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A. Kerem Coşar, Banu Demir, Devaki Ghose and Nathaniel Young

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Keywords: trade, market access, transportation infrastructure

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Abstract

What is the impact on intra-national trade and regional economic outcomes when the quality and lane-capacity of an existing paved road network is expanded significantly? We investigate this question for the case of Turkey, which undertook a large-scale public investment in roads during the 2000s. Using spatially disaggregated data on road upgrades and domestic transactions, we estimate a large positive impact of reduced inter-provincial travel times on trade as well as regional industrial sales and employment. A quantitative exercise using a workhorse model of spatial equilibrium implies a rate of return on investment around 70 percent.

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Correspondence: kerem.cosar@virginia.edu, banup@bilkent.edu.tr, devaki.ghose@gmail.com, youngna@ebrd.com. The authors wish to thank Steve Gibbons and David Nagy for helpful discussions, as well as conference participants at the 13th UEA Meetings, trade sessions of the 2018 Lisbon Meetings in Game Theory, 2018 Southern Economic Association meeting, International Conference on Infrastructure, Growth and Development in London, and 2018 EIB European Network for Research on Investment. All opinions expressed here are those of the authors and do not necessarily reflect the opinions of the European Bank for Reconstruction and Development.

1 Introduction

Transport is one of the largest contributors to infrastructure investment in the world. It plays a vital role in modern market economies, enabling domestic and international trade. High transport costs impede market access in isolated regions, both in terms of firms' ability to sell goods and in terms of their ability to buy the required inputs. Investment in transport infrastructure can reduce these frictions and improve growth prospects by facilitating trade. But how large are these gains, especially when there are various types or stages of investments that are possible? Arguably, constructing a new road from scratch or paving a dirt road would have a different effect than constructing a highway or expanding the lane capacity of existing roads. Previous empirical work has focused on cross-country analysis (Limao and Venables, 2001; Yeaple and Golub, 2007), on the impact of the US interstate highway system (Duranton, Morrow, and Turner, 2014; Allen and Arkolakis, 2014), and the construction or paving of new roads in low- or lower-middle income countries, such as Faber (2014) on the highway network in China, Asturias, Ramos, and Santana (2018) on the Golden Quadrilateral highway in India, and Kebede (2019) on improved village roads in Ethiopia. In this paper, we examine the benefits that a major capacity upgrade to existing transport infrastructure can have in middle-income economies by looking at the case of Turkey, which undertook major public investment in roads during the 2000s. We do so by providing reduced-form empirical evidence as well as by quantifying a structural model of economic geography.

The empirical exercise first measures the impact of road construction on reduced travel times, then links travel time reductions to changes in intra-national trade as well as regional sales, employment and productivity. We leverage a new dataset on within-country trade across the 81 provinces in Turkey. The data span a time period during which intensive road construction took place (2006-2015) and can be broken down by industry to analyze heterogenous effects as well as to control for compositional changes.

The nature and the quality of data improves upon Coşar and Demir (2016) who have examined the effect of the same investment program on the external trade of Turkish provinces between 2003-2012 using provincial shares of upgraded roads in the road stock. In contrast, this paper uses province-to-province trade, which captures a larger fraction of total economic activity, and GIS-based province-to-province travel times, a more precise measure of transportation costs. Our results suggest that travel time savings due to the investment program boosted intra-national trade in Turkey, increased output and generated employment. The results are robust to a number of checks, including a falsification test that investigates whether changes in domestic inter-provincial trade flows during the 2006-2011 period can be explained by travel time reductions over the 2010-2015 period.

The quantitative exercise adapts a workhorse model of economic geography (Allen and Arkolakis, 2014) to the case at hand. The framework allows labor mobility within a standard Armington trade model, capturing the spatial equilibrium within a country in the long-run. We calibrate provinces' productivities and amenities from their 2005 population shares and nominal wages. The quantified model helps us to gauge welfare changes across provinces through market access shifts in the short run when labor is immobile. We find a substantial increase in inter-provincial inequality: at conventional parameter values, the largest and smallest welfare gains across 81 provinces are 10.3 percent and 0.8 percent, respectively. In the long run, when labor is perfectly mobile across regions, the implied aggregate welfare increase is around 3 percent, implying a 70 percent rate of return on the road investment program.

2 Background

Turkey is an upper-middle-income country according to the World Bank classification, with a GDP per capita of USD 14,117 (in constant 2010 dollars) and a population of 79.8 million as of 2016. The dominance of roads as a mode of transportation in Turkey, accounting for about 90 percent of domestic freight (by tonne-km) and passenger traffic, motivated the country to undertake a major public investment in its transportation infrastructure during the 2000s. The road network was already extensive prior to this investment: in 2005, a paved road network already connected Turkey's 81 provincial centers (see thin grey lines in Panel A of Figure 1).[1] However, the lack of dual carriageways for most network segments resulted in limited capacity, long considered inadequate (see the thick green lines indicating dived multi-lane highways or expressways).

Consequently, the Turkish government launched a large-scale transportation investment program in 2002. The investment resulted in a significant percentage of existing single carriageways (undivided two-lane roads) being turned into dual carriageways.[2] By 2015, numerous arterial routes had been upgraded (see Panel B of Figure 1), with dual carriageways accounting for 35 per cent of inter-provincial roads, up from 10 per cent in 2002 (see Figure 2). The increase in capacity allowed vehicles to travel more reliably at higher speeds, making arrival times more predictable and reducing accident rates, with the number of fatalities per

[1]Provinces correspond to the NUTS 3 (Nomenclature of Territorial Units for Statistics) level in the Eurostat classification of regions.

[2]According to the World Bank, Turkish public expenditures on transport have almost doubled from 1.06 percent of Gross Domestic Product (GDP) in 2004 to 1.92 percent in 2010, and the transport sector accounted for the bulk of the increase in total public investments over this period (http://bit.ly/2Aw0XX4).

kilometer travelled declining by 57 per cent between 2002-2014.[3]

The objectives and design of the investment mitigate some concerns related to the selection of province pairs for domestic trade-related outcomes. First, policy documents explicitly emphasize the long-term goal as the improvement of connections between all provincial centers to form a comprehensive grid network spanning the country, rather than boosting trade between particular regions. The General Directorate of Highways policy describes the criteria as "ensuring the integrity of the international and national networks, and addressing capacity constraints that lead to road traffic accidents."(GDH, 2014). Second, the extent of road upgrading shows considerable variation across provinces, without any visible sign of concentration in particular regions. Finally, the investment was centrally planned and financed from the central government's budget with no direct involvement of local administrations. Additional details about the investment program and discussion of external evidence on its contribution to the improvement of road transport quality in Turkey are available in Coşar and Demir (2016).

3 Data

A distinguishing feature of our study is the availability of high-quality data on domestic trade flows within Turkey during a time period when the country undertook a significant upgrading of its road network. The source of the domestic trade data is the administrative firm-to-firm transaction data provided by the Turkish Ministry of Science, Industry and Technology. Since 2006, Turkish firms have been legally required to report all purchases and sales exceeding a certain threshold (≈USD 3,300 in 2010) to the Ministry of Finance. The objective of this requirement is to reduce tax evasion and increase value-added tax (VAT) collection. Each transaction report is cross-checked and in case of inconsistencies, both firms are audited to retrieve the correct information.

In this paper, we use annual bilateral trade flows between provinces at the 2-digit industry level (according to the NACE Rev.2 classification) constructed by aggregating the firm-to-firm transaction data described above. The agricultural sector is excluded since it is dominated by unincorporated small farmers whose transactions tend to fall under the reporting threshold. We group remaining industries into two groups: manufacturing and other non-agricultural/non-manufacturing. The latter includes wholesale, retail and services other

[3]See the second column from right in table 1 in Murat and Zorlu (2018). Since the reporting criteria was changed in 2015 from "fatality on impact" to "fatality within 30 days of the accident," we report the change until 2014.

than finance, insurance and utilities.[4] The dataset covers the 2006-2016 period. Data on provincial employment is collected by the Social Security Institution (SGK) and made available by the Ministry of Industry, while data on provincial population come from the Turkish Statistical Institute. Table 1 provides summary statistics for the data. As a benchmark, it also reports the value of nominal GDP and total non-agricultural employment obtained from the Turkish Statistical Institute.[5]

To measure the impact of the road upgrades, we calculate the decadal change in inter-provincial travel times. To do so, we digitized the official maps of the road network published by the General Directorate of Highways for 2005, 2010 and 2015. Figure 1 shows the first and last year's rendered maps. Using geographic information system (GIS) software, we then calculated the fastest possible travel times between the 81 provincial centers in each year.[6] Figure 3 plots the reduction in travel times between province pairs from 2005 to 2015 against their time-invariant geodesic distances. The average travel time between any two provinces has been reduced by 1.4 hours, relative to the average of 6.5 hours in 2005. Time savings increase the further apart cities are, reaching five hours in the case of cities that are 1,500 km or more apart.

