial d_{jk}} \times \frac{\partial d_{jk}}{\partial I_{jk}} - P_K c_{jk} \leq 0$$

Substituting the expression for the equilibrium wage in terms of market access from Equation (11), and $MA_{n,t} = P_{n,t}^{1-\eta}$ from Equation (6), into $V_{n,t}$ yields:

$$\begin{aligned} V_{n,t} \;=\; & \left(\frac{\alpha-2\alpha\eta}{\eta(1-\eta)}\right)\ln MA_{n,t} + \left[\alpha - 1 + \frac{\alpha}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right]\ln L_{n,t} - \nu \ln m_{nn,t} \\ & + (1-\alpha)\ln H_{n,t} + B_{n,t} - (1-\alpha)\ln(1-\alpha) + \frac{\alpha}{\eta}\ln \frac{A_{n,t}^{\eta-1}}{(\sigma F)^{\frac{1-\eta}{1-\sigma}}\left(\frac{\sigma}{\sigma-1}\right)^{\eta-1}} \end{aligned}$$

We can decompose the effect of a change in $d_{jk}$ on per-period $V_{n,t}$ by considering the effects on each of the endogenous terms (those pertaining to market access, population and migration shares):

$$\text{(A40)} \qquad \begin{aligned} \frac{\partial V_{n,t}}{\partial d_{jk}} \;=\; & \left(\frac{\alpha-2\alpha\eta}{\eta(1-\eta)}\right)\frac{1}{MA_{n,t}} \times \frac{\partial MA_{n,t}}{\partial d_{jk}} && (1) \\ & + \left[\alpha - 1 + \frac{\alpha}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right]\frac{1}{L_{n,t}} \times \frac{\partial L_{n,t}}{\partial d_{jk}} && (2) \\ & - \nu \frac{1}{m_{nn,t}} \times \frac{\partial m_{nn,t}}{\partial d_{jk}} && (3) \end{aligned}$$

Consider each of the terms in Equation (A40) separately in turn:

1. Term (1): $\left(\frac{\alpha-2\alpha\eta}{\eta(1-\eta)}\right)\frac{1}{MA_{n,t}} \times \frac{\partial MA_{n,t}}{\partial d_{jk}}$

(a) Combine equilibrium conditions (11) and (12):

$$MA_{n,t} = \sum_{i \in N} \left[ \frac{A_{i,t}^{\eta-1}}{(\sigma F)^{\frac{1-\eta}{1-\sigma}} \left(\frac{\sigma}{\sigma-1}\right)^{\eta-1}} \right]^{\frac{1}{\eta}} d_{in,t}^{1-\eta} L_{i,t}^{1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)} MA_{i,t}^{\frac{1-\eta}{\eta}}$$

(b) Compute $\frac{\partial MA_{n,t}}{\partial d_{jk}}$ separately for the following cases. In the interest of computational tractability, we abstract from network effects that mean that upgrades along one bilateral link may also have second order effects on trade costs along other bilateral links.

- When $n \notin \{j,k\}$:

$$\begin{aligned} \frac{\partial MA_{n,t}}{\partial d_{jk}} &= \sum_{i \in N} \left[ \frac{A_{i,t}^{\eta-1}}{(\sigma F)^{\frac{1-\eta}{1-\sigma}} \left(\frac{\sigma}{\sigma-1}\right)^{\eta-1}} \right]^{\frac{1}{\eta}} \times d_{in,t}^{1-\eta} \times \\ &\left[ L_{i,t}^{1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)} \left(\frac{1-\eta}{\eta}\right) MA_{i,t}^{\left(\frac{1-\eta}{\eta}-1\right)} \frac{\partial MA_{i,t}}{\partial d_{jk}} + \left(1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right) L_{i,t}^{\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)} \frac{\partial L_{i,t}}{\partial d_{jk}} MA_{i,t}^{\frac{1-\eta}{\eta}} \right] \\ &= \sum_{i \in N} d_{in,t}^{1-\eta} \left[ \left(\frac{1-\eta}{\eta}\right) \frac{w_{i,t} L_{i,t}}{MA_{i,t}^2} \frac{\partial MA_{i,t}}{\partial d_{jk}} + \left(1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right) \frac{w_{i,t}}{MA_{i,t}} \frac{\partial L_{i,t}}{\partial d_{jk}} \right] \end{aligned}$$

