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Abstract

Using administrative data covering the economic geography of Turkish manufacturing firms I show that density increases a location's productivity through both typical firm productivity and stronger association of firm size and productivity—a measure of within-sector allocative efficiency. IV estimates suggest a density elasticity of allocative efficiency that accounts for about one third of the overall impact of density on productivity. A model with decreasing returns to scale and convex cost of avoidance from the burden of regulations can explain the estimated density-allocative efficiency relationship on the grounds that denser locations provide lower degree of internal diseconomies.

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Non-technical Summary

This paper provides novel evidence on the impact of population density through more efficient allocation of resources. Consider two regions where the productive distribution across the firms are identical, but in one region more productive firms tend to be larger compared to the other. The region with a greater size-productivity association has a higher typical productivity experienced per worker. This paper argues that denser locations are more productive because more productive firms command a greater share of resources.

I motivate the existence of an urban allocative efficiency premium with a span-of-control model. A manager chooses both the scale of operation and how much effort to exert to avoid the burden of regulation. The model suggests that the strength of size-productivity relationship depends on a simple metric of internal diseconomies of the firm. In particular, higher returns to scale and lower convexity of effort cost enables more productive firms to become relatively bigger. If diseconomies are less severe in denser locations we can expect to estimate a positive density elasticity of allocative efficiency. To test this, I turn to the data and estimate the density elasticity of the sectoral sources of productivity.

Using firm-level administrative data on Turkish manufacturing firms from 2010 to 2017 I estimate the impact of density on the allocative efficiency. I address potential concerns related to the endogeneity of density and measures of productivity through instrumental variables that impose exogenous variation in current density and not related to the current productivity level other than its impact on density. I also address the potential impact of industry mix in a region's productivity by estimating measures of labor productivity and total factor productivity in a fixed-effects setting.

Results suggest that within-sector allocative efficiency is a substantial channel of the observed productivity impact of agglomeration. I estimate a density elasticity of allocative efficiency that is about one third of density's overall impact on productivity.

1 Introduction

Returns to economic activity are higher in cities. Moreover, the literature on agglomeration provides extensive empirical evidence that higher density leads to greater productivity levels arguably due to higher returns to scale (e.g., Ciccone and Hall, 1996; Ciccone, 2002). Most of the existing theoretical and empirical studies focus on how density boosts the typical productivity of a firm or workers through sharing, matching, or learning (Duranton and Puga, 2004).

Despite the large and developing interest on the economics of density, relatively little is known about how it may affect productivity through the efficiency of resource allocation across firms. This is surprising given the burgeoning literature on misallocation, which documents the substantial role of resource allocation in explaining productivity differences across countries especially following the seminal works of Restuccia and Rogerson (2008) and Hsieh and Klenow (2009).

The main contribution of this paper is to provide novel evidence on the impact of population density through more efficient allocation of resources. It also contributes to the growing evidence on the productivity impact of cities in developing countries by studying a recent administrative data of Turkish manufacturing firms. The Olley-Pakes decomposition expresses the average firm productivity and the covariance between productivity and resource share as the two sources of sectoral productivity (Olley and Pakes, 1996). The latter term, which is the measure of allocative efficiency in this paper, indicates the productivity gap due to resource allocation compared to the random allocation case where productivity-size relationship does not contribute to sectoral productivity. Consider two regions where the productive distribution across the firms are identical, but in one region more productive firms tend to be larger compared to the other. The region with a greater size-productivity association has a higher typical productivity experienced per worker. This paper argues that denser locations are more productive because more productive firms command a greater share of resources.

I motivate the existence of an urban allocative efficiency premium with a variant of Lucas (1978). A manager chooses both the scale of operation and how much effort to exert to avoid the burden of regulation. Unlike the former, involving with the latter activity by the manager is not productive per se but increases profits through increasing access to subsidies and lower taxes faced by the firm. The model suggests that the strength of size-productivity relationship depends on a simple metric of internal diseconomies of the firm—the degree of decreasing returns to scale in the production function and the degree of convexity of the effort cost function. In particular, higher returns to scale and lower convexity of effort cost enables more productive firms to become relatively bigger.

If diseconomies are less severe in denser locations we can expect to estimate a positive density elasticity of allocative efficiency, i.e., the percentage increase in the Olley-Pakes covariance term following a hundred percent increase in population density. On the one hand, one can argue that agglomeration increases the returns to scale or congestion lowers it. On the other, escaping regulation can be less or more costly in dense locations because of faster diffusion of information or fiercer competition in chasing subsidies. It is therefore mainly an empirical task to see which effects ultimately dominate. In addition to observe the direction of the relationship, it is also of interest to estimate the size of the allocative efficiency relative to the overall productivity impact of agglomeration. To address these questions I turn to data and estimate the density elasticity of the sectoral sources of productivity.

Using firm-level administrative data on Turkish manufacturing firms from 2010 to 2017 I estimate the impact of density on the allocative efficiency. As standard in the literature, I address potential concerns related to the endogeneity of density and measures of productivity through instrumental variables that impose exogenous variation in current density and not related to the current productivity level other than its impact on density. The first instrument is the pre-industrialization density of Turkish provinces based on the 1927 Census, which is largely shaped by dramatic population movements as a result of continuous wars during the last 50 years of the Ottoman Empire. The second instrument is a climate index based on average weather characteristics, which are influential in residential preferences. In particular, I construct a regression-based index of continental climate taking into account the density's own impact on weather conditions. I also address the potential impact of industry mix in a region's productivity by estimating measures of labor productivity and total factor productivity in a fixed-effects setting.

Results suggest that within-sector allocative efficiency is a substantial channel of the observed productivity impact of agglomeration. I estimate a density elasticity of allocative efficiency that is about one third of density's overall impact on productivity.

Related literature Restuccia and Rogerson (2008) use the span of control model of Lucas (1978) to study the resource misallocation across countries. Recently, a set of papers employed this model to estimate the economic impact of size-based distortions (Garcia-Santana and Pijoan-Mas, 2014; Garicano et al., 2016). In these applications, the only source of size-productivity relationship is decreasing returns to scale. I extend the model by incorporating a second source of internal diseconomies through endogenous effort choice which has convex costs and show that both channels matter in the strength of size-productivity relationship. By discussing that the agglomeration effects on allocative efficiency can be understood in terms of parameters of diseconomies in the sense of Rosen (1981) the paper connects to the theory of agglomeration along the lines of Marshall (1890).

This paper relates to the line of literature on within-sector misallocation of resources using the productivity decomposition of Olley and Pakes (1996). Bartelsman et al. (2013) show that the size-productivity covariance term in the decomposition alligns well with other measures of misallocation that is important to account for cross-country income differences (Hsieh and Klenow, 2009). In terms of empirically approaching to the decomposition the paper is closest to Andrews and Cingano (2014) who estimate the impact of public policy on the elements of decomposition in a cross-country-industry setting.

By studying the efficiency of resource allocation through the lens of agglomeration the paper is closest to Fontagné and Santoni (2019) who find that resource allocation improves in denser areas by examining marginal product-marginal cost gap at the firm level in France. Empirical findings in this paper extend theirs at the sector level and further show how much of the overall agglomeration effect can be accounted for by allocative efficiency.