4 Road Capacity and Domestic Trade

4.1 Baseline results

We start our analysis by checking whether the reduced travel times resulting from the road improvements between 2005 and 2015 increased bilateral domestic trade flows between Turkish provinces. Aggregating the data up to the level of province pairs, there are 6,561 pairs (81×81) that can potentially trade with each other as buyers or sellers. In 2006, only 3,704 of these pairs were trading with each other. In 2016, this number increased to 6,379. To account for this sizable extensive margin increase, we let the dependent variable $\Delta Trade_{ij}$

[4] Since the data are not at the establishment level, transactions of multi-establishment firms are accounted for at the headquarter province. The ensuing mismeasurement is most severe in utilities and financial services with numerous bank branches.

[5] It is worth noting that our data cover formal workers only while the aggregate employment statistics presented in Table 1 include both formal and informal workers.

[6] Average speeds are calculated for trucks using a representative sample of road segments on the basis of data from the General Directorate of Highways. While the maps in Figure 1 show both divided expressways and highways as dual carriageways, travel times assume a speed of 90 km/h on expressways and 110 km/h on highways. The speed on single carriageways is assumed to be 65 km/h. For each pair of provincial centers in Figure 1, ArcMap software is used to calculate the shortest possible travel time for both years on the basis of the above assumptions regarding speeds.

between source province i and destination province j to be the mid-point growth defined as

$$\Delta Trade_{ij} \;=\; 2 \cdot \frac{trade_{ij}^{2016} - trade_{ij}^{2006}}{trade_{ij}^{2016} + trade_{ij}^{2006}},$$

which ranges between -2 and 2, and approximates percentage change for pairs trading in both the initial and terminal years. Letting

$$\Delta TravelTime_{ij} \;=\; TravelTime_{ij}^{2015} - TravelTime_{ij}^{2005},$$

we estimate

$$\Delta Trade_{ij} \;=\; \alpha_i + \alpha_j + \beta \cdot \left|\Delta TravelTime_{ij}\right| + \epsilon_{ij}, \tag{1}$$

where source and destination province fixed effects control for province-level characteristics that affect domestic sales and purchases of each province. Since travel times decreased for all pairs between the two periods, the absolute value can be directly interpreted as travel time savings. We thus expect $\beta > 0$. We use two-way clustered standard errors by source and destination provinces. Columns (1) and (3) of Table 2 report the results for manufacturing and the non-agricultural/non-manufacturing sector separately for three samples: full sample (panel A), sample excluding Istanbul as destination (panel B), and sample Istanbul as source province (panel C). For all samples, we find economically and statistically significant results for manufacturing but not the other. The estimate presented in the first column of panel A implies that a one-hour reduction in travel times between two provincial centers increases bilateral trade between those provinces by around 5.3 percent. This effect is highly statistically significant and translates into a USD 2.6 million increase in trade flows in manufacturing over 10 years for a typical pair of cities. Results obtained for the alternative samples are qualitatively and quantitatively very similar.

By using a back-of-the-envelope calculation, we can quantify the effect in monetary terms. Suppose that there is a hypothetical route with length equal to the mean bilateral distance in 2006 (755 km), and it is entirely two-lane undivided. Given the assumptions we make about travel speeds on different types of roads, travel time on this route would be approximately 11.6 hours. To reduce travel time by one hour, about 30 percent of the route (234 km) needs to be transformed into four-lane divided roads, which would cost USD 25.7 million (per annum) based on the investment costs reported by Turkish authorities. Given that the value of domestic trade generated by such investment is USD 2.6 million, the value of domestic trade generated by a one USD investment in roads is USD 0.10.

To further examine the extensive margin effect of reduced travel times on the establishment of new trade links, we estimate a linear probability model in which the dependent variable equals 1 for province pairs with positive trade in 2016 conditional on zero trade in 2006, and 0 otherwise. The result in Column (2) of Table 2 suggests that an average province pair with zero trade in manufacturing in 2006 had a probability of 7 per cent to start trading in 2016, calculated by multiplying the estimated coefficient with 1.85 hours, the average time saving between two provinces at that quintile. The result obtained for services industries is even stronger. The estimated coefficient on $|\Delta TravelTime_{ij}|$ presented in the last column of Table 2 implies that an average province pair with zero trade in services in 2006 had a probability of 18 per cent to start trading in 2016. There exist two channels through which improvements in domestic transport infrastructure affect inter-provincial trade: first, by reducing the cost of transporting goods between the source and destination provinces, and second, by reducing the cost of finding new suppliers/buyers (i.e. establishing new trade relationships). While both channels matter for trade in manufacturing, one would expect the second channel to be more relevant for trade in services. Consider legal and accounting services. Even if work is completed in a firm?s office and transmitted electronically, lower travel times reduce the cost of recruiting new clients or holding initial face-to-face meetings. The message from Table 2 is consistent with this hypothesis. Manufacturing flows are affected by both the intensive and extensive margins, while services flows are only affected at the extensive margin and that effect has a larger magnitude.

Next, we use the industry dimension of the data to control for potential compositional effects. That is, depending on the covariance of industries' input-output linkages with their spatial distribution, the aggregate province-level estimates could be over- or under-stating the true effect. For instance, if industries widely used as intermediate inputs with low elasticity of substitution are located in provinces with good market access to begin with, while more substitutable final goods are produced in initially isolated locations, the differential response between such provinces will be inflated. Columns (1) and (2) of Table 3 present the results for all industries from estimating the same specifications with origin province-industry is and destination province-industry js' fixed effects clustered at origin-destination level. Both the the extensive margin effect in Column (2) and the combined effect in Column (1) remain close to the respective estimates obtained in Table 2. In particular, a one-hour reduction in travel times between two provincial centers increases inter-industry bilateral trade by about 4.9 per cent, implying about USD 9.3 million worth of additional trade flows over 10 years for an average origin-destination pair in the data.[7]

Next, we consider the possibility that provinces benefiting most from improved connectivity may be the ones with the greatest potential for new trade due to low initial levels. To address this concern, we include the initial share of each source province in its destinations, $TradeShare_{ij}^{2006}$, as an additional control in the specification where inter-industry bilateral trade changes is the dependent variable. Columns (3) and (4) of Table 3 confirm the importance of this channel: coefficients of travel time reduction shrink considerably with the difference being picked up by provinces' initial shares. The effect of road improvements, however, still remain statistically significant in this most demanding specification.

In Table 4, we present results from estimating the most demanding specifications in Table 3 for manufacturing and services industries separately. The coefficient on travel time savings for changes in inter-industry bilateral trade flows is estimated to be statistically significant for both sectors. The result for services highlights the importance of accounting for industry composition across provinces since the aggregate province-level estimate obtained for services is not statistically significant in Table 2. Controlling for industry composition of trade also matters for the extensive margin effect of reduced travel times as the estimates presented in Table 4 are smaller in size than the respective estimates presented in Table 2.

4.2 Robustness checks

We conclude this section by subjecting the baseline results to two robustness checks. These involve splitting the sample into sub-periods and estimating a placebo test.

Replicating the baseline specification for inter-industry bilateral trade estimated from decadal changes —presented in Column (3) of Table 3—first column of Table 5 presents the results for the 2006-2011 sub-period. Similarly, the main variable of interest, $|\Delta TravelTime_{ij}|$, measures travel time savings between 2005 and 2010. The results confirm that the effect is positive and highly significant in the first sub-period. The coefficient estimate is actually higher than the baseline presented in Column (3) of Table 3 from the entire sample period. This implies that most of the increase in bilateral trade took place in the first sub-period. In other words, initial road improvements starting from a low level can have a greater impact on inter-provincial trade than subsequent investments, consistent with diminishing returns to infrastructure investment.

[7] This estimate assumes positive trade in 14 2-digit NACE industries for an average source-destination pair, which is the average number of active industries for a given province in 2006. As it is estimated that a one-hour reduction in travel times creates USD 47,600 worth of additional trade flows over 10 years for an average industry pair between two provinces, the value of aggregate trade over all industries becomes approximately USD 9.3 million for an average source-destination province.

