

Competition and the welfare gains from transportation infrastructure: Evidence from the Golden Quadrilateral of India*

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Abstract

We quantify the benefits from improving transportation infrastructure. To do so, we use a model in which firms compete oligopolistically, which means that markups that firms charge change as a result of changes in transportation costs. We apply this model to the case of the construction of the Golden Quadrilateral (GQ), a large road infrastructure project in India. We find that the project generates large aggregate gains: benefits exceed the initial investment in just two years. We also find that: (i) pro-competitive gains are approximately 20% of total gains and (ii) the size and nature of welfare gains are very heterogeneous across states.

JEL classifications: F1, O4.

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1 Introduction

Poor transportation infrastructure is a common feature in low-income countries. For example, in 2000, it would take a truck four to five days to drive the 1,500 km distance between Delhi and Calcutta, which is five times longer than it would in the United States. International organizations and policymakers have not overlooked this fact: between 1995 and 2005, upgrades to the transportation network constituted around 12% of total World Bank lending. Out of this, 75% was allocated to the upgrading of roads and highways. Hence, understanding the impact of large-scale transportation infrastructure projects is a matter of great importance.

In this paper, we develop a model of internal trade that allows us to quantitatively evaluate the welfare gains which stem from improving the transportation infrastructure within a country. Our main contribution is to quantify the impact of improved transportation networks in a setting which allows to distinguish between different types of welfare gains. That is, we determine to what extent reductions in transportation costs improve productive efficiency (Ricardian gains), allocative efficiency (pro-competitive gains due to less misallocation due to an increase in competition), and the terms of trade for every trade partner. We use this model to study the welfare impact of building one of the biggest highway networks in the world: the Golden Quadrilateral (GQ) in India. The GQ project upgraded and expanded the roads connecting the four major cities in the country, providing India with around 6,000 km of modern highway roads.

In our model, the states of India trade with each other. There is a continuum of sectors and each sector has firms with heterogeneous productivity competing à la Cournot. The model generates endogenous heterogeneous markups. This heterogeneity in markups results in variation in the marginal revenue product of labor (MRPL) across firms.¹ Changes in transportation costs affect the misallocation in the economy since they change the market power that firms have and the distribution of markups. We contribute to the trade literature by extending a model similar to the one used by [Atkeson and Burstein \(2008\)](#) and [Edmond, Midrigan, and Xu \(2014\)](#) to include multiple non-symmetric economies for our quantitative exercises.

We also contribute to the literature on transportation infrastructure and development by considering the potential benefits of changing markups after improvements in infrastructure. Our framework allows us to separate the standard Ricardian channel from the pro-competitive and the terms of trade channels to account for the welfare gains stemming from lower transportation costs. Our decomposition of the welfare gains follows the methodology developed by [Holmes, Hsu, and Lee \(Forthcoming\)](#). The Ricardian component is simply the gains in real income if all firms charged their marginal cost. This component maps back to welfare in model in which firms have constant markups or operate in perfect competition. The pro-competitive component relates to the misallocation arising from the heterogeneous markups charged by firms. This misallocation

¹Recent papers have highlighted misallocation as a source of cross-country income differences. These papers include [Hsieh and Klenow \(2009\)](#), [Restuccia and Rogerson \(2008\)](#), [Guner, Ventura, and Xu \(2008\)](#).

arises due to the fact that the consumption of goods produced by firms with high markups is inefficiently low. The last component is the terms of trade, which compares the average markup of the goods sold with the average markup of the goods purchased by the state. *Ceteris paribus*, states with high markups on the goods that they sell relative to the goods that they buy, will enjoy a higher real income.

In order to discipline the key parameters of the model, we make use of a rich micro data set of Indian manufacturing plants and geospatial data on the Indian road network at several points in time. First, we combine two separate sets of micro-level data - the Annual Survey of Industries (ASI) and the National Sample Survey (NSS) - in order to construct a very detailed description of the Indian manufacturing sector over time, covering both formal and informal firms. From these data, among other things, we derive measures of internal trade and prices paid across destinations. Second, we use GIS information on the entire Indian road network in order to compute measures of effective distance across destinations, taking into account the quality of the roads and the evolution of the transportation network over time.

We derive a set of structural equations from the model that allow us to estimate the key parameters. One implication of the model is that transportation costs can be identified by comparing the prices charged by monopolistic firms across destinations. This is the case because the prices charged by these firms only depend on transportation costs across locations, as the level of competition they face is constant. To implement this strategy, we first identify all the goods that are produced by only one plant in India. We then regress the prices paid for these goods across locations against the effective distance between the location of the monopolistic producer and the location of the plant that uses it as an intermediate input. Our measure of effective distance takes the least costly path along the Indian road network into account, incorporating differences in road quality caused by the presence of the GQ. Using the coefficients of the regression we construct a matrix of bilateral transportation costs between Indian states for both 2001 (before the GQ) and 2006 (after the GQ).

Our next step is to identify the elasticity of substitution across sectors. This parameter governs the price elasticity of the demand curve of a sector, and hence it determines the market power of firms that are monopolists in their sector. We use intermediate input usage data to construct trade flows for goods produced by monopolists. For these goods, the model implies a gravity equation that relates bilateral flows to transportation costs. We use internal trade flows and estimated transportation costs to measure how trade flows decline with increases in transportation costs. We set the elasticity of substitution across sectors to match the gravity equation of monopolist trade flows in the data.

We next estimate the elasticity of substitution across products within the same sector. This parameter determines the elasticity of demand faced by firms with a small market share in their sectors. In order to do that, we exploit a linear relationship between sectoral shares and labor

shares implied by the model. In the model, firms with higher sectoral shares also charge higher markups, and hence have lower labor shares. The strength of this relationship depends on the gap between the elasticity of substitution both across and within sectors. Given our estimate of the elasticity of substitution across sectors, we set an elasticity of substitution within sectors that matches the slope coefficient of an OLS cross-sectional regression of the labor shares of plants against their sectoral shares. The values of these elasticities are crucial to quantify the size of the pro-competitive gains, since they determine the amount of misallocation that can potentially occur in the economy. In particular, the gap between the two elasticities determine to what extent firms with higher sectoral shares enjoy more market power in their sector and charge higher markups. We set the rest of parameters of the model such that, in equilibrium, the model reproduces some important features of the Indian manufacturing sector.

Next, we quantify the effects of the construction of transportation infrastructure. To do so, we measure the impact of changing the transportation costs to those estimated for 2001, before the construction of the GQ, in the model. We find that the aggregate gains for India derived from the construction of the GQ are 2.04% of real income. Because we only considered the manufacturing sector in our model, the result is in terms of manufacturing value-added. Putting the welfare gains from the model into dollar amounts yields a gain of *\$3.1 billion per year*. Since the GQ cost \$5.6 billion to build, our model predicts that it would take only two years for India to recover the initial cost.

Importantly, we also find wide heterogeneity in terms of welfare effects across states. States closest to the GQ gained the most, while those farthest had modest or even negative welfare gains. The negative effects stemming from the construction of the GQ come from the interplay of two forces at work. First, these states benefited from lower transportation costs. Despite their location, shipments can still travel for at least part of the route on the GQ, allowing them to import goods at a lower price. Second, the states that are closer to the GQ start trading more intensively with each other, which implies increases in wages in these states. This translates into an increase of the cost of purchasing goods from these states. Some states which are far from the GQ lost because this higher cost of purchasing goods from other states was not compensated for by the decrease in prices due to lower transportation costs.

We find that, on aggregate, pro-competitive gains account for 19% of the total gains from the construction of the GQ. These pro-competitive gains are positive in all but one state, and can reach up to 24% in some of them. This means that the GQ helped reduce the misallocation arising from variation in the market power of firms. There are two other important things to note. First, pro-competitive gains are strongest for states along the GQ relative to states farther away. Second, pro-competitive gains help mitigate the losses of states far from the GQ.