In addition to its dual focus on agglomeration including both resource allocation and typical firm productivity, the paper contributes to the large and growing body of literature on the economics of density by providing elasticity estimates from a developing country. My density elasticity on overall productivity is about 8% which is close to the estimates coming from developing countries reviewed in the meta-analysis of Ahlfeldt and Pietrostefani (2019).

A higher density elasticity for Turkey is also estimated by Özgüzel (2020) whose focus, different from the current paper, is on the level of average wages.[1]

2 Conceptual Framework

2.1 Internal Diseconomies and Size-Productivity Relationship

Firms are run by managers whose ability represents the firm TFP. A firm with manager of productivity A_i has the production function:

$$Y_i = A_i n_i^{\beta}, \tag{1}$$

where subscript i represents the individual firm identified by its manager, n_i represents the amount of input used in the production process. For simplicity of exposition, I assume labor is the only input with a total mass of unity. β governs the returns to scale of the production function. Firms produce a single output whose price (p) is taken as given, normalized to one. The unit cost of the homogenous input is w.

Following Lucas (1978) I assume that the firm-level productivity is determined by the productivity of managers. Each individual is equipped with a managerial productivity draw A_i from a continuous distribution with CDF $G(A)$. Based on their productivity draws individuals decide whether to be managers or workers.

The utility of the manager is founded by two objects. The first is the income from running the firm, which corresponds to profits. Second, the manager faces a convex effort cost function as a result of dealing with regulations that affect the productivity of the firm. In many models of misallocation, the impact of policy is manifested as exogenous taxes or subsidies. It is possible to interpret the managerial productivity here as a multiplicative combination of talent and idiosyncratic exogenous distortions. I allow for the possibility that the manager can affect the profits through managerial effort, which can increase the value of subsidies received or reduce the level of taxes paid. It also affects utility at some

[1] Another important difference in this paper is the use of a weighted density measure which takes into account the non-uniform distribution of population across subunits of a province. See the data section for a comparison of weighted and raw measures of density.

convex cost. The cost of effort can also be seen as a monetary cost, e.g., an expected value of fines if the effort is seen as some form of *bending the law*, which can sometimes end up with *breaking the law*.

In reality, the managerial effort to avoid the burden of regulation spans a vast area of activities ranging from searching and lobbying for subsidies and forming relationships with intermediaries for favorable financial terms to misreporting to diminish the cost of taxes.

The managers maximize the expected pay-off from running the business which is firm profits minus the cost of their effort.

$$\max_{n_i, e_i} \{A_i n_i^{\beta} - e_i w n_i - \frac{e_i^{-\phi}}{\phi}\}, \tag{2}$$

where $1/e_i$ is the managerial effort which can effectively decrease the unit cost of production and ϕ represents the curvature of the cost function.[2]

I introduce two sources of internal diseconomies through the parameters of the managerial pay-off function. In particular, I assume $0 < \beta < 1$ and $\phi > 1$. The former requires that the production function is subject to decreasing returns to scale, which is commonly used in the literature on productivity-size relationship. The latter formalizes the convexity of the effort cost.

The first order condition with respect to effort yields the following equation for optimal effort as a function of the scale of operation:

$$\frac{1}{e_i} = (w n_i)^{\frac{1}{\phi+1}} \tag{3}$$

Optimal managerial effort is increasing in size and decreasing in the convexity of effort cost.[3] Intuitively, the return from marginally increasing the effort level is higher for firms operating at a larger scale.

Combining equation (3) with the first order condition with respect to n_i the optimal firm

[2]Assuming non-linearity in the production cost function does not change the results below that are conditioned on ϕ. In particular, if the production cost is $e_i^{\rho} w n_i$ then any condition for ϕ holds through ϕ/ρ.

[3]It is consistent with the empirical evidence that large companies and the wealthiest individuals account for most of the tax evasion (Slemrod, 2007; Alstadsæter et al., 2019).

size is expressed as a function of wage and productivity:

$$n_i = w^{\frac{\phi}{(1+\phi)\beta-\phi}} (\beta A_i)^{\frac{1+\phi}{\phi-(1+\phi)\beta}} \tag{4}$$

Given wages, the size-productivity relationship is a function of internal diseconomies:

$$\frac{\partial \log n_i}{\partial \log A_i} = \left(\frac{\phi}{1+\phi} - \beta \right)^{-1} \tag{5}$$

Equation (5) establishes that when convexity of the effort cost is sufficiently low relative to returns to scale parameter such that $\phi > \beta/(1-\beta)$, a positive size-productivity relationship exists. Moreover, the sensitivity of size to productivity increases with a production function closer to linear (a higher β), and a cost function closer to linear (a lower ϕ).

The pay-off under optimal firm behaviour is given by the following:

$$\Pi_i = (1 - \beta - \frac{\beta}{\phi}) \left(A_i n_i^{\beta} \right), \tag{6}$$

where n_i is given by equation (4).

Where the pay-off is negative no individual prefers to work as a manager and production cannot take place. Hence, equation (6) requires $\phi > \beta/(1-\beta)$ as a condition for participation. As a result, a positive size-productivity relationship is guaranteed by the existence of economic activity.

The assignment rule in this model is standard. There exists a cut-off level of productivity, $\hat{A}$, above which an individual chooses to be manager and below which being a worker yields a higher pay-off. Consequently, the equilibrium in this model is obtained by the wage rate which clears the labor market—the total employment spanned by all managers equals the mass that chooses to be workers:

$$\int_{\hat{A}}^{A^{max}} n_i (A_i)\, dG(A) = G(\hat{A}). \tag{7}$$

The purpose of this toy model is to show how internal diseconomies govern the covariance between firm size and productivity. It can be generalized into a multi-location and multisector setting. A multisector version of a similar model is studied by Garcia-Santana and Pijoan-Mas (2014). Doing so adds several elements into the model such as sectoral and locational prices and wages, and sector and location decision of workers and managers. As a result, how productivity is distributed across sectors and locations emerges as an issue. However, equation (5), which is simply the result of within location-sector optimal firm behaviour, holds without loss of generality.

2.2 Locations and Internal Diseconomies

Equation (5) suggests that in economies where internal diseconomies are less severe, a sharper size-productivity relationship is expected. Guided by this result, in this paper, I explore whether density of a location affects this relationship. Existing theories of agglomeration support both larger and smaller diseconomies in denser places.

Agglomeration can enhance returns to scale in a location. Firms share physical and social infrastructure that enable to command more resources efficiently. This is reflected as a higher β in the model. Alternatively, density also creates congestion effects which might work in the opposite direction.

In high-density locations, interpersonal interactions are higher and information diffusion is faster. This again could have two effects on the convexity of effort cost. First, easier access to information and high-degree of spillovers suggest lower cost of avoidance from regulatory burden given that part of the cost is finding out how to do it. Second, it can make the efforts even costlier since higher level of interactions could bring in more competition in searching for subsidies as well as in relationship building with any authority that is important in the distribution of distortions. The former suggests a lower ϕ and the latter a higher one.

Therefore, it is mainly an empirical task to see which one dominates. In the next section, I test whether the model-based measure of internal diseconomies, $\frac{\phi_c}{1+\phi_c} - \beta_c$, decreases with the density of location c.