Column (2) reports the results from a placebo test which regresses changes in trade flows in the 2006-2011 period on travel time reductions in both the preceding 2005-2010 and the succeeding 2010-2015 periods. The main variable of interest, reduction in travel times in the preceding period, remains positive and highly significant while further improvements in the succeeding period are statistically insignificant, which strengthens the validity of our identification.

Finally, Figure 4 presents the distribution of the estimate of β in equation (1) on 500 random drawn samples of size 2,000. Both the mean and median of the distribution is almost identical to our baseline estimate. This robustness check alleviates potential concerns about dominance of certain provinces or province pairs, as well as selection of the location of road upgrades by the authorities.

5 Road Capacity and Regional Outcomes

Beyond its impact on trade, did the reduction in domestic travel times affect other key regional economic outcomes such as industry employment and productivity? To address this question, we construct a variable capturing improved domestic market access at the provincial level. In particular, weighting each province's time savings on the basis of destination provinces' population for 2005,

$$\left|\Delta\overline{TravelTime_i}\right| \;=\; \sum_{j=1}^{81}\left(\frac{population_j}{\Sigma_{k=1}^{81} population_k}\right)\cdot \Delta TravelTime_{ij},$$

calculates the average connectivity improvement experienced by a province when selling goods to other provinces. We will report the results from estimating various specifications of

$$\Delta \ln(Outcome_{is}) \;=\; \alpha_s + \beta \cdot \left|\Delta\overline{TravelTime_i}\right| + \epsilon_{is},$$

where $Outcome_{is}$ is origin province-industry sales (Y_{is}), employment (L_{is}) or labor productivity (Y_{is}/L_{is}) depending on specification. Aggregate industry-wide effects are controlled by α_s and standard errors are clustered at the province level.

The outcome of interest in the upper panel of Table 6 is total industry sales, further disaggregated into domestic and export sales in the middle and lower panels. In the first column, the coefficient on $\overline{TravelTime_i}$ is estimated to be positive and statistically significant, implying that improvements in domestic market access had a positive effect on industry-level sales. We subject this result to two robustness checks. In Column (2), we add initial population share of provinces (as of 2005) as an additional control to address the potential concern that larger provinces in terms of population attracted more investment. The coefficient of interest remains positive and highly significant. In Column (3), we also add the initial per capita GDP to control for the possibility that initially lagging regions posted greater sales growth, or they also attracted other public investment during the period under consideration. The coefficient estimate becomes significantly smaller in size and becomes statistical significant only at the 15 percent level. The middle panel presents the results for domestic sales. In Column (3), which presents the results from estimating the most demanding specification, the coefficient of interest remains statistically significant at the 10 per cent level. Consistent with the results in Coşar and Demir (2016), we find a positive impact on export sales (lower panel).

Upper panel of Table 7 confirms that the effect of improvements in domestic market access on sales were large enough to show an impact on employment, as opposed to increasing production and sales through increased capacity utilization alone. The estimated coefficient on $|\Delta \overline{TravelTime_i}|$ presented in Column (3) implies that a one-hour reduction in travel time increases average industry-level employment by 15.7 per cent. Given that about two-thirds of provinces experienced time-savings of an hour or more, the effect on regional job opportunities is non-negligible. At a population-weighted average time savings of 90 minutes, the mean of the $|\Delta \overline{TravelTime_i}|$ variable, the effect equals a 23.6 percent increase in industry-level employment.

In the lower panel of Table 7, we let the outcome of interest be the province-industry level labor productivity, Y_{is}/L_{is}. While the coefficient has the expected positive sign in the first two columns, improved market access does not seem to be associated with productivity gains at conventional levels of statistical significance. The coefficient of interest reverses its sign in Column (3) but remains statistically insignificant.

While our results so far suggest substantial regional effects, one cannot aggregate estimated local impacts due to treatment spillover effects between provinces. Moreover, counterfactual statements about real income necessitate the construction of a theory-based price index and incorporation of labor reallocation in the long-run. To do so, next section presents and calibrates a workhorse spatial equilibrium model. This allows us to quantify the short-run regional and long-run aggregate welfare effects from the expansion and upgrading of expressways in Turkey.

6 Quantifying the Welfare Effects

6.1 Model

The model follows (Allen and Arkolakis, 2014) closely. Each province produces a differentiated Armington variety linearly and competitively with L_i workers and productivity A_i. An exogenous aggregate labor supply $\overline{L}$, normalized to unity, is freely mobile between 81 provinces of the country.

Productivity of a province has an exogenous component $\overline{A}_i$, augmented by its labor force: $A_i = \overline{A}_i L_i^{\alpha}$. Production displays external increasing returns to scale due to agglomeration forces if $\alpha > 0$. Similarly, each province has an exogenous amenity level $\overline{u}_i$, augmented by its labor force: $u_i = \overline{u}_i L_i^{\beta}$. Amenities display decreasing returns to scale due to congestion forces if $\beta < 0$. We note that the (α, β) used in the model notation is completely unrelated to the reduced form coefficients used in previous sections.

The cost of trade between two provinces k, i is of iceberg type: $\tau_{ij} = \tau_{ji} > 1$ if $i \neq j$, and $\tau_{ii} = 1$. That is, province-i variety with an origin price p_i costs $\tau_{ij} p_i$ in province j. CES demand with elasticity $\sigma > 1$ implies trade flows from i to j equal to

$$X_{ij} = \left(\frac{\tau_{ij} p_i}{P_j} \right)^{1-\sigma} w_j L_j, \tag{2}$$

where w_j is the equilibrium nominal wage prevailing in province j, and P_j is the price index given by

$$P_j^{1-\sigma} = \sum_{i=1}^{81} \tau_{ij}^{1-\sigma} p_i^{\sigma-1}. \tag{3}$$

Since production is linear and competitive in each province, prices are $p_i = w_i / A_i$ at the origin. Utility of a worker living in province i is given by

$$W_i = \frac{w_i}{P_i} u_i.$$

Spatial long-run equilibrium holds when wages and labor allocations $\{w_i, L_i\}_{i=1}^{81}$ are such that

- welfare is equalized across provinces: $W_i = W$ for all i,
- aggregate labor demand equals aggregate labor supply: $\sum_i L_i = 1$,
- provinces' expenditures equal their total sales: $w_i L_i = \sum_j X_{ij}$.

Allen and Arkolakis (2014) characterize the conditions on (α, β, σ) that ensure the existence of an equilibrium. In particular, regardless of the magnitude of σ, a unique and stable equilibrium exists if $\alpha + \beta \leq 0$. Under this assumption on parameter values, which we maintain, there is a one-to-one relationships between the set of exogenous productivities and amenities, $\{\overline{A}_i, \overline{u}_i\}$, and the set of endogenous wage and population levels $\{w_i, L_i\}$. Thus, given the empirical levels of $\{w_i, L_i\}$ and the function of trade costs between provinces $\tau_{ki}^{1-\sigma}$, the following system of equations can be solved to back out composite amenities $u_i^{1-\sigma}$ and productivities $A_i^{1-\sigma}$ up to a scale W:

$$u_i^{1-\sigma} = W^{1-\sigma} \sum_{j=1}^{81} \tau_{ji}^{1-\sigma} w_i^{\sigma-1} w_j^{1-\sigma} \cdot A_j^{\sigma-1}, \tag{4}$$

and

$$A_i^{1-\sigma} = W^{1-\sigma} \sum_{j=1}^{81} \tau_{ji}^{1-\sigma} L_i^{-1} w_i^{-\sigma} L_j w_j^{\sigma} \cdot u_j^{\sigma-1}. \tag{5}$$

With values of $\{A_i^{1-\sigma}, u_i^{1-\sigma}\}$ at hand, exogenous components $\{\overline{A}_i, \overline{u}_i\}$ can be backed out for given values of (α, β, σ).