We also find important changes in trade patterns among Indian states. In particular, we find that there was *trade diversion*: states close to the GQ diverted their trade towards states that

experienced a greater decline in transportation costs. In fact, some states far from the GQ, such as the Northeast region of the country, became less open (value of exports as a fraction of state income) after the construction of the GQ due to this effect. Furthermore, we find that trade in India became more regionally concentrated. States that are both on the GQ traded more intensively as well as the cases in which neither state is located on the GQ. Often, trade between states that are on the GQ and off the GQ *declined*.

Lastly, we apply a difference-in-difference strategy to our data in order to isolate the effect of the GQ on prices and compare it with the outcome of the calibrated model. To do so, we compare the prices paid for intermediate goods by firms close to the GQ and by those that are further away before and after the construction of the highway. This strategy accounts for the potential endogeneity of infrastructure development, by focusing on price changes in non-nodal districts close and further away from the road network. We find that, in the data, the change in prices in non-nodal districts crossed by the GQ was around 36 percentage points lower than those in districts further away, implying a 1.57 times bigger decrease in prices in districts crossed by the GQ. We find a similar effect in magnitude when computing the equivalent differential effect with our calibrated model. The model predicts that the decrease in prices in states crossed by the GQ is 2.70 times larger than in average state.

The remainder of the paper is organized as follows. In Section 2 we present the related literature. In Section 3 we describe the main characteristics of the road network in India. In Section 4 we present the model. In Section 5 we describe our data, which we use to calibrate the model in Section 6. In Section 7 we present and discuss our quantitative results. In Section 8 we present quantitative results for alternative scenarios to the GQ. Finally, Section 9 concludes.

2 Related Literature

Our work builds on papers that quantify the gains from building transportation infrastructure using general equilibrium models of trade. The pioneering work of Donaldson (Forthcoming) studies the benefits from the construction of railroads in colonial India. Herrendorf, Schmitz, and Teixeira (2012) study the impact of transportation improvements during the 19th century United States transportation revolution on the regional distribution of population and welfare. Adamopoulos (2011) and Sotelo (2014) study the income losses due to high transportation costs for agricultural products in developing countries. Allen and Arkolakis (Forthcoming) use a novel theoretical framework to calculate the welfare effects of the construction of an interstate highway system in the United States. In a more recent paper, Donaldson and Hornbeck (2014) develop the “market access” approach in order to assess the gains from the construction of the railroads in the United States. Alder (2014) uses this approach to study the impact of the hypothetical construction in India of a highway network similar to that of China. All the papers in this literature do not consider how reductions in transportation costs affect markups. To our knowledge, our paper

is the first attempt to evaluate how improvements in infrastructure impact welfare through the pro-competitive channel.²

Our paper is also related to a large set of work that studies the pro-competitive effects of international trade. These papers study how trade affects the markups that firms charge and the resulting impact on welfare. [Markusen \(1981\)](#) is an example of early work in this area. [Bernard, Eaton, Jensen, and Kortum \(2003\)](#), [de Blas and Russ \(2010\)](#), [Devereux and Lee \(2001\)](#), [Epifani and Gancia \(2011\)](#), [Licandro and Impullitti \(2013\)](#), and [Holmes, Hsu, and Lee \(Forthcoming\)](#) study the pro-competitive effects of trade in a setting with oligopolistic competition. [Melitz and Ottaviano \(2008\)](#) study these effects in a setting with monopolistic competition. We differ from these papers in that our aim is to *quantify* the pro-competitive effects of reducing transportation costs. Such quantification is useful since theory is ambiguous as to whether pro-competitive effects are quantitatively significant. In fact, theory indicates that pro-competitive effects can be negative, as stressed by [Arkolakis, Costinot, Donaldson, and Rodríguez-Clare \(2012\)](#).

In this sense, our paper builds on [Edmond, Midrigan, and Xu \(2014\)](#). They quantify the pro-competitive gains channel by using a model in which Taiwan trades with a symmetric partner, which represents the rest of the world. We extend this analysis to a non-symmetric multi-country setting. This setting accounts for changes in labor income and terms of trade, which are not present in the symmetric case. Furthermore, the extended case allows for heterogeneity of the pro-competitive effects across Indian states and accomodates changes in trade patterns such as trade diversion. [Feenstra and Weinstein \(2010\)](#) quantify the effects of changing markups on US welfare in a context of monopolistic competition.³

Our paper is also related to [Arkolakis, Costinot, and Rodríguez-Clare \(2012\)](#) and the set of commonly used trade models that they consider in their paper. In these models, all firms charge the same markup or operate under the assumption of perfect competition. Our paper is different because it also considers the effects of changing markups after a reduction in trade costs.

Our work contributes to a large literature on the misallocation of resources across firms. Papers from this literature include [Restuccia and Rogerson \(2008\)](#), [Guner, Ventura, and Xu \(2008\)](#), [Hsieh and Klenow \(2009\)](#), and [Gabler and Poschke \(2013\)](#).⁴ We contribute to these papers by evaluating

²See [Redding and Turner \(2014\)](#) for a recent comprehensive survey of the literature on the relationship between the spatial distribution of economic activity and transportation costs.

³[Asturias and Petty \(2013\)](#) quantify pro-competitive gains in the transportation industry after a trade liberalization.

⁴There are many recent papers that emphasize the misallocation of resources across firms as a source of income difference across countries. [Buera, Kaboski, and Shin \(2011\)](#), [Midrigan and Xu \(2014\)](#), [Moll \(Forthcoming\)](#), [Caselli and Gennaioli \(2013\)](#), [Erosa and Allub \(2013\)](#), and [Lopez-Martin \(2013\)](#) focus on financial frictions. [Gourio and Roys \(2013\)](#), [Garicano, Lelarge, and Reenen \(2012\)](#) and [Garcia-Santana and Pijoan-Mas \(2014\)](#) study the marginal effect of size-dependent policies in France and India respectively. [Peters \(2013\)](#) calibrates a model of imperfect competition with heterogeneous firms to Indonesian data to investigate the impact of misallocation on growth. See [Restuccia and Rogerson \(2013\)](#) and [Hopenhayn \(2014\)](#) for nice surveys of the literature.

how improvements in transportation infrastructure alleviate the misallocation.

3 Roads in India and the Golden Quadrilateral

India has the second largest road network in the world, spanning approximately 3.3 million kilometers. It comprises expressways, national highways (79,243 km), state highways (131,899 km), major district highways, and rural roads. Roads play an important role in facilitating trade in India: approximately 65 percent of freight in terms of weight and 80 percent of passenger traffic are transported on roads.⁵ National highways are critical since they facilitate interstate traffic and carry about 40 percent of the total road traffic.

At the end of the 1990s, India's highway network left much to be desired. The major economic centers were not linked by expressways, and only 4% of the roads had four lanes. In addition to the limited lane capacity, more than 25% of national highways were considered to be in poor surface condition.

Congestion was also an important issue, with 25% of roads categorized as congested. This was due to poor road conditions, increased demand from growing traffic, and crowded urban crossings. Frequent stops at state or municipal checkpoints for government procedures such as tax collection or permit inspection also contributed to congestion (see [World-Bank \(2002\)](#)).

In order to improve this situation, the Indian government launched the National Highways Development Project (NHDP) in 2001. The goal of the initiative was to improve the performance of the national highway network. The first phase of the project involved the construction of the Golden Quadrilateral (GQ), a 5,800 km highway connecting the four major metropolitan areas via four and six-lane roads. The four metropolitan centers that were connected include Delhi, Mumbai, Chennai, and Calcutta. Apart from the increase in the number of lanes, additional features of a high-quality highway system were constructed. These features include grade separators, over-bridges, bypasses, and underpasses.

The cost was initially projected to be 600 billion rupees (equivalent to \$13.4 billion in 2006). As of October 2013, the total cost incurred by the Indian government was approximately half of the projected sum (250 billion rupees or \$5.6 billion). In [Section 7](#), we compare this cost with the benefits predicted by our model.