3 Density and Allocative Efficiency

3.1 Data

Productivity I calculate productivity measures using a panel of data at the firm-province-industry level. The data source is the administrative records on balance sheets and firm-to-firm trade merged with the number of workers from social security registry at the firm level.[4] I restrict the analysis to manufacturing sector at 92 three-digit NACE industries in 81 official provinces of Turkey for the 2010-2017 period. Two productivity measures are derived at the firm level. First, labor productivity of a firm is calculated as value-added per employee. Second, based on a Cobb-Douglas production function, total factor productivity is calculated using material inputs as proxies for productivity following the procedure described in Ackerberg et al. (2006).[5] [6]

I follow the steps explained in detail by Combes et al. (2010) to obtain adjusted productivity measures of labor productivity and TFP at the province level. First, industry productivity, calculated as the employment-weighted mean in each province-year, is regressed on log of the employment share of industry in the local labor market to control for regional sector specialization, dummies for three-digit sectors to control for the industry composition, and province-year fixed effects through weighted OLS where weights are number of firms in the province-year. Second, the mean of the estimated province-year fixed effects weighted by the number of firms are retained as adjusted productivities at the province-year level. Finally, simple averaging over the sample period yields the province-level adjusted productivity measure.

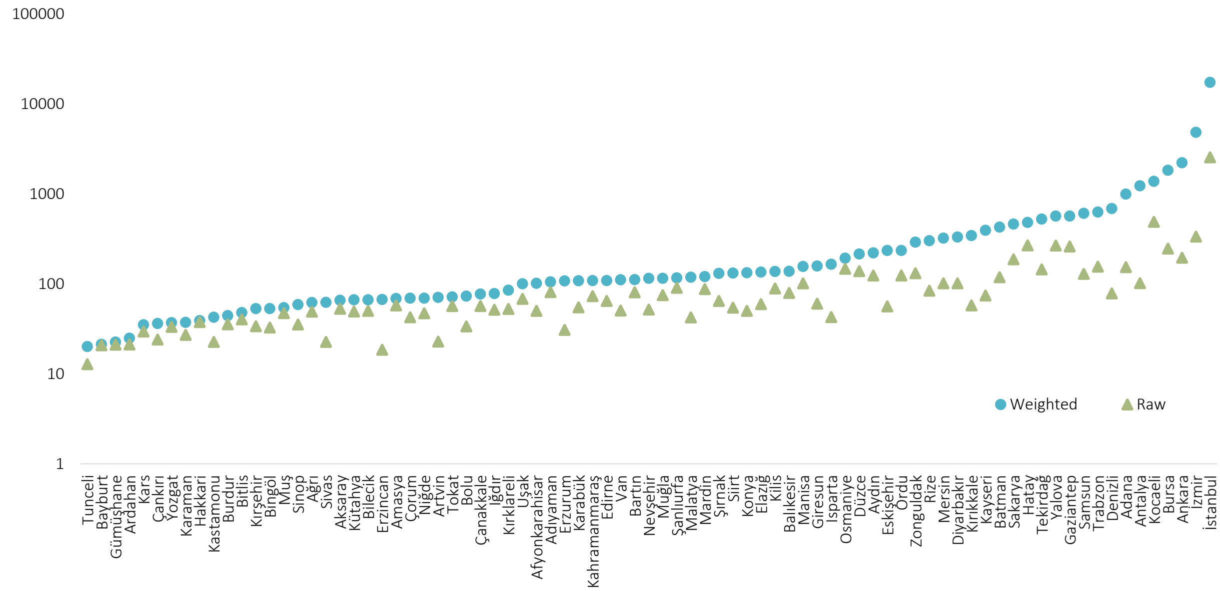
Density The population density is calculated at the level of 957 districts for each year of the sample, which is then aggregated to the province level. For each province and year, I calculate the district-population-weighted mean of the population per land area at the

[4] This dataset excludes firms that do not report balance sheets and covers around 90% of all sales.

[5] See also Wooldridge (2009) for discussion and an alternative estimation. Given the computational complexity and the existing range of different methods in the calculation of TFP, as to provide a simpler and more direct reference, I reproduce all results using value-added per worker.

[6] The balance sheets provide no quantity information and hence productivity measures are only deflated at the industry-level. Hence they are revenue-based productivity measures. See Bartelsman et al. (2013) on the correlations between revenue- and quantity-based productivity measures.

Figure 1: The weighted density measure (Log scale)



Notes: Figure shows the weighted and raw population density measures across Turkish provinces on log scale. Weighted density is the population weighted mean density of districts in each province.

district level, which are then averaged over the period. Weighting by districts yields a better measure for the typical crowdedness of a province since often there are cases where the city density is high at the center yet low in many surrounding districts (Duranton and Puga, 2020).

A good example is the national capital, Ankara, which ranks the third according to the district-weighted density and only eighth according to the raw density measure. Similarly, the average raw density is 2555 people per km square in the densest city, Istanbul, while the district-weighted measure more accurately suggests 17407 people per km square (Appendix Table A1). Figure 1 provides a visual representation of how the two measures differ across provinces. The underestimation of density by the raw density measure is aggravated especially for denser places.

Instrument I The first instrument for modern population density is based on historical density which is widely used in the literature on the economics of density. I construct measures of historical density using 1927 Census data.

While popularly used as the main instrument for density since Ciccone and Hall (1996), the history-based instrument is used to estimate the density elasticity of size-productivity covariance for the first time in this study. In the context of typical firm productivity, however, this type of instruments are not perfect (Ahlfeldt and Pietrostefani, 2019). In particular, the instrument is a valid one as long as historically high-productivity locations, which consequently attracted masses back in time, did not become persistent reservoirs of productive infrastructure (Glaeser and Gottlieb, 2009; Duranton and Puga, 2020). Such persistency can also be a concern for the allocative efficiency component.[7]

Despite potential concerns, there are also good reasons justifying the use of history-based instrument in the Turkish context. First, it comes from a period where economy mainly rests on agriculture and the share of manufacturing activity is negligible, about 10% of national income throughout the 1920s (Ünal, 1989). Second, specific to the Turkish context, the population structure of the 1920s reflects big demographic shocks through continuous wars during the preceding 50 years combined with forced in- and outflux of migrants at large scale. The geographical distribution of population at the end of the 1920s is substantially shaped by exogenous political developments more than the preceding century as well as the decades coming after.[8] [9]

Instrument II The second instrument is a climate index based on mean, maximum, minimum temperatures and rainfall statistics using long-run averages from State Meteorological Service. This instrument expects that households' modern residential preferences are biased towards places with nicer weather conditions (Glaeser and Gottlieb, 2009; Abel et al., 2012).

My implementation of climate index differs from the literature by taking into account the potential influence of urbanization on local weather. Population density can affect the local climate through urban heat island effect (Masson et al., 2020). Hence directly using weather

[7]The correlation coefficient between the log of current and the historical density is 0.5. While this shows that population density is significantly persistent, the development process in the last decade also made important changes in the distribution of population density. To name a few, Antalya, Batman, and Zonguldak experienced disproportionate increases in density due to the rising importance of tourism, the discovery of oil, and coal, respectively.