Given the calibrated exogenous productivities and amenities, the following set of 81 equations implied by spatial utility equalization, together with the national labor market clearance condition, help to solve for the level of welfare W and labor allocations $\{L_i\}$:

$$L_i^{\tilde{\sigma}\gamma_1} = W^{(1-\sigma)} \overline{u}_i^{(1-\tilde{\sigma})(\sigma-1)} \overline{A}_i^{\tilde{\sigma}(\sigma-1)} \sum_j \tau_{ji}^{(1-\sigma)} \overline{A}_j^{(1-\tilde{\sigma})(\sigma-1)} \overline{u}_j^{\tilde{\sigma}(\sigma-1)} L_j^{\tilde{\sigma}\gamma_2}. \tag{6}$$

Here, $(\tilde{\sigma}, \gamma_1, \gamma_2)$ are functions of the parameters (σ, α, β).[8] We refer the reader to Allen and Arkolakis (2014) for the proofs and the description of the solution algorithm.

To quantify the welfare impact of the road program, we need a measure of trade costs τ_{ki} before and after the upgrades, as well as values for the parameters $\{\alpha, \beta, \sigma\}$. In what follows, we first estimate trade costs as a function of travel times in 2005. We then use these trade cost estimates together with the empirical level of wages and urban populations in the same year to back out composite amenities and productivities $\{A_i^{1-\sigma}, u_i^{1-\sigma}\}$. We then tease out exogenous amenity and productivity components $\{\overline{A}_i, \overline{u}_i\}$ at various values for the parameters $\{\alpha, \beta, \sigma\}$. To attain our main objective—evaluating the welfare effect of the transport infrastructure investment—we fix these exogenous components at their calibrated values and solve the model using the reduced travel times in the upgraded 2015 network. This gives us an estimate of the long-run increase in aggregate welfare W, and a prediction

[8] In particular, $\gamma_1 = 1 - \alpha(\sigma - 1) - \beta\sigma$, $\gamma_2 = 1 + \alpha\sigma + (\sigma - 1)\beta$ and $\tilde{\sigma} = (\sigma - 1)/(2\sigma - 1)$.

on the associated population shifts across provinces. We now explain each step in detail.

6.2 Trade costs

Taking the logarithm of equation (2), trade flows between provinces are given by the gravity equation

$$\ln(trade_{ij}) \;=\; \mu_i + \mu_j + (1-\sigma)\ln(\tau_{ij}), \tag{7}$$

where μ's are origin and destination fixed effects. We specify trade costs as a function of travel times, $\tau_{ij} = TravelTime_{ij}^{\theta}$, and estimate the following equation for $i \neq j$:[9]

$$\ln(trade_{ij}) \;=\; \mu_i + \mu_j + \underbrace{(1-\sigma)\theta}_{\delta} \cdot \ln(TravelTime_{ij}) + \epsilon_{ij}. \tag{8}$$

As standard in the literature, this estimation cannot separately identify the elasticity of trade to trade costs $(\sigma - 1)$ from the elasticity of trade costs to travel times θ. The results in Table 8 therefore report $\hat{\delta} = (1-\sigma)\theta$. The estimate in Column (1) using 2006 trade flows and 2005 travel times before the upgrades equals -1.461, a number consistent with the gravity literature. In Column (2), we use the 2015 trade flows and travel times in the upgraded road network for the set of provinces that had positive trade in 2006. This sample yields a close but slightly higher estimate. We continue with the conservative $\hat{\delta}$ value from Column (1).[10]

6.3 Solving for amenities and productivities

Given trade costs, and the empirical levels of provincial wages and populations, we solve the system of 162 equations captured by equations (4)-(5) for the 162 unknowns $\{A_i^{1-\sigma}, u_i^{1-\sigma}\}$, normalizing the baseline welfare to $W = 1$. In order to purge out the exogenous components $\overline{A}_i = A_i/L_i^{\alpha}$ and $\overline{u}_i = u_i/L_i^{\beta}$, we need values for (α, β, σ).

To calibrate β, the parameter capturing congestion forces, we use the isomorphism of the model to one that features residential land/housing in consumption (Allen and Arkolakis, 2014). In that version of the model, the price of the immobile fixed factor (land) is increasing in population, thereby decreasing the utility of residents. The isomorphism holds if land has a Cobb-Douglas expenditure share of $-\beta/(1-\beta)$. According to the Household Budget

[9] The calculation of travel times has been described in Section 3, and the levels before and after the road upgrades plotted in Figure 3. In order to make the travel time units irrelevant, we take the lowest level of τ_{ki} for $k \neq i$ in the combined 2005 and 2015 data, and normalize all other τ_{ki}'s by that level. We set $\tau_{ii} = 1$.

[10] Note that in the model described above, trade costs only appear as $\tau^{1-\sigma}$, which equals $TravelTime_{ij}^{(1-\sigma)\theta}$. This implies that to get a measure of trade costs, we can simply use the estimated gravity coefficient $TravelTime_{ij}^{\hat{\delta}}$ without the need to make an assumption on the value of σ.

Survey of the Turkish Statistical Institute, housing has a stable expenditure share around 25 percent across the relevant data period.[11] We set $\beta = -1/3$ to match that value. This is very close to the value of $\beta = -0.3$ in Allen and Arkolakis (2014) who use the US housing expenditure share as the calibration target.

We consider a range of values for α satisfying the constraint $\alpha \in [0, -\beta]$ to ensure existence and uniqueness of equilibrium. In particular, we report results for when there are no agglomeration economies ($\alpha = 0$), when agglomeration economies are as strong as permissible ($\alpha = -\beta = 1/3$), and for the intermediate value $\alpha = 1/6 \approx 0.167$. The estimates of this parameter in the literature range between 0.04 and 0.1 (Rosenthal and Strange, 2004). Finally, we take a baseline value of $\sigma = 5$ to attain a trade elasticity of $\sigma - 1 = 4$ (Simonovska and Waugh, 2014), and report results for upper and lower bounds of $\sigma = 3$ and $\sigma = 7$.

In Figure 5, we plot the exogenous amenities ($\overline{A}$) and productivities ($\overline{u}$) of provinces against the data from which they were backed out: population shares and wages (normalized around the average) in 2006. Evidently, amenities are the main driver of city sizes while productivities correlate with nominal wages.

6.4 Results

When labor is immobile, road upgrades generate spatial inequality between provinces through changes in market access. To solve for the short-run equilibrium, we keep the population vector $\{L_i\}$ in its 2005 level, change trade costs τ to its 2015 level, and find market clearing wages w_i for each province. We then calculate provincial price indices P_i as defined by equation (3) using the lower trade costs. Since labor is fixed, amenities enjoyed by residents do not change. The only variation in welfare comes from the real wage component of utility, that is, from the response of w_i/P_i to the change in trade costs.

Note that in principle, some provinces can incur welfare losses through trade diversion in the short run. For the parameter values we consider, that is not the case, i.e., all locations experience a real wage increase. There is, however, a substantial increase in inter-provincial inequality: for the baseline value of $\sigma = 5$, the largest and smallest welfare gains are 10.3 percent and 0.8 percent, respectively.[12] Weighted by population, aggregate welfare increase is 2.84 percent.

To demonstrate the mechanism through which real incomes are affected with immobile labor, we calculate for each province a reduced-form measure of change in market access:

[11] http://www.tuik.gov.tr/MicroVeri/HBA_TH_14-15-16/english/index.html

[12] Short-run welfare responses are invariant to (α, β) values.

$$\Delta MarketAccess_i = \frac{\sum_{j=1}^{81}(w_j^{2015}L_j)/\tau_{ij}^{2015}}{\sum_{j=1}^{81}(w_j^{2005}L_j)/\tau_{ij}^{2005}}.$$

The scatter plot of percentage real wage changes against this measure in Figure 6 visualizes the variation in welfare in response to the heterogenous shift in market access across provinces. The correlation between the two variables is 0.51. The maps in Figure 7 display the spatial distribution of this relationship, confirming that provinces with larger improvements in market access tend to experience higher welfare gains in the short run.

The long run effect on aggregate welfare is calculated by jointly solving the system in equation (6) with the national labor market constraint $\sum_i L_i = 1$. In Table 9, we present the percentage welfare increase resulting from the travel time reductions for various parameter combinations. The response is larger when the differentiated varieties produced by provinces are less substitutable. This is expected, since a lower elasticity of substitution in demand increases the welfare impact of trade costs. Stronger agglomeration economies imply larger welfare gains, although the variation within the permissible range of α values is limited. Depending on the parameter combinations, welfare gains vary between 1.89 percent and 6.25 percent. For the baseline value of $\sigma = 5$, the gains range between 2.86 percent and 3.08 percent. The long-run gains are only slightly higher than the population weighted aggregate welfare gain in the short run, which implies that market access rather than the reallocation of labor is the primary driver of the overall welfare impact.