The second phase of the NHDP consists in the construction of the North-South and East-West corridor, a highway that aims to connect Srinagar in the north to Kanyakumari in the South and, Silchar in the east to Porbandar in the west. Although this second phase was approved in 2003, there have been many delays for its construction, and less than 10% of the work was completed

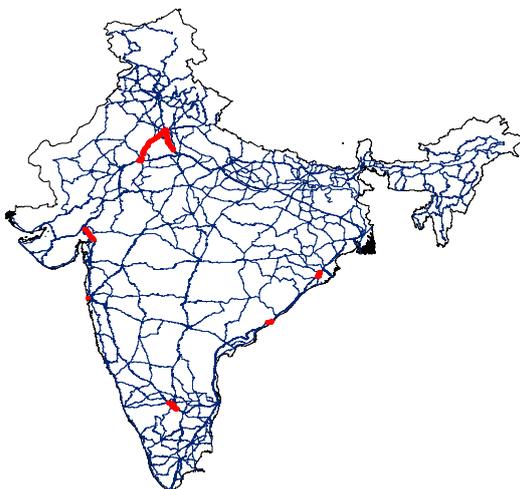
⁵The importance of railroads has declined in India over time. Although in 1950 more than 80% of freight traveled by rail, this figure has steadily decreased over the decades. At present, rail carries mostly bulk freight such as iron, steel, and cement. Non-bulk freight represents only around 3 percent of total rail freight in terms of ton-km.

by the end of 2006. Thus, we will not consider that project in our analysis.

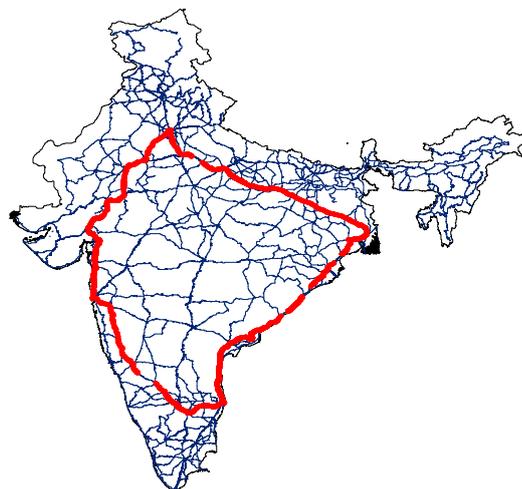
Geospatial data We have geospatial data that consists of all the National Highways of India, which was supplied by ML Infomap. We complement this data using information provided by the National Highways Authority of India (NHAI) on the completion dates of various portions of the GQ. The GQ consisted of 127 stretches and we have detailed information about the start and end points.⁶ Figure I shows the evolution of the GQ (in red) in 2001 and 2006. Although the GQ was finished in 2013, more than 90 percent of the project was completed by 2006. We will link this geospatial data to manufacturing data for 2001 and 2006.

FIGURE I
ROAD NETWORK IN INDIA AND THE GQ

A: GQ construction in 2001



B: GQ construction in 2006



Panel A of Figure I shows a map with the road network in India at the end of 2001, including the sections of the Golden Quadrilateral that were finished by then (around 10% of the total project). Panel B shows the same map but for 2006 (around 95% of the total project).

4 Model

In this section, we present our static general equilibrium model of internal trade. We consider N asymmetric states trading with each other. In each state, there is a measure 1 of sectors. Within each sector, there is a finite number of firms that compete in an oligopolistic manner. Labor is immobile across states.⁷

⁶See nhai.org/completed.asp and the Annual Reports of NHAI.

⁷Interstate migration flows in India are among the lowest in the world. According to the 2001 Indian Population Census, around 96% of people report to be living in the state where they were born.

4.1 Consumers

In each state n , there is a representative household with a utility function:

$$C_n = \left(\int_0^1 C_n(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \quad (1)$$

where $C_n(j)$ is the composite good of sector j and $\theta > 1$ is the elasticity of substitution across composite goods of different sectors. The sector-level composite good is defined as:

$$C_n(j) = \left(\sum_{o=1}^N \sum_{k=1}^{K_{oj}} c_n^o(j, k)^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}}, \quad (2)$$

where $c_n^o(j, k)$ is the good consumed by state n and provided by firm k in sector j shipped from state o , N is the number of states, K_{oj} is the number of firms that operate in sector j in state o , and $\gamma > 1$ is the elasticity of substitution between goods produced by different firms in the same sector. We assume that $\gamma > \theta$, which means that goods are more substitutable *within* sectors than *between* sectors.

The budget constraint of the representative household in state n is given by:

$$\int_0^1 \left(\sum_{o=1}^N \sum_{k=1}^{K_{oj}} p_n^o(j, k) c_n^o(j, k) \right) dj = W_n L_n + \Pi_n, \quad (3)$$

where W_n is the equilibrium wage, L_n is the labor endowment, and Π_n is the income derived from the profits of firms located in n . Note also that $C_n = W_n L_n + \Pi_n$.

4.2 Firms

In each sector j in state o , there is a finite number of K_{oj} firms. Firms draw their productivity from a distribution with CDF $G(a)$. A firm with a productivity level a has a constant labor requirement of $1/a$ to produce one unit of good. Because firms do not pay any fixed cost to operate in a market, they sell to all N states.

To determine the firm's pricing rule, we first find the demand faced by that firm. Equations (1), (2), and (3) generate demand:

$$c_n^o(j, k) = \left(\frac{P_n}{P_n(j)} \right)^\theta \left(\frac{P_n(j)}{p_n^o(j, k)} \right)^\gamma C_n, \quad (4)$$

where

$$P_n(j) = \left(\sum_{o=1}^N \sum_{k=1}^{K_{oj}} p_n^o(j, k)^{1-\gamma} \right)^{\frac{1}{1-\gamma}} \quad (5)$$

is the price index for sector j in state n and

$$P_n = \left(\int_0^1 P_n(j)^{1-\theta} dj \right)^{\frac{1}{1-\theta}} \quad (6)$$

is the aggregate price index in state n .

Firms within sectors compete à la Cournot. Firm k takes as given the demand characterized by equation (4) and the quantity supplied by competitor firms in the sector and solves the following problem:

$$\pi_d^o(j, k) = \max_{c_d^o(j, k)} p_d^o(j, k) c_d^o(j, k) - \frac{W_o \tau_d^o}{a_o(j, k)} c_d^o(j, k), \quad (7)$$

where $a_o(j, k)$ is the productivity of firm j in sector k in state o , τ_d^o is the iceberg transportation cost to ship one unit of good from o to d . Note that, because of the constant returns to scale technology, the problem of a firm across all different destinations can be solved independently. The solution of this problem is:

$$p_d^o(j, k) = \frac{\epsilon_d^o(j, k)}{\epsilon_d^o(j, k) - 1} \frac{W_o}{a_o(j, k)} \tau_d^o, \quad (8)$$

where

$$\epsilon_d^o(k, j) = \left(\omega_d^o(j, k) \frac{1}{\theta} + (1 - \omega_d^o(j, k)) \frac{1}{\gamma} \right)^{-1}, \quad (9)$$

and $\omega_d^o(k, j)$ is the market share of firm k in sector j in state d :

$$\omega_d^o = \frac{p_d^o(j, k) c_d^o(j, k)}{\sum_{o=1}^N \sum_{k=1}^{K_{oj}} p_d^o(j, k) c_d^o(j, k)}. \quad (10)$$

The price that firms set in equation (8) is similar to the markup over marginal cost that is found in a setup with monopolistic competition. The difference is that the markups depend on the market structure of the sector. For example, suppose that there is only one firm in a given sector, then that firm will compete only with firms operating in other sectors and its demand elasticity will be equal to θ . This means that the firm faces the sector-level elasticity of demand. At the other extreme, suppose that a firm's market share is close to zero, then the firm will compete only with firms in its own sector and its elasticity of demand will be equal to γ . Notice that a given firm will generally have different market shares and hence charge different markups across different destinations.