[8]See Karpat et al. (1985) for a detailed account of population movements and a review of how political demography was the dominant force in the last decades of the Ottomon Empire. See Shaw and Shaw (1977) for a broader discussion on the relevant political history.

[9]In addition, I constructed two more alternative geographical history instruments—one based on the early railroad structure and the other based on being a key part of the silk road. These are in the form of dummy variables and ruled out as weak instruments.

Table 1: Spearman's rank correlations with the distance measure

Temperature				Rain		
Mean	Max	Min	Max-Min	Quantity	Rainy Days	Sun Hours
-0.39*	-0.22	-0.47*	0.42*	-0.43*	-0.26	0.49*

Notes: The shortest land route from sea data is from the General Directorate of Highways. The weather statistics are 1981-2010 averages from the Turkish State Meteorological Service. * indicates significance at the level of 1%.

variables is not perfect in exerting an exogenous variation on density. In order to address this concern I build an index of continental climate. Continental climate is defined by more volatile temperatures within a year, lower average temperature and low levels of precipitation (Duckson, 1987). The geography of Turkey, in particular the Anatolian peninsula, is typically characterized by increasing density of mountains as one moves away from the shores as shown in Appedix Figure A1.

The continental characteristics of climate in Turkey expectedly increase with the distance from the sea. Table 1 shows the rank correlation of long-run weather statistics of provinces to the distance from the sea. Further inland, the mean temperature is lower, the max-min temperature difference is higher, and rainfall diminishes.

Consequently, I use the shortest land route distance from the sea as a proxy of continental climate and regress it on weather variables and their interactions. The predicted values from this regression is retained as the climate instrument for population density.[10] This strategy extracts flexibly the climate information up to its capacity to predict how inland a province is.[11]

3.2 Empirical Framework and Strategy

I start with the Olley and Pakes (1996) decomposition of productivity, which expresses the weighted log of aggregate productivity as the simple mean of log productivity plus the allocative efficiency term—the covariance between productivity and the size of the firm within an industry-year cell. The identity is summarized below:

[10] The adjusted R^2 of the regression is 0.45.

[11] Note that using solely the distance from sea as an instrument can violate the exclusion restriction since it potentially affects productivity through channels other than density such as providing additional cost and market advantages through the existence of ports.

$$\sum_{i \in sc} \theta_{isc} A_{isc} = \overline{A}_{sc} + \sum_{i \in sc} (\theta_{isc} - \overline{\theta}_{sc})(A_{isc} - \overline{A}_{sc}), \tag{8}$$

where θ_{isc} is the within-industry employment share and A_{isc} is the log productivity of firm i in industry s and province c. The terms with the overscore indicate mean of productivity or employment share at the province-industry level. The left-hand side is the weighted mean of productivity (WP) at the province-industry pair. The first term on the right-hand side is plain average of productivity (P) for province-industry pairs and the second term is the Olley-Pakes allocative efficiency (AE) term—resulting from the variation in the shares of different firms.

The convenience of such decomposition is its simplicity of interpretation on the sources of productivity. AE term can be interpreted as the percent change in the aggregate weighted productivity resulting from the distribution of resources compared to the case when resources are randomly distributed within a given industry. Utilizing this convenience, I estimate the density elasticity of all the elements of equation (8) in order to see how much of the density elasticity of WP, which is the object concerned by most of the existing literature, is accounted for by the AE term.[12]

The empirical strategy rests on instrumental variables regression of productivity and allocative efficiency at the province-industry level. In particular, I estimate the following equation:

$$y_c = \alpha \text{ density}_c + \gamma_r + \epsilon_c, \tag{9}$$

where y_c is one of AE, P, or WP of a province, density_c is the log population density at the province level, and γ_r are regional dummies to account for shared characteristics within geographically similar places, and ϵ_c is the disturbance term. α is the density elasticity of productivity, i.e., the percentage change in the productivity measure following doubling of density.

Two important issues should be taken into account when estimating equation (9). First,

[12]See Andrews and Cingano (2014) for a similar approach in studying the impact of regultions on AE and P in the cross-country-industry setting.

the size-productivity covariance as well as average firm productivity potentially depend on the industry structure. If sectoral measures of productivity has a sector-specific element, the estimated relationship between density and productivity at the province level could simply reflect sectoral specialization of regional economic activity. Second, the well known potential simultaneity of productivity and density can bias the estimate of density elasticity of productivity measures.

Following the literature, I use a combination of fixed effects and instrumental variables in the estimation. In particular, as described in section 3.1, I first estimate adjusted productivity measures at the province level free from sectoral averages, specialization and time-variation and use them as y_c. Then I estimate equation (9) using instrumental variables.