- When $k = n$:

$$\begin{aligned} \frac{\partial MA_{n,t}}{\partial d_{jk}} &= (1-\eta)\, d_{jk,t}^{-\eta} \frac{w_{j,t} L_{j,t}}{\boldsymbol{MA_{j,t}}} \\ &+ \sum_{i \in N} d_{ik,t}^{1-\eta} \left[ \left(\frac{1-\eta}{\eta}\right) \frac{w_{i,t} L_{i,t}}{MA_{i,t}^2} \frac{\partial MA_{i,t}}{\partial d_{jk}} + \left(1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right) \frac{w_{i,t}}{MA_{i,t}} \frac{\partial L_{i,t}}{\partial d_{jk}} \right] \end{aligned}$$

- Symmetrically, when $j = n$:

$$\begin{aligned} \frac{\partial MA_{n,t}}{\partial d_{nk}} &= (1-\eta)\, d_{jk,t}^{-\eta} \frac{w_{k,t} L_{k,t}}{\boldsymbol{MA_{k,t}}} \\ &+ \sum_{i \in N} d_{ij,t}^{1-\eta} \left[ \left(\frac{1-\eta}{\eta}\right) \frac{w_{i,t} L_{i,t}}{MA_{i,t}^2} \frac{\partial MA_{i,t}}{\partial d_{jk}} + \left(1+\frac{1}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right) \frac{w_{i,t}}{MA_{i,t}} \frac{\partial L_{i,t}}{\partial d_{jk}} \right] \end{aligned}$$

(c) Considering first order effects only, the first term in the first order condition at Equation (A39) corresponding to term (1) in Equation (A40) therefore simplifies to:

(A41)

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{\alpha-2\alpha\eta}{\eta(1-\eta)}\right) \sum_{n \in VN} \frac{L_{n,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{n,t}} \times \frac{\partial MA_{n,t}}{\partial d_{jk}} \times \frac{\partial d_{jk}}{\partial I_{jk}} =$$

$$\begin{cases} \sum_{t=0}^{\infty} \beta^t \left(\frac{\alpha-2\alpha\eta}{\eta}\right) \left\{ d_{jk,t}^{-\eta} \left[ \frac{L_{k,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{k,t}} \frac{w_{j,t} L_{j,t}}{\boldsymbol{MA_{j,t}}} + \frac{L_{j,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{j,t}} \frac{w_{k,t} L_{k,t}}{\boldsymbol{MA_{k,t}}} \right] \right\} \times \frac{\partial d_{jk}}{\partial I_{jk}} & if\ j,k \in VN \\ \sum_{t=0}^{\infty} \beta^t \left(\frac{\alpha-2\alpha\eta}{\eta}\right) \left\{ d_{jk,t}^{-\eta} \left[ \frac{L_{j,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{j,t}} \frac{w_{k,t} L_{k,t}}{\boldsymbol{MA_{k,t}}} \right] \right\} \times \frac{\partial d_{jk}}{\partial I_{jk}} & if\ j \in VN, k = ROW \end{cases}$$

2. Term (2): $\left[\alpha - 1 + \frac{\alpha}{\eta}\left(\frac{\sigma-\eta}{1-\sigma}\right)\right] \frac{1}{L_{n,t}} \times \frac{\partial L_{n,t}}{\partial d_{jk}}$ and Term (3): $\nu \frac{1}{m_{nn,t}} \times \frac{\partial m_{nn,t}}{\partial d_{jk}}$