The aggregate profits of firms in state n are characterized by:

$$\Pi_n = \int_0^1 \left(\sum_{n=1}^N \sum_{k=1}^{K_{oj}} \pi_n^o(j, k) \right) dj. \quad (11)$$

4.3 Balanced Trade and Labor Clearing Condition

All states n must have balanced trade:

$$\int_0^1 \left(\sum_{o=1, o \neq n}^N \sum_{k=1}^{K_{oj}} p_n^o(j, k) c_n^o(j, k) \right) dj = \int_0^1 \left(\sum_{d=1, d \neq n}^N \sum_{k=1}^{K_{nj}} p_d^n(j, k) c_d^n(j, k) \right) dj. \quad (12)$$

The labor clearing condition for state n is:

$$\int_0^1 \left(\sum_{d=1}^N \sum_{k=1}^{K_{nj}} \frac{c_d^n(j, k)}{a_n(j, k)} \tau_d^n \right) dj = L_n. \quad (13)$$

4.4 Definition of Equilibrium

Equilibrium. For all states n and n' , sectors j , and firms k_{nj} , an equilibrium is a set of allocations of consumption goods $\{c_{n'}^n(j, k), C_n(j)\}$, firm prices $\{p_{n'}^n(j, k)\}$, sector prices $\{P_n(j)\}$, and aggregate variables $\{W_n, P_n, \Pi_n\}$ such that:

1. Given firm prices, sector prices and aggregate variables, $\{c_{n'}^n(j, k)\}$ is given by (4), $C_n(j)$ by (2), and they solve the consumer's problem in (1), and (3).
2. Given aggregate variables, $p_{n'}^n(j, k)$ is given by (8), (9), and (10), and solves the problem of the firm in (7).
3. Aggregate profits satisfy (11), aggregate prices satisfy (6), and sector prices satisfy (5).
4. Trade flows satisfy (12).
5. Labor markets satisfy (13).

4.5 Misallocation in the Model

Misallocation in this setting arises due to *dispersion* in markups across producers: the marginal revenue product of labor (MRPL) of firms with high markups becomes inefficiently high, which implies that the goods produced by these firms are under-consumed relative to the goods produced by firms with low markups.⁸ The model is hence relevant to think about the cross-firms misallocation emphasized by Restuccia and Rogerson (2008), Hsieh and Klenow (2009), and Guner, Ventura, and Xu (2008), among others.

These papers have interpreted this misallocation as resulting from government policies that create idiosyncratic distortions at the firm level, which affect the optimal decision of firms. In our model, dispersion in MRPL is caused by dispersion in the market power, which translates into variation in markups: firms with higher productivity draws, charge higher markups because they are able to capture bigger market shares. The constant returns to scale technology implies that the MRPL of a firm operating in state o is $W_o^{\epsilon(j,k)/(\epsilon(j,k)-1)}$. Thus, firms with high productivity draws (and high markups) also have a high MRPL.

This misallocation is hence similar in nature to the one studied by Restuccia and Rogerson (2008) and Hsieh and Klenow (2009), in the particular case in which the size of the idiosyncratic distortions of firms is positively correlated to their productivity. Firms with high productivity draws are smaller in size than they would be in the case of perfect competition. Thus, India's aggregate welfare would increase by reallocating labor from firms with low productivity draws (low-markup firms) to firms with high productivity draws (high-markup firms).

⁸MRPL is the price of the good multiplied by the marginal product of labor. This is equivalent to the TFPR in Hsieh and Klenow (2009) since labor is the only factor of production, and the production function exhibits constant returns to scale.

5 Plant-Level Data on Indian Manufacturing

In this section, we describe the construction of the data set used in the paper. We link firm-level data on the Indian manufacturing sector with geospatial data in order to construct two snapshots in time (2001 and 2006) with detailed manufacturing data and road quality data. The data provides the necessary information to analyze how changes in infrastructure quality affect the manufacturing sector. See Section (A) of the Technical Appendix for details about the data.

We first construct a representative sample of the Indian manufacturing sector. To do so, we merge two separate sets of plant-level data: the Annual Survey of Industries (ASI) and National Sample Survey (NSS). The ASI targets plants that are in the formal sector. It is the main source of manufacturing statistics in India and has been commonly used in the development literature.⁹ This consists of plants that have more than 10 workers if they have electricity and 20 if they do not. The information provided by the establishments is very rich, covering several operational characteristics: sales, employment, capital stock, wage payments, and expenditures on intermediate goods. The NSS covers all informal establishments in the Indian manufacturing sector. “Informal” refers to all manufacturing enterprises not covered by the ASI. The survey is conducted every five years by the Indian Ministry of Statistics, as one of the modules in the Indian National Sample Survey.

The process of merging the data from the ASI and NSS is straightforward since very similar questions are used to collect the data. Thus, we can create a representative sample of manufacturing plants in India using the weights provided. After merging the ASI and NSS, we have around 190,000 observations for the fiscal year 2000-2001 and 140,000 observations for the fiscal year 2005-2006. Once these observations are properly weighted, each year we have around 17 million manufacturing plants in our data, which employ around 45 million workers.

It is important to note the huge differences in productivity between formal and informal plants in India. Informal plants account for around 80% of employment and around 20% of total value-added. Thus, it is crucial to merge these data sets to have an accurate picture of the Indian manufacturing sector.

Prices and the consumption of intermediates The ASI and NSS contain detailed information about production and intermediate good usage. For each plant in our data, we observe the value and physical quantity of production and intermediate input usage broken down by product.¹⁰ This means that we can compute the output prices charged by plants and the input prices paid by plants.¹¹ To compute the price of inputs, we divide the expenditure on a particular good by

⁹See for instance Aghion, Burgess, Redding, and Zilibotti (2005), Chari (2011), Hsieh and Klenow (2009) and Bollard, Klenow, and Sharma (2013).

¹⁰All plants report intermediate inputs imported from outside India separately from those which are not imported. This is important for our analysis, since we abstract from international trade in this paper.

¹¹Although these data sets are becoming widely used (for instance see Garcia-Santana and Pijoan-Mas (2014) and Hsieh and Klenow (2009) for example), not much attention has been paid to the price information. A notable

physical units.

The product classification used in both the ASI and NSS is the Annual Survey of Industries Commodities Classification (ASICC). The ASICC contains around 5,400 different classified products, which are very narrowly defined. For instance, the ASICC distinguishes between different types of black tea: leaf, raw, blended, unblended, dust, etc. In the processed mineral category, for example, the ASICC distinguishes between around 12 different types of coke.

6 Inferring Parameter values

We calibrate our model to 2006, when the GQ was already in place. Our calibration strategy is as follows. Our model is characterized by (i) a set of bilateral iceberg costs between states $\{\tau_d^o\}_{d=1}^{d=N}$ for all o , (ii) the elasticity of substitution across sectors θ , (iii) the elasticity of substitution within sectors γ , (iv) a number of producers for each state-sector K_{ij} for i and j , (v) a set of labor endowments $\{L_n\}_{n=1}^{n=N}$ of the states, and (vi) the parameters governing the productivity distribution of the firms.

Using structural equations from the model, we first estimate the transportation costs and the two elasticities (Sections 6.1, 6.2, 6.3, and 6.4). We next plug into the model the number of firms per state-sector that we observe in the data, and calibrate the labor endowment of the states and the productivity distribution to match relevant statistics of the Indian manufacturing sector (Section 6.5).

6.1 Estimating Transportation Costs

The first step is to infer transportation costs. To do so, we use pricing data from intermediate inputs used across India. Equation (8) shows that the prices charged by firms depend both on transportation costs and market shares in the destination market.¹² In order to identify transportation costs, we exploit one implication of the model: variation in prices for monopolists (i.e. firms with market shares equal to one) are due solely to variation in transportation costs across destinations. To see this formally, equation (8), along with the fact that a monopolist firm faces a demand elasticity given by θ , implies that the firm will charge:

$$p_d^o(j, k) = \frac{\theta}{\theta - 1} \frac{W_o}{a_o(j, k)} \tau_d^o. \quad (14)$$

Then, the relative price charged by a monopolist across destinations is:

$$\frac{p_d^o(j, k)}{p_{d'}^o(j, k)} = \frac{\tau_d^o}{\tau_{d'}^o},$$

exception is [Kothari \(2013\)](#).