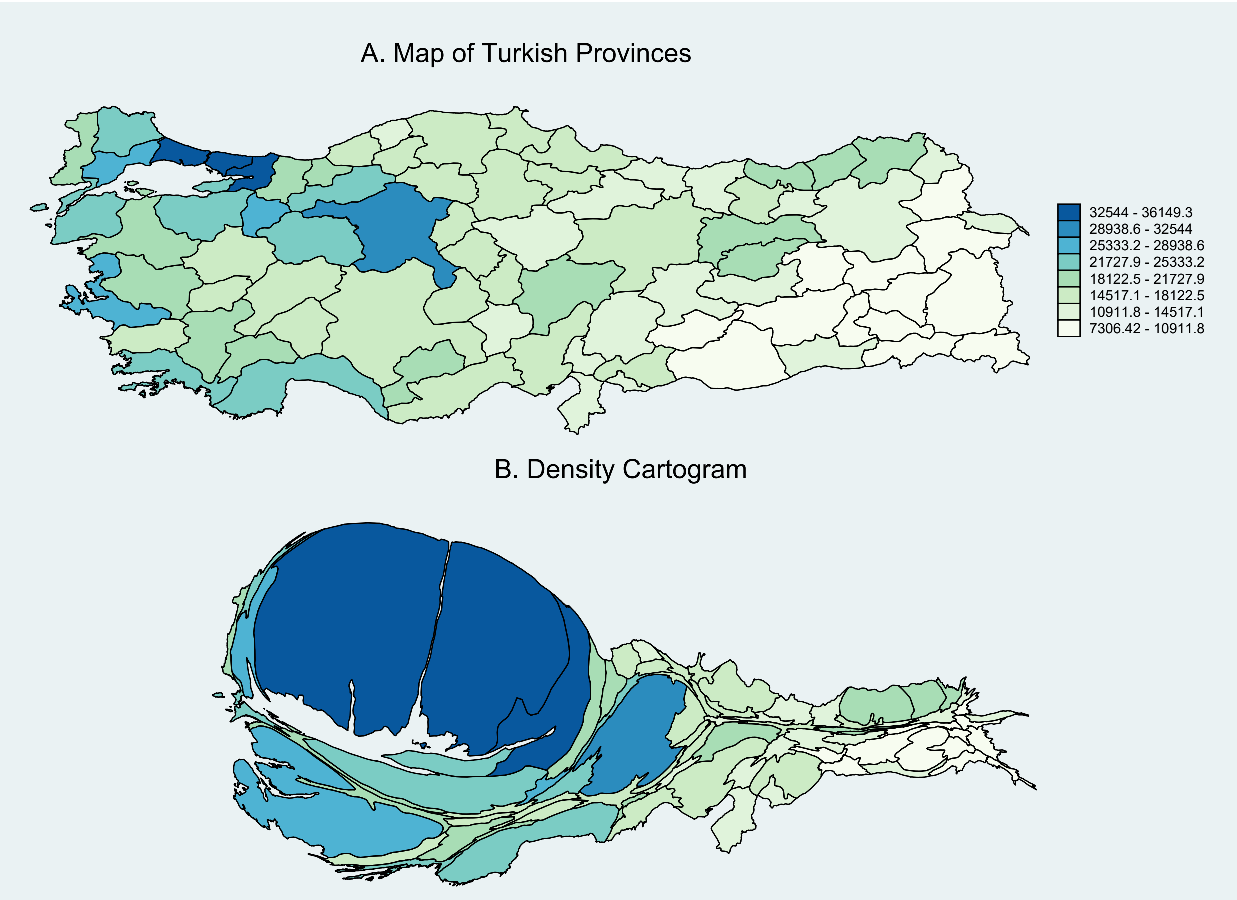
3.3 Geography of Productivity in Turkey

There are large disparities across provinces of Turkey in terms of productivity. Panel A of Figure 2 shows the heatmap of GDP per capita across Turkish provinces. The west-east gap can be spotted clearly as the provinces of darker color intensify particularly the west of capital city of Ankara. The amount of variation is also substantial. Table A1 presents a summary of quality and density indicators across provinces. The highest GDP per capita is observed in Istanbul which is five times larger compared to eastern border province of Ağrı. A similar pattern is also observed across weighted productivity of manufacturing and the size-productivity covariance, shown by high rank correlation in the lowest row. The cross-province GDP per capita variation also lines up well with measures of capital quality, particularly human capital, having a rank correlation coefficient of 0.85.

Panel B of the figure introduces the dimension of density into the heatmap by showing a cartogram of population density, which increases the province size proportional to the density without altering topological relations. The cartogram boosts the representation of highly productive western cities, as darker colors and province sizes largely coincide. The eastern and inner regions substantially shrink in the cartogram.

Just as productivity, density exhibits substantial locational variation in the data. The mean density triples between the densest 20 and bottom 20 provinces. There is also considerable productivity differences between the most and the least dense places. Figure 3 plots the

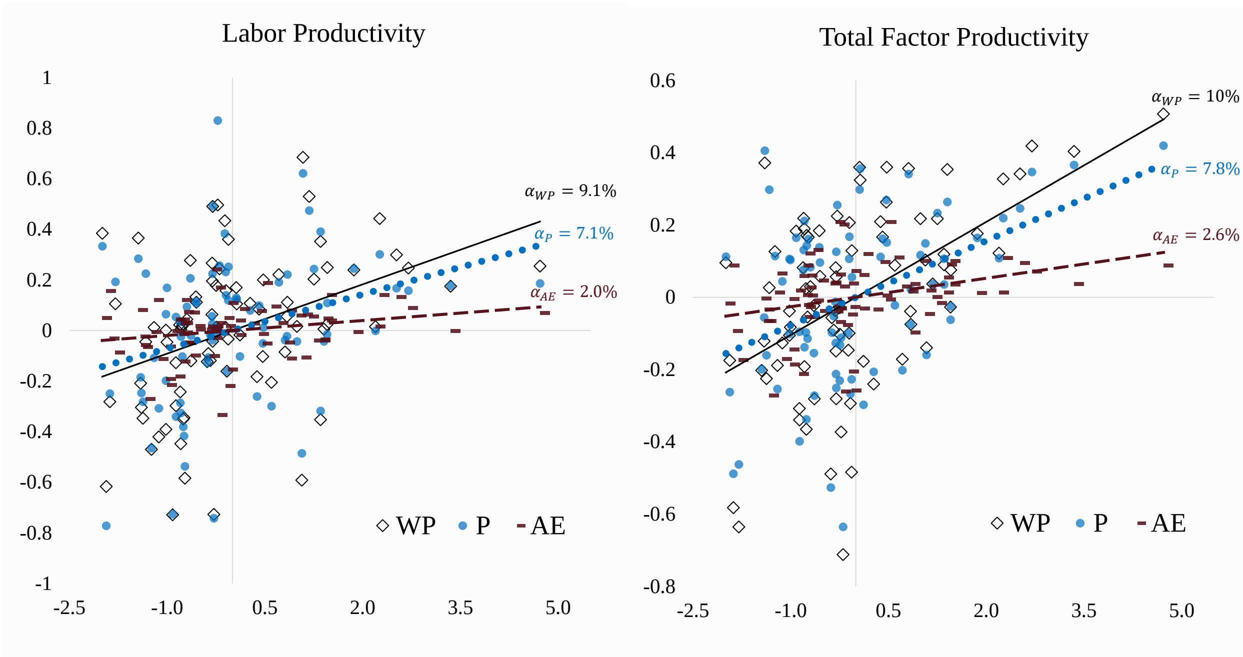
Figure 2: GDP per capita and density across provinces



Notes: Panel A shows a heat map of the 2006-2017 average GDP per capita across 81 official provinces of Turkey, expressed in terms of Turkish Lira in the legend. Panel B shows the heat map on a cartogram which distorts actual area of provinces with population density. Cartogram produced based on Gastner and Newman (2004) diffusion-based algorithm adapting actual map surfaces to population density without altering their topological relations. The source of GDP per capita is Turkstat's regional accounts.

unadjusted manufacturing productivity measures weighted by sectoral employment in each province against the log of density. Data in the figure suggests that WP of labor productivity and TFP increase by about 30% and 20% between the top and bottom 20 dense provinces. About 20% and 30% of this productivity difference can be accounted for by AE. The figure also provides the slopes of the linear relationship between raw productivity measures and density. The elasticity is about 9%-10% for WP, 7-8% for P, and 2-3% for AE. This is a novel evidence showing that a sizeable part of elasticity of density at the economy-level is through a stronger size-productivity association in denser places.

Figure 3: Density and unadjusted productivity measures



Notes: WP, P, and AE are calculated according to equation (8). Unadjusted labor productivity and TFP aggregated to 81 provinces using employment weights. Density is weighted by district population within each province. Lines show the fitted linear relationship between log density and the respective productivity measure. The slopes are reported by each line.

3.4 Results

Table 1 reports the estimation results following equation (2) where adjusted productivity measures are the dependent variables. OLS and IV estimates are shown in odd and even numbered columns respectively. While instrumentation shrinks elasticity of P as common in the literature, it inflates the elasticity of AE.

IV estimate in column (2) of panel A suggest 2.7% elasticity for AE of labor productivity. The IV estimates suggest an elasticity of 4.3% and 7% for P and WP. The TFP results in panel B are similar: 3% for AE, 6.4% for and P, 9.4% for WP. The F statistic rejects weak identification in all cases and Hansen's p-values consistently indicate instrument validity, supporting causal interpretation of IV estimates. Elasticities for weighted productivity are somewhat higher than most of the estimates in the literature while consistent with the tendency of typically higher elasticities found in non-high-income economies.[13] In particular,

[13] A higher agglomeration effect for Turkey is also estimated by Özgüzel (2020), whose estimation relies on wages and raw population density suggests an elasticity of around 6%.