7 Conclusion

Developing countries need large investments in transport infrastructure (EBRD, 2017). Yet, evidence on the rates of return for various types of road projects—paving dirt roads, expanding the capacity of existing paved roads, constructing highways—is still scant. We make a contribution to filling this gap by providing an empirical analysis of the lane-capacity expansion to Turkey's national road network during the past decade and a half. Our results suggest that travel time reductions due to the ambitious public investment program undertaken by Turkey boosted its intra-national trade and yielded a sizable return on investment. In particular, a one-hour reduction in travel times between two provincial centers increases bilateral trade by about 4.9 percent. To gauge the long-run welfare impact, we quantify a workhorse spatial equilibrium model with labor mobility and find an aggregate real income gain of 2.9 percent. With a cost around 1.7 percent of GDP per year, an annual welfare increase of 2.9 percent implies a rate of return equal to $(2.9 - 1.7)/1.7 = 70$ percent.

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Tables and Figures

Table 1: **Summary Statistics**

	2006	2016
Trade value	4.6	5.2
	(150.7)	(284.3)
Employment	1,385.4	2,247.4
	(8,787.2)	(14,824.0)
Domestic sales	161.4	525.7
	(2,350)	(7,785.7)
Time savings (hours)		1.4
		0.9
Total non-agriculture employment (million)	15,516	21,900
Nominal GDP	46,011	115,218

Notes: Table shows the mean and standard error (in parentheses) of the main outcome variables at the industry-province level (industry-province pair level for trade values) used in the regressions. All monetary values are in million USD, calculated using the average within-year TL/USD exchange rate in 2006 (1USD=1.4TL). Aggregate statistics (last two rows) are obtained from Turkish Statistics Institute.

Table 2: **Changes in Travel Times and Inter-provincial Trade by Sector**

	(1)	(2)	(3)	(4)
	Manufacturing		Non-agri./non-manuf.	
	Panel A: All provinces			
	$\Delta Trade_{ij}$	$NewTrade_{ij}$	$\Delta Trade_{ij}$	$NewTrade_{ij}$
$\lvert\Delta TravelTime_{ij}\rvert$	0.0527*	0.0367**	0.0009	0.0957***
	(0.030)	(0.014)	(0.021)	(0.015)
N	3,995	4,977	4,725	4,977
R^2	0.218	0.187	0.133	0.294
	Panel B: Excluding Istanbul as destination			
	$\Delta Trade_{ij}$	$NewTrade_{ij}$	$\Delta Trade_{ij}$	$NewTrade_{ij}$
$\lvert\Delta TravelTime_{ij}\rvert$	0.0542*	0.0361**	0.0005	0.0978***
	(0.031)	(0.015)	(0.022)	(0.015)
N	3,914	4,896	4,644	4,896
R^2	0.215	0.186	0.133	0.293
	Panel C: Excluding Istanbul as source			
	$\Delta Trade_{ij}$	$NewTrade_{ij}$	$\Delta Trade_{ij}$	$NewTrade_{ij}$
$\lvert\Delta TravelTime_{ij}\rvert$	0.0527*	0.0368**	0.00105	0.0961***
	(0.030)	(0.014)	(0.021)	(0.015)
N	3,962	4,944	4,692	4,944
R^2	0.217	0.185	0.130	0.292
Origin FE	Y	Y	Y	Y
Destination FE	Y	Y	Y	Y

Notes: Robust standard errors clustered at the source and destination provinces (two-way) are in parentheses. Non-agri./non-manuf. includes wholesale, retail trade and services other than finance and utilities. Significance: *10%, **5%, ***1%.

Table 3: **Changes in Travel Times and Inter-provincial Industry-level Trade**

	(1)	(2)	(3)	(4)
	$\Delta Trade_{is,js'}$	$NewTrade_{is,js'}$	$\Delta Trade_{is,js'}$	$NewTrade_{is,js'}$
$\lvert\Delta TravelTime_{ij}\rvert$	0.0493***	0.0512***	0.0338***	0.0292***
	(0.005)	(0.007)	(0.004)	(0.003)
$TradeShare_{ij}^{2006}$			-0.307***	-0.464***
			(0.049)	(0.065)
N	436093	529897	436093	529897
R^2	0.168	0.146	0.169	0.150
Origin-Ind. FE	Y	Y	Y	Y
Dest.-Ind. FE	Y	Y	Y	Y

Notes: Robust standard errors clustered at the source-destination pairs are in parentheses. Significance: *10%, **5%, ***1%.

Table 4: **Changes in Travel Times and Inter-provincial Industry-level Trade by Sector**

	(1)	(2)	(3)	(4)
	Manufacturing		Non-agri./non-manuf.	
	$\Delta Trade_{is,js'}$	$NewTrade_{is,js'}$	$\Delta Trade_{is,js'}$	$NewTrade_{is,js'}$
$\lvert \Delta TravelTime_{ij} \rvert$	0.0272***	0.0213***	0.0374***	0.0336***
	(0.006)	(0.004)	(0.005)	(0.003)
$TradeShare_{ij}^{2006}$	-0.211***	-0.274***	-0.361***	-0.532***
	(0.041)	(0.044)	(0.035)	(0.061)
N	173884	213819	262209	316078
R^2	0.189	0.167	0.162	0.156
Origin-Ind. FE	Y	Y	Y	Y
Dest.-Ind. FE	Y	Y	Y	Y

Notes: Robust standard errors clustered at the source-destination pairs are in parentheses. Non-agri./non-manuf. includes wholesale, retail trade and services other than finance and utilities. Significance: *10%, **5%, ***1%.

Table 5: **Robustness Checks**

	(1)	(2)
	$\Delta Trade_{is,js'}^{2006-2011}$	$\Delta Trade_{is,js'}^{2006-2011}$
$\lvert \Delta TravelTime_{ij}^{2005-2010} \rvert$	0.0357***	0.0350***
	(0.005)	(0.006)
$TradeShare_{ij}^{2006}$	-0.459***	-0.458****
	(0.051)	(0.051)
$\lvert \Delta TravelTime_{ij}^{2010-2015} \rvert$		0.00879
		(0.031)
N	354289	354289
R^2	0.151	0.151
Origin-Ind. FE	Y	Y
Dest.-Ind. FE	Y	Y

Notes: Robust standard errors clustered at the source-destination pairs are in parentheses. Significance: *10%, **5%, ***1%.

Table 6: **Impact of Travel Times on Regional Sales**

	(1)	(2)	(3)
Panel A:		$\Delta\ln(Y_{is})$	
$\left\|\Delta\overline{TravelTime_i}\right\|$	0.239***	0.221***	0.114+
	(0.048)	(0.049)	(0.076)
$PopShare_i^{2005}$		-2.994***	-1.624
		(0.912)	(1.127)
$\ln GDPpc_i^{2005}$			-0.303*
			(0.170)
N	4174	4174	4174
R^2	0.168	0.170	0.171
Panel B:		$\Delta\ln(Y_{is}^{dom})$	
$\left\|\Delta\overline{TravelTime_i}\right\|$	0.234***	0.216***	0.118*
	(0.044)	(0.045)	(0.069)
$PopShare_i^{2005}$		-2.771***	-1.508+
		(0.827)	(0.975)
$\ln GDPpc_i^{2005}$			-0.279*
			(0.150)
N	4139	4139	4139
R^2	0.171	0.173	0.174
Panel C:		$\Delta\ln(Y_{is}^{exp})$	
$\left\|\Delta\overline{TravelTime_i}\right\|$	0.227**	0.235*	0.407**
	(0.114)	(0.119)	(0.201)
$PopShare_i^{2005}$		0.736	-0.901
		(1.296)	(1.974)
$\ln GDPpc_i^{2005}$			0.446
			(0.420)
N	1574	1574	1574
R^2	0.107	0.107	0.108
Industry FE	Y	Y	Y

Notes: Robust standard errors clustered at the province level are in parentheses. Significance: +15%, *10%, **5%, ***1%. Dependent variables in Panel A, B and C are the logarithms of total sales of province p's industry i, its domestic sales and export sales, respectively.