¹²[Atkin and Donaldson \(2014\)](#) also studies issues regarding the fact that dispersion in prices contain information about markups and transportation costs.

which only depends on the ratio of transportation costs. Hence, the prices charged by monopolists across states reveal differences in transportation costs.

Empirically, we define a monopolist firm as a plant selling at least 95 percent of the value of each 5-digit ASICC product nationally. Using the ASI and NSS for the years 2001 and 2006, we identify 261 products that are manufactured by monopolists.¹³ The largest category is “Manufacture of chemicals and chemical products,” which contains around 40 percent of the products identified. This is consistent with the nature of the chemical industry, in which production is often concentrated in one plant due to economies of scale and then shipped to many locations.¹⁴

Once we have identified the products manufactured by monopolists, the strategy is to use the variation in prices across locations where they were used as intermediate inputs to identify transportation costs. We regress variation in prices on a measure of transportation costs that we call effective distance. This measure takes into account the least costly path to go from origin to destination given the road structure. Furthermore, the varying road quality is also incorporated into this measure. The price of an input in each district is computed as the weighted average of the prices paid by all the plants that use that input in that district.

We estimate equation (14) as follows:

$$\log p_{d,t}^o(j, k) = \beta \log \text{Effective Distance}_{d,t}^o + \sum_o \delta_o + \sum_j \alpha_j + \sum_t \eta_t + \epsilon_{d,t}^o(j, k) \quad (15)$$

where $p_{d,t}^o(j, k)$ is the average price in district d paid for product j produced by a monopolist located in district o , δ_o are a set of districts of origin fixed effects, α_j a set of product fixed effects, η_t are time dummies, and $\epsilon_{d,t}^o(j, k)$ is the error term. The origin fixed effects control for local wages and the product fixed effects control for firm productivity.¹⁵

In order to compute the effective distance, we first convert the national highway network into a graph. The graph consists of a series of nodes that are connected by arcs. In our case, a node is the most populous city in each district and an arc is the national road that connects them. An arc is referred to as being GQ or non-GQ, depending on whether it was completed in the specific year. We then use Dijkstra’s shortest-path algorithm to construct a matrix of lowest-cost distances between all the districts for the years 2001 and 2006. The transportation costs in these two years are different since this algorithm takes into account the fact that traveling on a better quality road (i.e. across the Golden Quadrilateral) is less costly. Specifically, we assume that:

¹³We exclude goods that are not used as intermediate inputs in at least five districts.

¹⁴A description of the production structure of the chemical industry in India can be found at http://smallb.in/sites/default/files/knowledge_base/reports/IndianChemicalIndustry.pdf

¹⁵We exploit the cross-sectional variation using the two years in our sample to estimate the relationship between prices and effective distance in equation (15). Although we calibrate the model to the year 2006, we proceed in this way in order to maximize power in our estimations.

$$\begin{aligned} \text{Effective Distance}_{n_2}^{n_1} &= \text{Road Distance}_{n_2}^{n_1} \text{ if GQ} = 0 \\ \text{Effective Distance}_{n_2}^{n_1} &= \alpha \text{Road Distance}_{n_2}^{n_1} \text{ if GQ} = 1, \end{aligned} \tag{16}$$

where n_1 and n_2 are nodes, and α indicates the effective distance of the GQ relative to stretches of road that are not GQ. We use a value of $\alpha = 0.52$, which is based on average speeds calculated by the World Bank.¹⁶ This value of α indicates that if a given stretch is GQ, the effective distance is roughly half of what it is if it is not GQ. The effective distance used to estimate equation (15) is the sum of the effective distance along all the arcs traveled along the shortest path.

Table I presents the results from estimating equation (15). In column (1), we show that a 10 percent increase in the effective distance is associated with a 0.86 percent increase in the price of the good.¹⁷ In column (2), we use a more flexible specification, in order to incorporate potential non-linearities in transportation costs. Note that kind of flexible specification is commonly used to estimate the parameters of trade models using gravity equations, such as in Eaton and Kortum (2002) and Waugh (2010). We include ten deciles of log effective distance, and find that the highest deciles are associated with large increases in the price of the good. We find, for instance, that the prices paid at destinations falling in the second decile of effective distance (around 280 km) are 37% higher than the prices paid at destinations within the first decile (70 km on average). The effect is particularly strong for destinations that are very far from the location where production takes place: the prices are around 52% higher when the effective distance to the destination is in the 10th percentile of the distribution. The 10th decile includes districts located more than 1,800 kilometers away in effective distance, which is roughly the road distance from New York City to Des Moines, Iowa. Although the overall pattern is increasing, the effect seems to be non-monotonic. For example, the coefficient associated with the third decile is 8 percentage points lower than the second decile coefficient. In order to avoid having non-monotonic transportation costs to effective distance in the model, we assume that the relationship between iceberg costs and effective distance is given by a discrete cubic function $g(\text{Coeff. of Effective Distance}_d^o)$, and set the parameters that better fit the coefficients implied by the regression. See Section (B) of the Technical Appendix for details.

Lastly, we assume that the iceberg cost for all destinations in the first decile is equal to one.

¹⁶The value of α is based on the fact that the average speed on a national highway is between 30 and 40 km/h according to World-Bank (2002). By contrast, the average speed on the GQ is estimated to be around 75 km/h. This can be computed by calculating the predicted average speed traveling from a random sample of origins-destinations over GQ roads using Google Maps.

¹⁷Costinot and Donaldson (2012) estimate a similar regression for the price of agricultural goods and their distance to the nearest wholesale market over time in the United States. They find coefficients for distance of a similar magnitude during the 1880-1920 period (0.09 to 0.14). Note that the effective distance is exactly equal to the road distance before the construction of the GQ.

The iceberg cost predicted for all other deciles becomes:

$$\hat{\tau}_d^o = e^{\text{g(Coeff. of Effective Distance}_d^o)}. \quad (17)$$

Direct measures of transportation prices In order to have additional estimates of the transportation costs across Indian locations, we have assembled an additional dataset that contains information on prices charged for shipping a container by truck within India. In particular, we have collected pricing data for shipping a container of size 20 ft x 8 ft x 8.5 ft for around 900,000 origin-destination Indian city pairs. Using this dataset we construct measures of bilateral iceberg costs as a function of effective distance and compare them with the ones we obtain from Equation (17). The overall pattern of the two sets of iceberg costs is remarkably similar. Importantly, in both cases, transportation costs increase more than linearly at higher levels of the distribution of effective distance. See Section (C) of the Technical Appendix for further details about the construction of these transportation costs.

What do transportation costs look like? As a starting point, we will take the district of New Delhi (located in the National Capital Territory of Delhi) in the year 2001. Panel A of Figure II shows a map of the transportation costs to all districts from New Delhi. The legend on the map shows transportation costs divided into quartiles. The figure also shows that only a small portion of the GQ was upgraded by this point (depicted in red). The first thing to notice is the concentric circles that surround New Delhi. This means that the further the destination, the higher the transportation costs. The concentric circles also show that straight-line distances are highly correlated to the shortest path on the highway system. The reason is that the highway system is dense, as can be seen in Figure I. The second thing to notice is the general level of transportation costs. The map shows iceberg costs of 1.43-1.50 for transporting goods from New Delhi to the southern tip of India.

Our next step is to look at transportation costs from New Delhi in the year 2006 (panel B of Figure II), after a large part of the upgrade of the GQ had been completed. The color categories for the map have not changed from panel A, so that the colors are comparable across maps. The lighter colors reflect a general decrease in transportation costs.

6.2 Estimating the Across-Sector Elasticity of Substitution (θ)

The next step consists in estimating of elasticity of substitution across sectors. The identification strategy is to compare the differences in the transportation costs of the goods produced by monopolists across destinations with the trade flows across these destinations.