Table 2: Density elasticity of allocative efficiency and productivity

	AE		P		WP	
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
A. Labor Productivity						
Log Density	0.019***	0.027**	0.056***	0.043*	0.075***	0.070***
	(0.007)	(0.012)	(0.014)	(0.023)	(0.013)	(0.021)
F statistic	-	20.15	-	20.15	-	20.15
Hansen J	-	0.44	-	0.77	-	0.46
R^2	0.45	0.44	0.40	0.39	0.47	0.47
B. Total Factor Productivity						
Log Density	0.025***	0.030**	0.066***	0.064***	0.091***	0.094***
	(0.007)	(0.011)	(0.012)	(0.019)	(0.012)	(0.021)
F statistic	-	20.15	-	20.15	-	20.15
Hansen J	-	0.17	-	0.50	-	0.18
R^2	0.48	0.48	0.53	0.52	0.62	0.62

Notes: The dependent variables are AE, P, and WP from equation (8) in columns. Results for labor productivity and total factor productivity are reported in panels A and B, respectively. All specifications include dummies for 11 geographic regions. Instruments are historical (1927) density and the climate index. F statistic refers to Kleibergen-Paap rk Wald F statistic with the null of weak identification. Hansen J statistic refers to the p values under the null of instrument validity, i.e., excluded instruments are correctly excluded. Instrumental variable estimations are performed using Limited Information Maximum Likelihood. Standard errors in parentheses. Number of observations in each specification is 81. *, **, *** indicate significance at 1, 5, and 10%, respectively.

our estimates on WP of labor productivity and TFP both are only one percentage point lower than the citation-weighted median elasticities reported for non-high-income economies in the meta-analysis of Ahlfeldt and Pietrostefani (2019).

According to Table 1, around 30-40% of the effect of density on overall productivity is accounted for by its influence on allocative efficiency. Moreover, the estimates reveal the remarkable role of density in understanding productivity differences across provinces. A back of the envelope calculation suggests that the inter-decile difference (p90-p10) in log density can explain around 35% of inter-decile difference in allocative efficiency and 50% in weighted productivity.

3.5 Alternative Specifications

This section presents robustness of the results under alternative specifications. Instead of the procedure of Combes et al. (2010) taking a more direct estimation approach is given by the following regression equation:

$$y_{cst} = \alpha\ density_{ct} + \gamma_r + \gamma_{st} + \varepsilon_{cst}, \tag{10}$$

where everything reads the same as in equation (9) except that now the estimation is at the industry-province-year level and γ_{st} captures the industry-year fixed effects.

The density elasticities for the TFP-based productivity components are presented in Table A2. The three columns show the OLS, IV with one instrument (historical density), and IV with full instrument set estimated for all manufacturing industries, and the last three columns show the corresponding estimates for the sample restricted to industries with an average rate of informal employment smaller than 5%.

Compared to Table 2, directly running the estimation at the province-industry-year level results in lower estimates with higher statistical significance and greater F-statistics for the IV. The share of the density impact on weighted productivity accounted for by allocative efficiency is also slightly lower at around 25%.

The results from the restricted sample which only includes low-informality sectors point to larger estimates for all components of productivity which suggests that the remarkable influence of the allocative efficiency channel is not driven by highly informal sectors. Next section continues to explore the potential impact of the incidence of informality on the density elasticities estimated with the Turkish data.

3.6 Informal Employment and Density Elasticities: A Test

The administrative data provides employment from the social security registers. The part of employment that is not formally registered is missing from the data, which potentially affects both the productivity and the size estimates given that the incidence of informal employment is common in developing economies. Turkish labor market is not an exception in this regard and the potential impact of informal employment on density elasticity should

Table 3: Informality, firm size, and density

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Size	-0.093***		-0.094***	-0.098***	-0.096***	-0.093***	-0.060***
	(0.005)		(0.005)	(0.008)	(0.007)	(0.007)	(0.006)
Density		0.010	-0.007	-0.015	-0.013		0.004
		(0.012)	(0.009)	(0.015)	(0.014)		(0.010)
Size × Density				0.007	0.006	0.004	0.000
				(0.005)	(0.005)	(0.005)	(0.005)
Observations	55,426	55,426	55,426	55,426	55,426	55,426	52,918
R^2	0.19	0.09	0.19	0.19	0.18	0.21	0.33

Notes: Table reports the estimated coefficients of equation (11). The source is the 2015-2017 waves of Household Labor Force Survey (HLFS). Sample includes all workers in the manufacturing sector. The dependent variable is a binary indicator of informality. Size and density are in logs. In the interaction term both variables are standardized to have zero mean and unit variance. The original firm size variable of HLFS is categorical. It is made continuous through imputation of the median employment from the administrative data. Locations are 26 Nomenclature of Territorial Units for Statistics (NUTS-2) according to the definition of Turkstat. Density at the NUTS-2 level is calculated as the mean provincial density weighted by provinces' population. All columns include year and two-digit sector dummies. Column (6) includes dummy variables at NUTS-2 level. Column (7) includes variables on gender, education, occupation, marital status, a quadratic polynomial of age, indicator of work in public company, part-time status, origin of birth, the continuity of employment contract, and log wages as a proxy of job quality. All columns except (5) are weighted by population weights. Standard errors in parentheses are clustered by NUTS-2 region. *, **, *** indicate significance at 1, 5, and 10%, respectively.

be addressed.[14]

This section explores whether informality in the labor market is capable of mechanically driving the estimates reported in Table 2.[15] It is easy to see why informality imposes an upward bias of any productivity measure—inputs are measured less than they actually are and the output seems as it is produced with less resources than actually used. If informality is more prevalent in denser locations, the estimated density elasticity of typical productivity (P) is biased upwards and vice versa.

Informality also influences the AE term through informality-size connection. Typically, informal employment is more common for smaller firms (Maloney, 2004). Consequently, for small firms productivity is disproportionately measured with an upward bias and employment share is underestimated. However, its impact on the AE term is ambiguous. Understanding the final impact boils down to comparing the changes in the weighted productivity versus

[14]From the Labor Force Survey of Turkstat I calculate that 34% of all and 19% of manufacturing workers in 2017 are employed informally in Turkey.

[15]It is important to distinguish between informality in employment and other sources of regulatory avoidance. The model predicts greater overall avoidance for larger firms though silent in how firms differ in their avoidance strategy with respect to size (See Bennedsen et al., 2009; Harstad and Svensson, 2011, on a specific case of size-dependent avoidance strategies).

the change in the typical productivity, which is sensitive to the variance of productivity in a location.