(a) $L_{n,t}$ evolves according to $L_{n,t+1} = \sum_{i \in N} m_{ni,t} L_{i,t}$. The derivatives $\frac{\partial L_{n,t}}{\partial d_{jk}}$ can be computed recursively with knowledge of $\frac{\partial m_{ni,t}}{\partial d_{jk}}$. Taking $L_{i,0}$ as given yields:

$$\frac{\partial L_{n,1}}{\partial d_{jk}} = \sum_{i \in N} \frac{\partial m_{ni,1}}{\partial d_{jk}} L_{i,0}, \quad \frac{\partial L_{n,t+1}}{\partial d_{jk}} = \sum_{i \in N} \frac{\partial m_{ni,t}}{\partial d_{jk}} L_{i,t} + \sum_{i \in N} m_{ni,t} \frac{\partial L_{i,t}}{\partial d_{jk}} \quad \text{for } t \geq 0$$

(b) Differentiating the expression for $m_{in,t}$ in Equation (14) yields an expression for $\frac{\partial m_{in,t}}{\partial d_{jk}}$ as a function of $\frac{\partial V_{l,t+1}}{\partial d_{jk}}$ for $\ell \in N$:

$$\frac{\partial m_{in,t}}{\partial d_{jk}} = \frac{\frac{\beta}{\nu} \exp(\beta V_{i,t+1} - \mu_{in} + B_{i,t})^{1/\nu} \sum_{\ell \in N} \exp(\beta V_{\ell,t+1} - \mu_{\ell n} + B_{\ell,t})^{1/\nu} \left[\frac{\partial V_{i,t+1}}{\partial d_{jk}} - \frac{\partial V_{\ell,t+1}}{\partial d_{jk}}\right]}{\left(\sum_{\ell \in N} \exp(\beta V_{\ell,t+1} - \mu_{\ell n} + B_{\ell,t})^{1/\nu}\right)^2}$$

Computing the terms in the first order condition at Equation (A39) corresponding to terms (2) and (3) in Equation (A40) is therefore a very high dimensional problem that requires data on bilateral migration costs and local amenity values, which are not observed in the data. As a result, the simplified allocation rules considered prioritize road upgrades drawing on the first term in the first order condition based on Equation (A41), which pertains to the welfare contribution of road investments via endogenous improvements in market access. Approximating this in a computationally-feasible manner by prioritizing road upgrades along pairwise connections between pairs of Vietnam's districts $j$ and $k$ according to $\sum_{t=0}^{\infty} \beta^t \left\{ d_{jk,t}^{-\eta} \left[ \frac{L_{k,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{k,t}} \frac{w_{j,t} L_{j,t}}{\boldsymbol{MA_{j,t}}} + \frac{L_{j,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{j,t}} \frac{w_{k,t} L_{k,t}}{\boldsymbol{MA_{k,t}}} \right] \right\}$ and between a district $j$ and the nearest international port according to $\sum_{t=0}^{\infty} \beta^t \left\{ d_{jROW,t}^{-\eta} \left[ \frac{L_{j,0}}{\sum_{i \in VN} L_{i,0}} \frac{1}{MA_{j,t}} \frac{w_{ROW,t} L_{ROW,t}}{\boldsymbol{MA_{ROW,t}}} \right] \right\}$ is a stylized case which abstracts from relevant features of the allocation decision, including consideration of the implications of upgrading a given bilateral link for trade costs along other links and heterogeneous construction costs in the pairwise rankings, and the possibility of optimizing over the number of categories by which each link is upgraded. Nonetheless, this allocation rule draws on the model's optimality conditions to more closely approximate the efficient allocation of road upgrade investments in a computationally feasible manner.

This approach allows me to examine the central policy-relevant question of how accounting for future sea level rise may influence the returns to alternative counterfactuals based on allocation rules that policy makers do or could use to approximate an efficient network. The estimated welfare gains from these allocations may underestimate the available gains from the truly optimal network, and the welfare difference between the unforesighted and foresighted counterfactuals may over- or under-estimate the welfare difference between the unforesighted and foresighted versions of the truly optimal network. The key contribution is to highlight that among a range of transport infrastructure allocation rules linked to those used by policy makers in practice – as well as related implementable allocation rules more closely tied to the model's optimality conditions – accounting for future sea level rise has important implications for how investments should be allocated.

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