Formally, we derive a gravity equation implied by the model for the trade flows of monopolist firms. Combining equations (4) and (14), we derive the following condition for the trade flow values:

TABLE I
IMPACT OF ROAD DISTANCE AND INFRASTRUCTURE QUALITY
ON PRICES

	(1)	(2)
<u>Dep. Variable:</u> Log price at district of destination		
Log Effective Distance	0.086*** (0.023)	
Log Effective Distance 2 nd decile		0.371*** (0.115)
Log Effective Distance 3 th decile		0.298*** (0.114)
Log Effective Distance 4 th decile		0.137 (0.112)
Log Effective Distance 5 th decile		0.168 (0.131)
Log Effective Distance 6 th decile		0.398*** (0.121)
Log Effective Distance 7 th decile		0.355*** (0.133)
Log Effective Distance 8 th decile		0.445*** (0.142)
Log Effective Distance 9 th decile		0.341** (0.141)
Log Effective Distance 10 th decile		0.516*** (0.136)
District of Origin Fixed Effects	YES	YES
Product Fixed Effects	YES	YES
Year Fixed Effects	YES	YES
Observations	2,235	2,235
R-squared	0.876	0.881

Table I shows the estimation of equation (15). The dependent variable is the log price of a product manufactured by a monopolist at destination. The variable of interest is the effective distance between the district where the product is manufactured and the district of destination. Effective distance is defined as the lowest cost path between both districts, taking into account road distance and infrastructure quality. Specifically, going across the Golden Quadrilateral reduces road distance 48 per cent, relative to roads not in the Golden Quadrilateral. The lowest path is computed by means of road networks and applying the Dijkstra's search path algorithm. Column (1) uses a linear specification of effective distance, whereas column (2) estimates a non-linear specification, using 10 deciles of effective distance. District of origin, product and year -2001 and 2006- fixed effects are included. Robust standard errors are in parenthesis. Significance levels: *: 10%; **: 5%; ***: 1%.

$$\begin{aligned} \log c_d^o(j, k)p_d^o(j, k) &= (1 - \theta) \log W_o + (\theta - 1) \log a_o(j, k) + \log P_d^\theta Y_d \\ &+ (1 - \theta) \log \tau_d^o + (1 - \theta) \log \frac{\theta - 1}{\theta}. \end{aligned} \quad (18)$$

The model predicts that higher transportation costs reduce trade flows, and the strength of this relationship depends on the value of θ . The intuition behind this identification strategy is that if small differences in transportation costs across destinations are associated with big differences in trade flows, then the value of θ must be high (and vice versa). It is also important to note that this straightforward relationship only holds when firms are monopolists.

We estimate equation (18) as follows:

$$\log \text{Sales}_{d,t}^o(j, k) = \beta \log \hat{\tau}_{d,t}^o + \sum_o \delta_o + \sum_j \alpha_j + \sum_d \lambda_d + \sum_t \eta_t + \epsilon_{d,t}^o(j, k) \quad (19)$$

where $\text{Sales}_{d,t}^o(j, k)$ is the value of sales of product j in year t consumed in district d and produced by a monopolist located in district o , $\hat{\tau}_d^o$ is the predicted iceberg transportation cost between districts o and d (obtained from equation (17)), δ_o is a set of districts of origin fixed effects, α_j is a set of product fixed effects, λ_d is a set of districts of destination fixed effects, η_t is a set of year fixed effects, and $\epsilon_{d,t}^o(j, k)$ is the error term. The origin fixed effect controls for local wages. The product fixed effect controls for firm productivity. The destination fixed effect controls for market size and aggregate prices at the destination.

Table II presents the results of estimating equation (19). We find that higher transportation costs are associated with lower trade flows at statistically significant levels. The empirical specification indicates that transportation costs which increase by 10 percent are associated with an 8.3 percent decrease in trade flows. This relationship implies that the value of θ is 1.83.

TABLE II
GRAVITY EQUATIONS FOR MONOPOLISTS

	(1)
Dep. Variable: Log value of sales at destination	
$\hat{\tau}_d^o$	-0.840** (0.401)
District of Origin Fixed Effects	YES
District of Destination Fixed Effects	YES
Product Fixed Effects	YES
Year Fixed Effects	YES
Observations	2,235
R-squared	0.538

Table II shows the estimates of equation (19). The dependent variable is the log value of sales at destination of products manufactured by monopolists. The variable of interest is the predicted values of equation (15), namely the predicted transport costs across districts. Origin, destination, product and year fixed effects are included. Product fixed effects correspond to 5-digit ASICC products. Robust standard errors are in parenthesis. Significance levels: *: 10%; **: 5%; ***: 1%.

6.3 Estimating the Within-Sector Elasticity of Substitution (γ)

We now estimate the within-sector elasticity of substitution. To do so, we derive the following condition from the model between a firm's labor share and its sectoral share for a given destination:

$$\frac{W_o l_d^o(j, k)}{\tilde{p}_d^o(j, k) c_d^o(j, k)} = 1 - \frac{1}{\gamma} - \left(\frac{1}{\theta} - \frac{1}{\gamma} \right) \omega_d^o(j, k) \quad (20)$$

where $\tilde{p}_d^o(j, k)$ is the factory gate price of the good. This condition implies that firms with a higher sectoral share at a destination have a lower labor share. The reason is that firms with higher sectoral shares charge higher markups, which result in lower labor shares. See Section (D) of the Technical Appendix for details.

In the data, we do not observe the market share of any given firm by destination. However, a similar condition can be derived for goods that are only produced in one state. In these sectors, the market shares of firms are constant across destinations.

We find that approximately 15% of sectors are operated only in one state. These sectors comprise 30,000 firms. Using data from these firms, we estimate equation (20) as follows:

$$LS_o(j, k) = \beta \omega^o(j, k) + \sum_o \delta_o + \sum_j \alpha_j + \epsilon^o(j, k) \quad (21)$$

where $LS_o(j, k)$ and $\omega^o(j, k)$ are the labor and sectoral shares respectively in state o , δ_o is a set of fixed effects to control for the state where the firm operates, α_j is a set of product fixed effects, and $\epsilon^o(j, k)$ is the error term.

TABLE III
LABOR SHARES VS SECTORAL SHARES

	(1)	(2)
	Labor Share	Cap+Labor Share
Sectoral Share	-0.416*** (0.094)	-0.493*** (0.105)
Constant	0.707*** (0.042)	0.807*** (0.052)
Sector FE	YES	YES
Year FE	YES	YES
Observations	1,181	1,009
R-squared	0.870	0.893

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

Column (1) of table III shows an OLS regression of firms' labor shares against sectoral shares for sectors that are operated only in one state. Column (2) shows the same regression but including also capital remuneration on the left hand side. Product fixed effects correspond to 5-digit Indian sectoral codes (ASICC). Robust standard errors are in parenthesis: *: 10%; **: 5%; ***: 1%.

We present the results in Table III. Column (1) shows the results when including only labor remuneration on the left-hand side of the equation. In column (2), we also include capital remuneration on the left-hand side of the equation. The second specification controls for across-firm

variations in capital intensity. We choose this second specification as our preferred one. An OLS slope coefficient of -0.49 together with an across-sector elasticity of substitution θ of 1.84 implies a value of γ of 19.77.

6.4 Aggregating Transportation Costs to the State Level

In order to exploit all the variations that exist in the data, we use district-level data in the estimates of transportation costs, θ , and γ . It is necessary to aggregate the district-to-district transportation costs to state-to-state transportation costs since the model that we simulate is based on interstate trade. We do so in two steps. In the first step, for every district we find the average transportation cost to the districts located in a given destination state. This average is weighted by the population of the destination districts. This yields a measure of district-to-state transportation costs. In the second step, we aggregate the district-to-state measure to obtain state-to-state transportation costs. To do so, we find the average transportation cost from the origin districts of the origin state to a given destination state. This average is weighted by the population of the origin districts.