The results of the previous sections are only reliable if informality and informality-size association do not depend on density. This can be tested with a regression design that uses the variation on the informality of workers across firm size and spatial dimensions. The Turkstat's Household Labor Force Survey (HLFS) provides the information needed.[16]

In particular, I estimate the following equation:

$$\text{informal}_{isct} = \text{constant} + \eta_1 \times \text{size}_{isct} + \eta_2 \times \text{density}_{ic} + \eta_3 \times \text{size}_{isct} \times \text{density}_{ic} + \gamma_s + \gamma_t + X\Gamma + \epsilon_{isct}, \tag{11}$$

where informal is a dummy variable which takes the value of one if worker i in sector s, location c and year t and zero otherwise; γ_s and γ_t are sector and year fixed effects; X is a vector of potential covariates at the individual level such as job quality, occupation, age, gender and Γ is a vector of coefficients; ϵ_{isct} is the error term. The size and density variables are in logs.

The two hypotheses in question are $\eta_2 = 0$ and $\eta_3 = 0$. These respectively test whether the incidence of informality and informality-size relationship are sensitive to density. Table 3 reports the results of estimating equation (11) for manufacturing sector. Column (1) confirms that $\eta_1 < 0$, i.e., smaller firms are more likely to employ informal workers. Columns (2) and (3) show that $\eta_2 = 0$ cannot be rejected. Column (4) involves the interaction term and suggests that $\eta_3 = 0$ also cannot be rejected, i.e. the size-informality relationship is not affected by density.

Columns (5)-(7) provide a sense of robustness for the results. Column (5) shows unweighted estimates. Column (6) includes the full set of locational dummies. Column (7) includes a set of individual-level controls. To sum up, though conceptually plausible, I find no empirical evidence that elasticities reported in Table 2 are affected by the incidence of informality.

[16]One limitation is that the HLFS' location information is only available at the NUTS-2 level.

4 Conclusion

Returns to economic activity are higher in denser places. Using administrative data from Turkish manufacturing, this paper documents that denser locations have higher productivity both because the typical firm is more productive and more productive firms command a greater share of resources. In particular, I estimate that around one third of the density elasticity of productivity is accounted for by a tighter size-productivity association.

This result can be explained in a model of size-productivity distribution if factors internal to firm allow more room for economies in denser locations. Two candidates studied in this paper are lower decreasing returns to scale and lower marginal cost of avoidance from regulations in denser places. These can come in the form of more efficient matching as Fontagné and Santoni (2019) argue, direct physical impacts of shared infrastructures, and easier access to knowledge and networks that make it less costly for firms to escape from the burden of regulation. The remarkable size of the density elasticity of allocative efficiency is encouraging for future research that focuses on these channels in detail.

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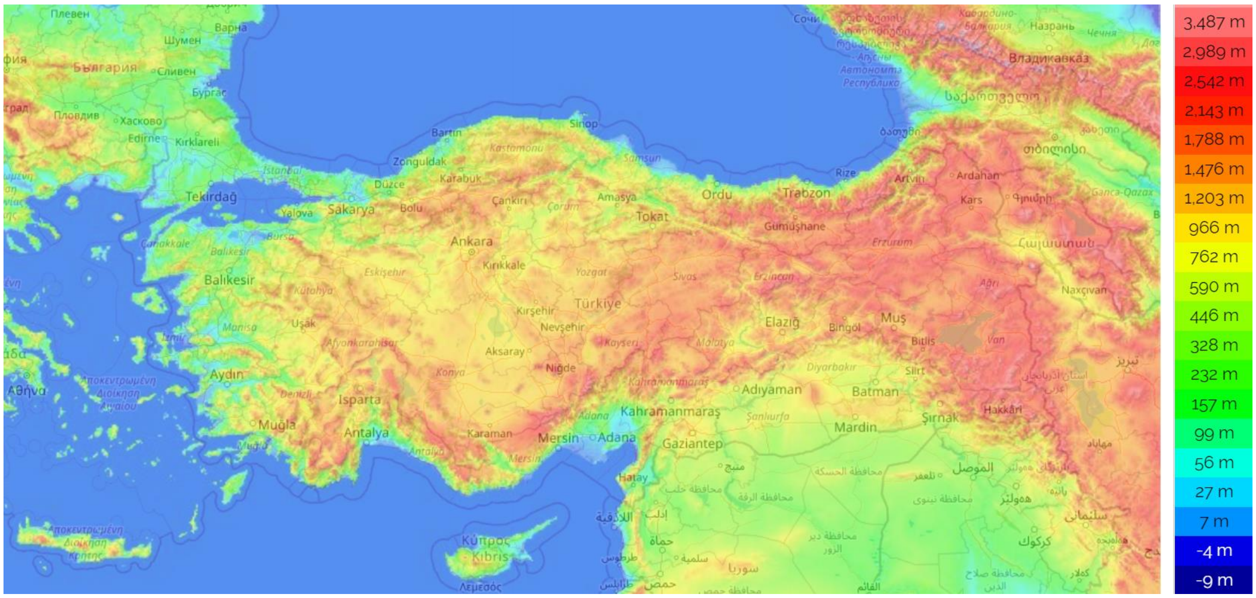
Appendix

Figure A1: Elevation map of Turkey and the surrounding region



Notes: Figure retrieved from "topographic-map.com" which uses the data of Yamazaki et al. (2017).

Table A1: Quality and density indicators of Turkish provinces

		Relative to top			Population per km-sq		Share of (%)	
Rank	Province	GDP pc	WP	AE	Weighted	Raw	College Worker	Divided Roads
1	İstanbul	1.00	1.00	0.89	17407	2555	11.37	51.29
2	Kocaeli	0.98	0.84	0.90	1382	489	9.35	36.33
3	Ankara	0.84	0.92	0.87	2218	196	15.72	39.97
4	Tekirdağ	0.75	0.75	0.80	524	145	8.27	40.22
5	Bilecik	0.71	0.73	0.79	67	50	8.74	30.52
6	İzmir	0.70	0.90	0.84	4841	336	11.99	30.92
7	Bursa	0.67	0.85	0.89	1831	247	9.00	30.23
8	Bolu	0.67	0.62	0.77	73	34	9.29	26.27
9	Antalya	0.67	0.68	0.82	1231	102	10.00	25.39
10	Eskişehir	0.64	0.86	1.00	235	56	12.25	35.23
11	Yalova	0.64	0.68	0.82	567	267	10.19	34.53
12	Kırklareli	0.63	0.64	0.78	85	53	9.14	23.07
13	Muğla	0.61	0.58	0.99	115	75	10.41	36.67
14	Çanakkale	0.61	0.59	0.93	77	57	10.10	23.47
15	Sakarya	0.55	0.52	0.83	463	188	7.58	43.61
16	Denizli	0.55	0.86	0.89	689	78	8.54	35.76
17	Manisa	0.54	0.86	0.86	156	101	6.97	32.87
18	Karaman	0.54	0.48	0.76	37	27	7.22	13.21
19	Düzce	0.54	0.74	0.89	215	139	7.29	56.84
20	Burdur	0.53	0.50	0.87	44	36	8.59	33.64
21	Kayseri	0.52	0.75	0.90	394	74	8.46	41.91
22	Edirne	0.52	0.64	0.76	109	65	9.67	27.25
23	Erzincan	0.52	0.50	0.77	67	19	9.07	33.33
24	Tunceli	0.51	0.66	0.80	20	13	10.60	5.70
25	Artvin	0.51	0.57	0.86	71	23	8.50	6.26
26	Balıkesir	0.51	0.69	0.87	138	80	9.21	34.79
27	Rize	0.50	0.51	0.84	302	84	8.37	25.90
28	Trabzon	0.49	0.59	0.84	630	156	9.98	18.17
29	Uşak	0.49	0.37	0.84	100	68	7.66	31.89
30	Mersin	0.48	0.86	0.82	323	101	8.40	21.92
31	Isparta	0.48	0.50	0.92	166	43	10.08	20.51
32	Karabük	0.47	0.65	1.00	109	55	9.32	28.16
33	Konya	0.46	0.74	0.84	133	50	7.55	27.49
34	Kırıkkale	0.46	0.58	0.84	344	58	8.19	59.04
35	Kastamonu	0.45	0.68	0.82	43	23	7.18	18.41
36	Kütahya	0.45	0.75	0.89	67	49	7.46	20.09
37	Amasya	0.44	0.62	0.92	69	58	8.20	45.62
38	Adana	0.44	0.72	0.82	994	154	8.14	21.53
39	Çankırı	0.44	0.53	0.76	36	24	7.07	31.86
40	Aydın	0.43	0.71	0.82	221	124	8.84	39.88
41	Samsun	0.43	0.65	0.90	608	129	8.06	34.59