Table 7: **Impact of Travel Times on Regional Employment and Labor Productivity**

	(1)	(2)	(3)
Panel A:		$\Delta \ln(L_{is})$	
$\left\lvert \Delta \overline{TravelTime_i} \right\rvert$	0.203***	0.202***	0.157***
	(0.032)	(0.033)	(0.047)
$PopShare_i^{2005}$		-0.125	0.452
		(0.412)	(0.732)
$\ln GDPpc_i^{2005}$			-0.128
			(0.122)
N	4139	4139	4139
R^2	0.215	0.215	0.216
Panel B:		$\Delta \ln \left(\frac{Y_{is}}{L_{is}}\right)$	
$\left\lvert \Delta \overline{TravelTime_i} \right\rvert$	0.0411	0.0232	-0.0236
	(0.052)	(0.053)	(0.073)
$PopShare_i^{2005}$		-2.843***	-2.246**
		(0.826)	(0.875)
$\ln GDPpc_i^{2005}$			-0.133
			(0.121)
N	4047	4047	4047
R^2	0.0994	0.102	0.103
Industry FE	Y	Y	Y

Notes: Robust standard errors clustered at the province level are in parentheses. Significance: *10%, **5%, ***1%.

Table 8: **Estimation of Trade Costs**

	(1)	(2)
	$\ln(Trade_{ij})$	
$\ln(TravelTime_{ij})$	-1.461***	-1.537***
	(0.026)	(0.025)
Observations	3704	3704
Year	2006	2015
R^2	0.781	0.816

Notes: $TravelTime_{ij}$ is travel times divided by the minimum travel time in the data. Within-province travel times are set to $TravelTime_{ii} = 1$. See section 6.2 for details. Robust standard errors are in parentheses. Significance: *10%, **5%, ***1%.

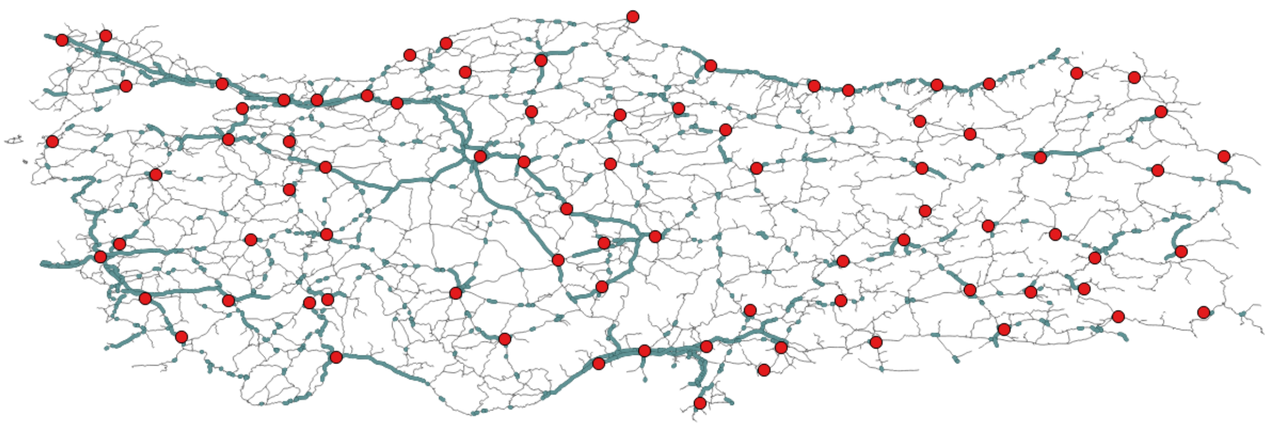
Table 9: **Long-run Aggregate Welfare Effects**

		σ		
		3	5	7
α	0	5.86%	2.86%	1.89%
	1/6	5.92%	2.89%	1.9%
	1/3	6.25%	3.08%	2.04%

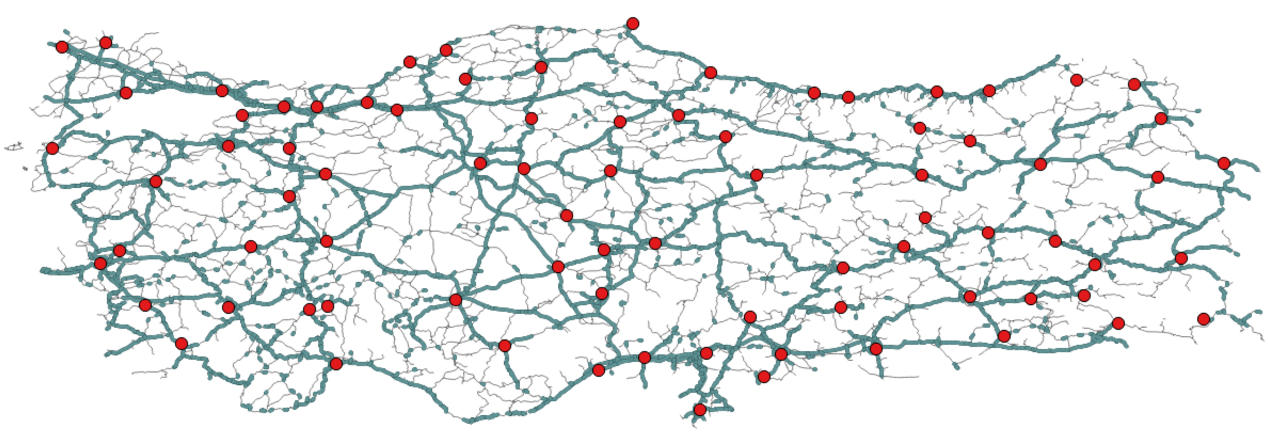
Notes: This table reports the aggregate percentage welfare gains for combinations of values for the elasticity of substitution σ and strength of agglomeration economies α.