Given this new set of transportation costs, we repeat the exercise above in which we map the transportation costs from the National Capital Territory of Delhi to all of the states in India. Panel C of Figure II shows a map of these transportation costs. The pattern of faraway states having higher transportation costs that we observed at the district level is also visible in this figure. Panel D of Figure II depicts transportation costs in 2006. The fact that the colors are lighter means that there is a decline in transportation costs to most regions.

Importantly, there is a high variation in the decline of transportation costs across locations. As an illustration, Figure III shows the percentage decline in transportation costs from Delhi. As in the previous figure, the colors of the states represent the quartile in terms of decline in transportation costs. States in the top quartile tend to be far away from Delhi and close to the GQ upgrades. The states in the top quartile underwent a decline of 3.9 to 8.7%. The states with the smallest decline in transportation costs are the ones that are far from the GQ upgrades. For example, the northern state of Jammu and Kashmir and the northeastern states of Arunachal Pradesh, Assam, Manipur, Tripura, and Mizoram. The percentage decline in transportation costs for the bottom quartile ranges from 0 to 0.59%.

6.5 Calibrating the Remaining Parameters

Labor endowment For the labor endowments of each state, L_n , we first normalize the labor endowment of the smallest state to 1. We then set the labor endowments of the remaining states so that the model matches the ratio of manufacturing value-added observed in the data across states.

TABLE IV
PARAMETER VALUES

Param.	Definition	Value
(A) PARAMETERS ESTIMATED WITH STRUCTURAL EQUATIONS		
τ_d^o	Iceberg transportation costs between states	varies by state pair
θ	Elasticity of substitution across sectors	1.83
γ	Elasticity of substitution within sector	19.77
(B) PARAMETERS TAKEN DIRECTLY FROM DATA		
K_{ij}	Number of firms operating in sector j of country i	varies by state
(C) PARAMETERS CALIBRATED IN EQUILIBRIUM		
L_i	Labor endowment of the states	varies by state
α	Shape parameter Pareto	2.05

Notes: Table IV refers to a calibration in which productivity draws across states are independent.

Parameters that govern within-industry productivity across states We will now calibrate the parameters that relate to the number of firms that operate and the productivity distribution. These parameters are crucial for the size of the Ricardian and pro-competitive effects of reducing transportation costs.

The number of firms in sector j of state n , K_{nj} , is set to match the number of plants observed in the data.¹⁸ Since there is no operating cost in the model, all firms operate and there is no entry and exit of firms even after changes in transportation costs. Abstracting from firm entry and exit in these kinds of models does not quantitatively affect the final results. The reason is that a reduction in transportation costs will lead to the entry and exit of low-productivity firms. These firms do not significantly affect the markups that large firms charge. This is consistent with the findings of Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2014). Furthermore, the data does not show a significant change in terms of the firms across sectors in each state. For example, the auto-correlation of the number of producers per sector-state between 2001 and 2006 is 0.98.¹⁹

The distribution of the number of firms across state-sectors is important in determining the nature of gains from lower transportation costs. As a simple example to illustrate this idea,

¹⁸In order to reduce the computational burden, we limit the number of firms operating in each sector of a given state to 50. This means that we set the maximum number of producers in a given sector to 1450 (29x50).

¹⁹The number of active sectors across states remained stable over this period. The change in the percentage of active sectors within states is around 3% on average. The total number of firms did not vary significantly either. The percentage change in the total number of firms within states is around 2% on average.

consider a two-state example. Suppose that these two states go from autarky to trading with each other. If there is no overlap in the sectors that these two states produce in, the effects from trade will be purely Ricardian. This is true since trading with another state will not change markups. However, if two states produce very similar goods, then there is room for pro-competitive effects from trade. Note that this can greatly limit the scope of pro-competitive gains if states produce different types of goods in the calibrated data.

Another important factor to consider is the correlation of productivity draws across regions. The correlation determines the extent to which local firms with market power face new competition when the economy opens to trade. [Edmond, Midrigan, and Xu \(2014\)](#) show that the correlation in productivity draws is important to determine the size of pro-competitive gains from trade. In a situation in which productivity draws across states are independent, the pro-competitive gains from trade are zero or even negative. Furthermore, they infer a very high correlation (0.93) for the Taiwanese case.

We assume that firms across states, conditional on operating in a given sector, have perfectly correlated draws in our benchmark calibration. To generate productivity draws for an industry, we generate productivity draws equal to the maximum number of firms present in any state. We sort the productivities in descending order. If a state has one firm, then we select the first productivity on the sorted list. If a state has ten firms, then we select the first ten productivities on the sorted list. This setup ensures that the firms with the highest productivity face high levels of head-to-head competition. Importantly, note that this does not imply the sectors are symmetric across states. The reason is that states have different number of firms operating in a given sector. Furthermore, locations have different wages and transportation costs, which affect the marginal cost that firms face.

It is important to determine whether the model is generating reasonable levels of head-to-head competition given the assumption of perfectly correlated productivity draws. It is especially important to match the level of head-to-head competition facing the largest firms since they are the ones that drive the dispersion in markups as we will show in [Section 7](#).

We create an index that measures the similarity in size of the largest firms in India. This index measures the degree to which firms face head-to-head competition since the size of firms is related to their productivity. To calculate the index, for each sector and state we identify the firm with the largest value-added. Then, we regress the log of the value-added of these firms on sector dummies. The R squared of that regression, which we use as our index, indicates the extent to which the large firms in each sector are of similar size. For example, an R squared of one indicates that the largest firms in each state are exactly the same size. We calculate the index in the data as well as in the data generated by the model and find an index of 0.44 in the data and 0.37 in the model. This exercise indicates that the model is generating levels of head-to-head competition that are in line with the data.

Finally, we use a Pareto distribution for the productivity draws. The tail parameter, α , is calibrated in equilibrium to match the fact that the top 5% of firms in manufacturing value-added account for 89% of value-added in this sector.

6.6 Discussion of the distribution of markups

Table IX summarizes the distribution of markups by destination market. The average markup implied by the model is approximately 1.06 across all markets. The median markups is also very similar. This result comes from the fact that the vast majority of firms have small market shares and thus charge markups close to $\gamma/(\gamma-1)$, which is the lowest possible markup. Markups do not become significantly larger until the 99th percentile of the distribution, which ranges from 1.24 to 1.32 across states. It is important to note that the model predicts a convex relationship between sectoral shares and markups. The few firms that get very high productivity draws (given the Pareto distribution of productivity draws) are those that have nontrivial sectoral shares and hence can charge high markups.

This dimension of the distribution of markups implied by the model is consistent with the distribution of markups estimated in the IO literature. These papers find that most firms have small markups and a handful of firms have large markups. For example, [De Loecker, Goldberg, Khandelwal, and Pavcnik \(2014\)](#) estimate the markups of medium and large Indian firms using the Prowess dataset. They find a median markup of 1.18 and an average of 2.24 across sectors. [Loecker and Warzynski \(2012\)](#) estimate the markups of Slovenian firms and find a median markup of 1.17-1.28 across sectors. They also find a large standard deviation of markups of 0.50 across all specifications.

The level of markups implied by our model is lower than those estimated using empirical methods, especially on the high end of the distribution. As mentioned above, the 99th percentile of markups implied by the model range from 1.24 to 1.32 across states. Furthermore, the highest possible markup that firms can charge is $\theta/(\theta-1)$, which in our case is 2.20. These markups are lower than those estimated by [De Loecker, Goldberg, Khandelwal, and Pavcnik \(2014\)](#). They find that the average is 2.24, which is above the maximum markups the firms can charge in the model.