Table A1 continues

42	Nevşehir	0.43	0.54	0.84	115	52	7.09	52.82
43	Sivas	0.42	0.43	0.86	62	23	7.60	30.08
44	Gaziantep	0.42	0.66	0.86	567	261	5.16	36.69
45	Kırşehir	0.42	0.54	0.81	53	34	8.43	26.88
46	Zonguldak	0.41	0.66	0.91	291	132	7.57	33.53
47	Afyonkarahisar	0.41	0.57	0.85	101	50	6.36	45.57
48	Aksaray	0.41	0.65	0.82	66	53	5.58	40.37
49	Niğde	0.40	0.42	0.79	69	47	6.66	35.75
50	Çorum	0.39	0.71	0.83	69	43	6.48	27.24
51	Gümüşhane	0.39	0.34	0.74	23	21	7.41	8.47
52	Sinop	0.39	0.72	0.83	59	35	7.58	16.38
53	Elazığ	0.39	0.45	0.79	136	60	8.22	36.34
54	Hatay	0.39	0.62	0.81	483	268	6.34	47.91
55	Bartın	0.39	0.75	0.79	111	81	6.72	18.12
56	Osmaniye	0.36	0.47	0.78	193	147	7.11	20.48
57	Kahramanmaraş	0.36	0.52	0.86	109	73	5.66	25.23
58	Yozgat	0.36	0.87	0.78	37	33	5.55	31.20
59	Bayburt	0.36	0.51	0.89	21	21	6.93	20.49
60	Giresun	0.35	0.83	0.79	158	60	7.78	15.11
61	Malatya	0.35	0.72	0.85	118	42	8.65	26.17
62	Erzurum	0.35	0.58	0.79	108	31	7.18	30.17
63	Ardahan	0.35	0.32	0.68	25	21	6.20	16.91
64	Ordu	0.34	0.78	0.81	236	124	6.56	11.52
65	Iğdır	0.33	0.45	0.80	78	52	5.60	82.50
66	Kilis	0.33	0.37	0.63	138	89	5.97	22.40
67	Tokat	0.33	0.71	0.82	72	57	6.90	30.43
68	Mardin	0.30	0.30	0.75	121	88	4.26	31.86
69	Kars	0.30	0.49	0.81	35	30	5.36	22.50
70	Adıyaman	0.29	0.55	0.78	106	81	5.61	19.48
71	Bingöl	0.29	0.58	0.70	53	33	5.78	21.74
72	Diyarbakır	0.29	0.56	0.74	331	102	5.14	33.15
73	Şırnak	0.28	0.55	0.66	131	65	3.86	22.62
74	Batman	0.27	0.67	0.77	427	119	4.87	26.80
75	Siirt	0.27	0.52	0.77	132	54	4.72	18.07
76	Hakkari	0.27	0.62	0.62	39	38	5.34	9.88
77	Muş	0.27	0.55	0.67	54	47	3.60	17.95
78	Bitlis	0.26	0.53	0.68	48	40	4.79	37.41
79	Şanlıurfa	0.23	0.41	0.63	117	91	3.29	27.62
80	Van	0.22	0.45	0.79	111	51	3.81	36.93
81	Ağrı	0.20	0.44	0.66	62	49	3.39	51.93

Table A1 continues

Rank Correlation Coefficient

1.00	0.46	0.58	0.37	0.27	0.85	0.23

Notes: The table ranks provinces based on GDP per capita. Columns of GDP pc, WP, and AE report average productivity relative to the most productive province. WP and P are employment weighted mean unadjusted measures at the province-level. Weighted and raw density report population per km-square. Weighted density is the population weighted mean of districts in a province. Share of college worker reports the percentage of labor force with university degree. Share of divided roads reports the percentage of the length of divided roads to total length of roads in a province. All in 2010-2017 averages. The last row reports the rank correlation coefficient of each variable with GDP pc.

Table A2: Density elasticity of productivity under alternative specifications

	All Manufacturing			Low-informality Industries		
	OLS	IV-1	IV-2	OLS	IV-1	IV-2
	(1)	(2)	(3)	(4)	(5)	(6)
	A. Allocative Efficiency (AE)					
Log Density	0.010***	0.016***	0.014***	0.015***	0.024***	0.021***
	(0.001)	(0.001)	(0.001)	(0.003)	(0.005)	(0.005)
Observations	18,323	18,323	18,323	4,452	4,452	4,452
R^2	0.14	0.14	0.14	0.15	0.15	0.15
F-Test	-	21899	13265	-	4639	2488
	B. Unweighted Poductivity (P)					
Log Density	0.045***	0.048***	0.048***	0.047***	0.060***	0.060***
	(0.001)	(0.002)	(0.002)	(0.004)	(0.005)	(0.005)
Observations	18,323	18,323	18,323	4,452	4,452	4,452
R^2	0.90	0.90	0.90	0.89	0.89	0.89
F-Test	-	21899	13265	-	4639	2488
	C. Weighted Productivity (WP)					
Log Density	0.055***	0.065***	0.062***	0.061***	0.084***	0.082***
	(0.002)	(0.002)	(0.002)	(0.005)	(0.007)	(0.007)
Observations	18,323	18,323	18,323	4,452	4,452	4,452
R^2	0.88	0.88	0.88	0.85	0.85	0.85
F-Test	-	21899	13265	-	4639	2488

Notes: The dependent variables are TFP-based productivity measures AE, P, and WP from equation (8) in panels. Columns (1)-(3) include all manufacturing industries and (4)-(6) include industries that have average informal employment share below 5%. All specifications include dummies for 11 geographic regions, industry-year fixed effects and are weighted by the firm number at the province-industry-year level. Instruments are historical (1927) density and the climate index. Columns (2) and (5) use historical density as the only instrument, columns (3) and (6) use both instruments. F statistic refers to Kleibergen-Paap rk Wald F statistic with the null of weak identification.Instrumental variable estimations are performed using two-stage least squares. Standard errors in parentheses. *, **, *** indicate significance at 1, 5, and 10%, respectively.

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