Figure 1: **Turkish Provinces and Roads**

Panel A: Road Network in 2005

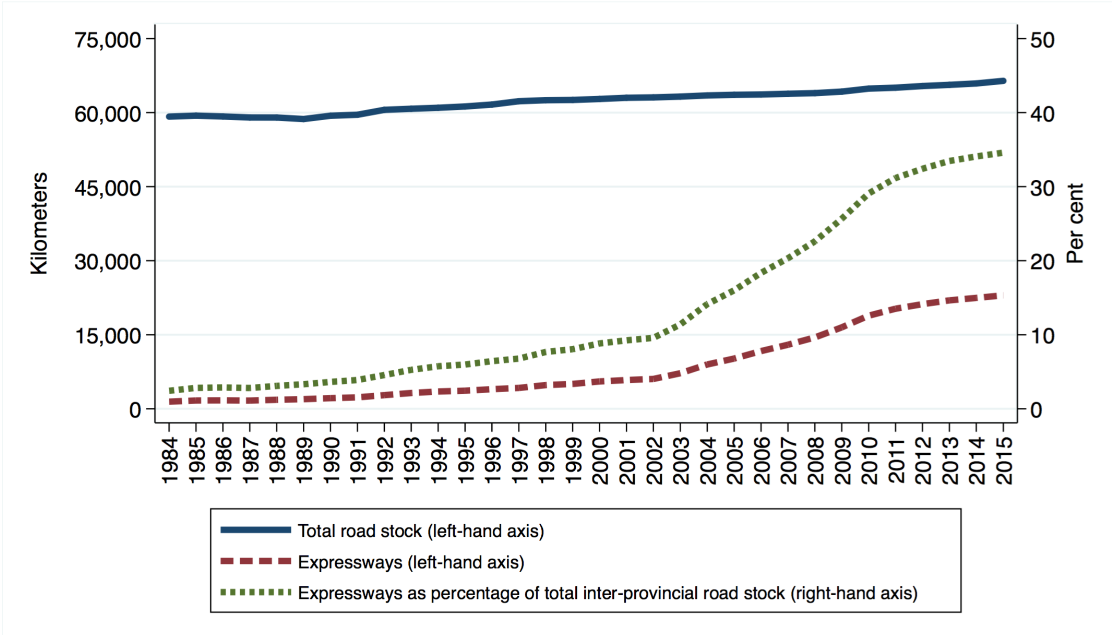


Panel B: Road Network in 2015



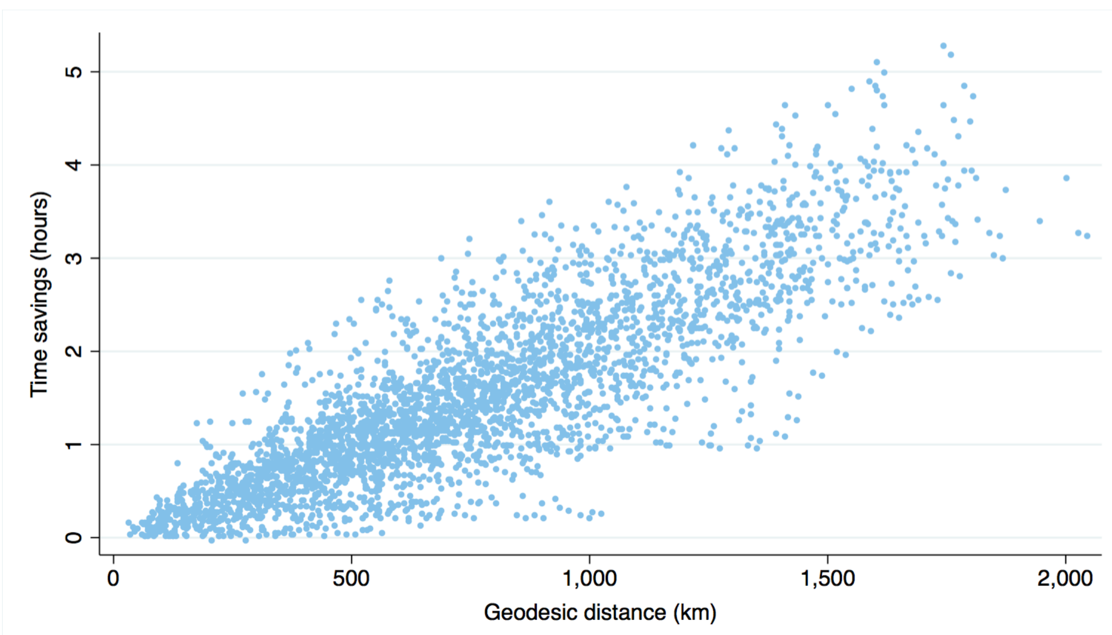
Notes: Data source is Turkish General Directorate of Highways. Red nodes denote provincial centers, thin grey lines represent single-carriageway roads, and thick green lines represent dual-carriageway roads (highways and expressways).

Figure 2: **Turkish Roads over Time**



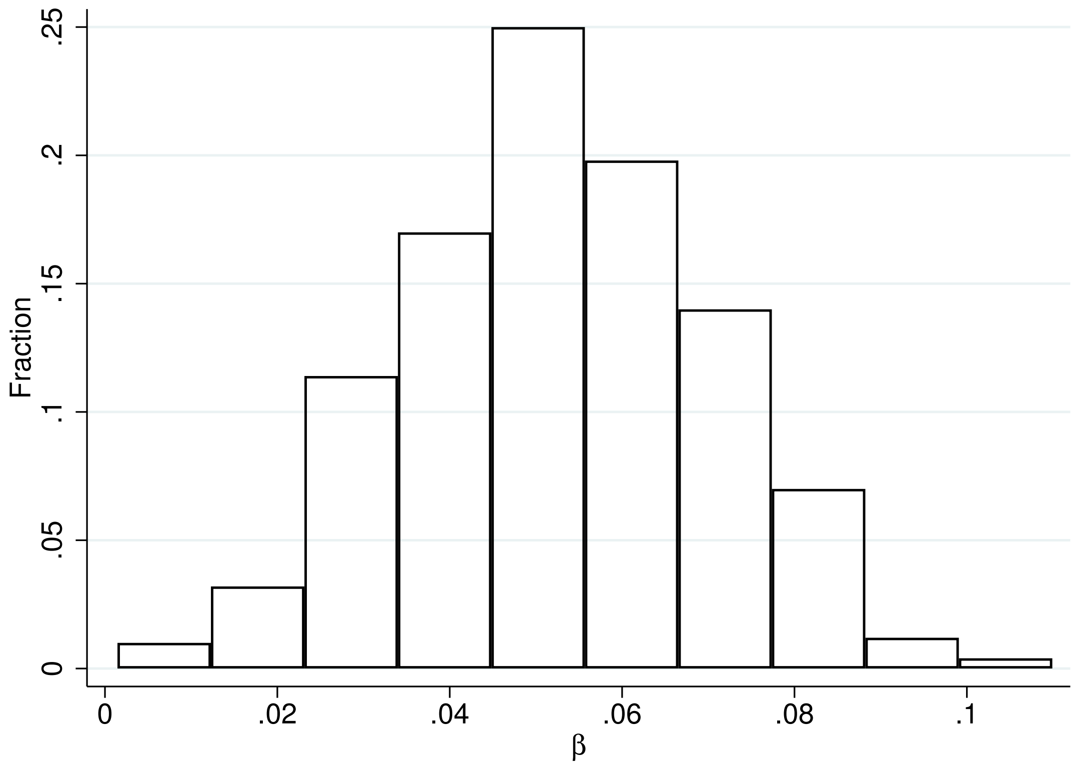
Notes: Data source is Turkish Statistical Institute and General Directorate of Highways. Data downloaded from http://bit.ly/2E3Qh4m, accessed on January 2018.

Figure 3: **Time Savings on Inter-Provincial Travel from 2005 to 2015**



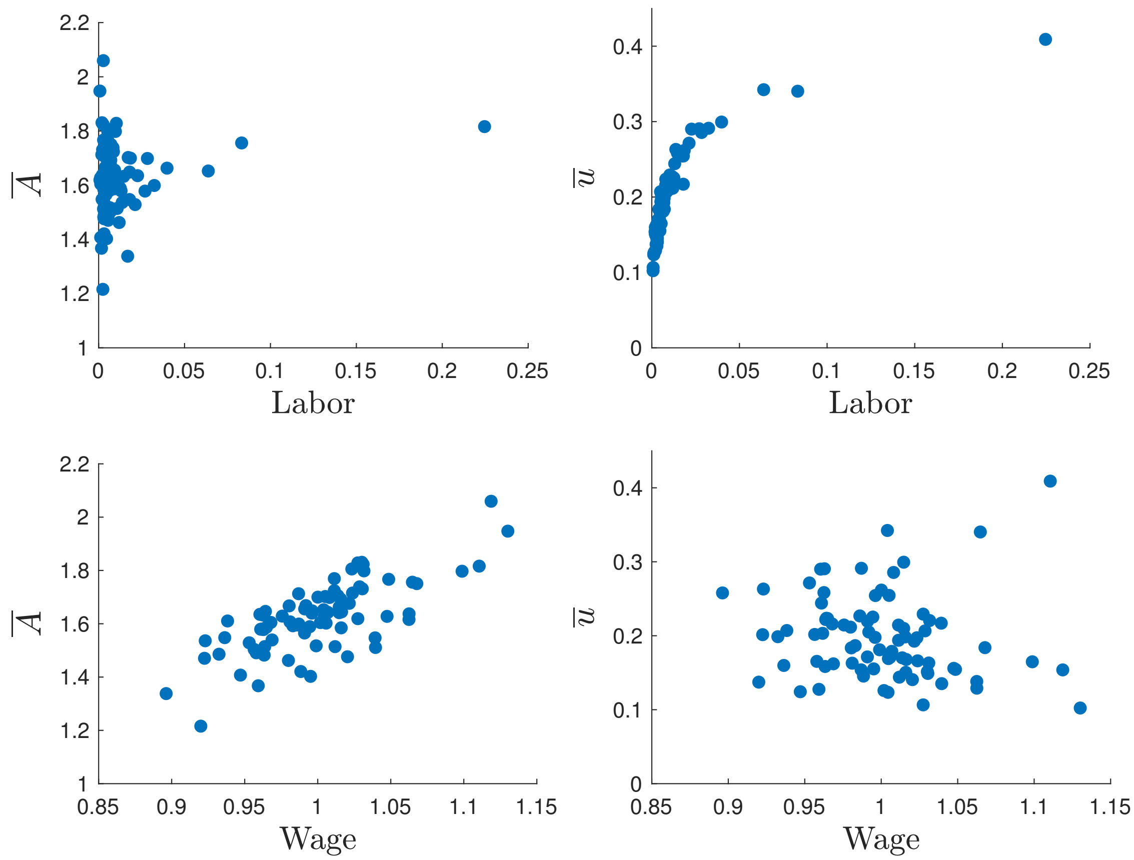
Notes: This chart plots declines in the fastest province-to-province travel times from 2005 to 2015 against the time-invariant distances as the crow flies. Each observation represents a pair of provinces. With 81 provinces, there are $(81 \times 80)/2 = 3,240$ unique pairs.

Figure 4: **Distribution of** β



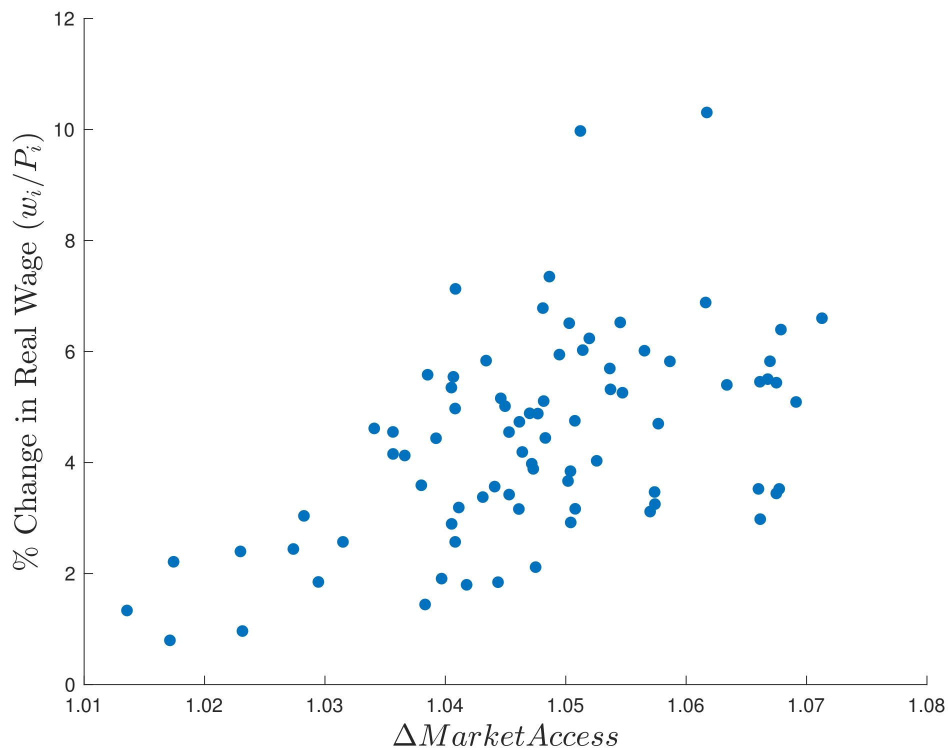
Notes: This figure plots the distribution of the estimate of β in equation (1), obtained from estimating the equation on 500 randomly drawn samples of province pairs of size 2000.

Figure 5: **Calibrated Exogenous Characteristics of Provinces**



Notes: Each observation is a province. Labor and wages are provinces' employment shares and normalized wages in 2006. $\overline{A}$ and $\overline{u}$ are the exogenous productivities and amenities, respectively. For their calibration, see Section 6.3.

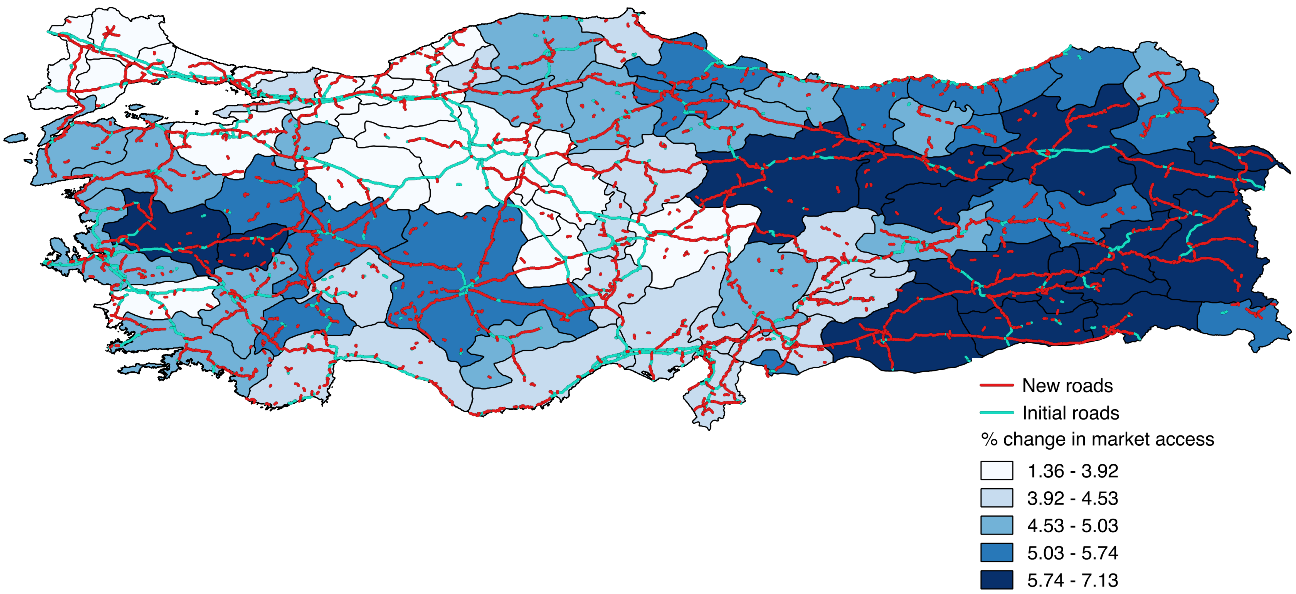
Figure 6: **Short-run Changes in Market Access and Real Wage**



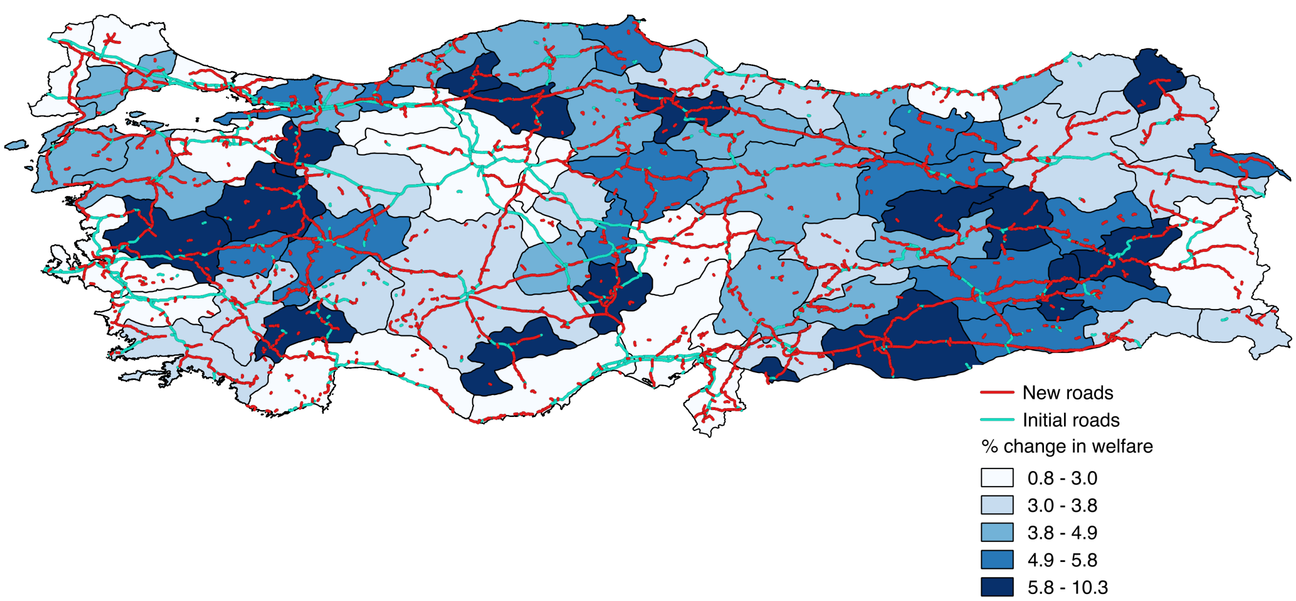
Notes: Each observation is a province. The y-axis is the percentage change in real wage (w/p) when labor is immobile in the short-run. The x-axis is a measure of market access change defined in Section 6.4.

Figure 7: **Short-run Changes in Market Access and Real Wage**

Panel A: Change in Market Access



Panel B: Change in Welfare



Notes: In both panels, initial roads in light green represent roads that were dual carriageways in 2005 (corresponding to the green roads in Panel A of Figure 1), and new roads in red represent the additions to the dual carriageway network in 2015. Short-run welfare results are changes in real wage w/P assuming labor is immobile.