It is also interesting to note that firms that account for a large sectoral share are usually far from being monopolists. For instance, for the destination market of Aruchanal Pradesh, the average maximum sectoral share across industries is 35%. The equivalent number is higher in bigger states, being 49% in Maharashtra. This distribution of market shares predicted by the model is consistent with other empirical work. [Hottman, Redding, and Weinstein \(2014\)](#) use Nielsen HomeScan database for the US. They find that half of all output in a product group is produced by five firms on average. Furthermore, they find that 98% of firms have market shares of less than 2 percent.²⁰

²⁰This comparison has to be taken with caution for a main reason. They look at much more narrowly de-

7 Quantifying the Impact of the GQ

In this section, we quantify the aggregate and state-level effects of the construction of the GQ. To this end, we compare the outcomes from our calibrated model in 2006 with the outcomes when we remove the GQ. To remove the GQ, we use the estimates from Section 6.1 to determine the changes in transportation costs. For illustrative purposes, we present all the results as changes from before to after the construction of the GQ (2001 to 2006). Lastly, we use a difference-in-difference strategy to estimate the decline in prices for districts close to the GQ compared to those that are further away. We compare these results with the predictions of the model.

7.1 Simulating the Construction of the GQ

In order to quantify the effects of the GQ, we begin with our baseline calibration described in Table IV. We change the transportation costs to reflect the absence of the GQ. To do so, we change the cost to travel on roads that were upgraded by the GQ as described in equation (16). Given these new costs, we re-compute the shortest path using Dijkstra’s algorithm. Finally, we re-aggregate the district-to-district transportation costs to state-to-state transportation costs as described in Section 6.4.

Benefits from the GQ First, we consider the aggregate change in real income resulting from the GQ. Table V shows that real income increases by 2.04% for India. Changes in aggregate real income are calculated as the mean percentage change of all states weighted by real income. The increase in real income is in terms of the manufacturing value-added, since this is the only sector considered in our model. The value-added of the manufacturing sector was \$152.8 billion in 2006. This implies that the static benefit of the construction of the GQ is \$3.1 billion. These are the benefits that accrue to India *each year* as a result of the construction of the GQ. We can compare these benefits to the cost of the construction of the GQ. Estimates indicate that the government spent approximately \$5.6 billion on the GQ. Thus, the benefits over a two-year period exceed the initial construction costs.

A framework to decompose the Ricardian and pro-competitive effects of the GQ We apply the framework developed by Holmes, Hsu, and Lee (Forthcoming) to decompose the changes in real income in a way that highlight the various mechanisms at work in the model. The framework allows us in particular to distinguish between Ricardian, pro-competitive, and terms of trade effects from lowering transportation costs.

We now introduce some notation for the purpose of the decomposition. We define the aggregate markups on the goods sold. This reflects how much market power firms producing in a state have

finned products. While our definition of sector is based on the 5-digit Annual Survey of Industries Commodities Classification (ASICC), they use 12-digit Universal Product Codes (UPCs).

when selling to other states. First, the revenue-weighted mean labor cost share for the products sold by state n is:

$$c_n^{sell} = \int_0^1 \left(\sum_{d=1}^N \sum_{k=1}^{K_{nj}} c_d^n(j, k) s_d^n(j, k) \right) dj,$$

where $s_d^n(j, k)$ is the share of state n 's revenue that comes from goods produced by firm k in sector j and sold at state d . The aggregate markup on the goods sold can be expressed:

$$\mu_n^{sell} = \frac{R_n}{W_n L_n} = \frac{1}{c_n^{sell}},$$

where $R_n = W_n L_n + \Pi_n$, which is the states's total revenue. Note that there is an analogous expression at the firm level which is that the firm's markup is equal to the reciprocal of the labor share.

We next define the aggregate markups on the goods purchased by state n , which reflects how much market power firms located in other states have when selling to state n . The revenue-weighted mean labor cost for the products purchased by state n is:

$$c_n^{buy} = \int_0^1 \left(\sum_{o=1}^N \sum_{k=1}^{K_{oj}} c_n^o(j, k) b_n^o(j, k) \right) dj.$$

where $b_n^o(j, k)$ is the share of expenditure in state n on goods produced by firm k in sector j located at state o . The aggregate markups on the goods purchased are:

$$\mu_n^{buy} = \frac{1}{c_n^{buy}}.$$

Lastly, let P_n^{pc} be the aggregate price of state n if every firm engages in marginal cost pricing. P_n^{pc} is the aggregate price index that would emerge in a context of perfect competition. This price index depends on the factors that determine the marginal cost of firms: the distribution of firm productivity, the wages paid by firms, and the transportation costs that these firms face.

Using this notation, the real income in state n can be rewritten into the following components:

$$Y_n = \underbrace{W_n L_n}_{\text{Labor income}} * \underbrace{\frac{1}{P_n^{pc}}}_{\text{Prod. efficiency}} * \underbrace{\frac{\mu_n^{sell}}{\mu_n^{buy}}}_{\text{Markup ToT}} * \underbrace{\frac{P_n^{pc}}{P_n} \mu_n^{buy}}_{\text{Allocative efficiency}} \quad (22)$$

The first component is the aggregate *labor income*. The second component is the *productive efficiency* component of welfare. This component is simply the inverse of the price index if all firms charged the marginal cost. The third component is *terms of trade*. This component compares the aggregate markup charged for the goods a state sells with those that it purchases. The last component is *allocative efficiency*. It can be shown that this term is equal to the cost of one unit of utility under marginal cost pricing divided by the cost of acquiring one unit of utility with the equilibrium bundle under marginal cost pricing. In a situation with no misallocation, i.e. no

variations on markups across firms, this index is equal to one. As misallocation increases, this index decreases.

Combining the first two terms leads to an expression that is equal to real income if firms charge the marginal cost. This expression maps back to welfare in the large class of models considered by [Arkolakis, Costinot, and Rodriguez-Clare \(2012\)](#), in which the markups of firms remain unchanged. Thus, we consider changes in this component to be Ricardian effects. We consider changes in the allocative efficiency to be pro-competitive effects as this directly maps back to the welfare losses due to dispersion in markups. Given the expression in equation (22), we decompose the changes in real income into the following terms:

$$\Delta \ln Y_n = \underbrace{\Delta \ln W_n L_n + \Delta \ln \frac{1}{P_n^{pc}}}_{\text{Ricardian}} + \underbrace{\Delta \ln \frac{P_n^{pc}}{P_n} \mu_n^{buy}}_{\text{Pro - competitive}} + \underbrace{\Delta \ln \frac{\mu_n^{sell}}{\mu_n^{buy}}}_{\text{Markup ToT}}$$

Quantifying the decomposition Table V shows these three components at the aggregate and state level. We find that, for India as a whole, the pro-competitive component accounts for approximately 19% of the aggregate gains (0.39% of the 2.04% total gains). The pro-competitive component can be up to 29% of the gains at the state level (0.46% of the 1.61% of the gains for Maharashtra).

The welfare effects of the GQ are very heterogeneous across states. Overall, large states gain more from the reduction in transportation costs. Small states see modest gains and in some cases even lose. This is driven by the fact that, due to its placement, the GQ has lowered transportation costs primarily for large states. Many of the small states are located in northeastern India, which is far from the GQ.²¹ The states in the Northeast that gained less than 1% include: Assam and Meghalaya. The states in the Northeast that experienced losses include: Arunachal Pradesh, Manipur, Mizoram, Nagaland, and Tripura. Figure IV shows a map of the welfare effects across states, including the states that lost.

First, we turn to the Ricardian components across states. These terms are generally positive and large across all states. This term also explains the modest or negative effects for the states in the Northeast. The only two factors that affect a firm’s marginal cost to serve a destination are the transportation costs that it faces and local wages. First, we know that the GQ lowers transportation costs for some destinations and leaves the transportation costs for others unchanged. Thus, reductions in transportation costs increase the productive efficiency component. Transportation costs declined relatively more in states closer to the GQ, and hence these states benefited from a higher increase in productive efficiency. These states start trading more intensively with each other, which increases their degree of openness and relative wages. The fact that the Ricardian

²¹Northeastern Indian states include: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura.

TABLE V
QUANTITATIVE RESULTS

state	size	income change	Descomposition			
			η_w	η_{PE}	η_{ToT}	η_{ae}
India		2.04	2.09	-0.44	0.00	0.39
Maharashtra	100.00	1.61	1.94	-0.96	0.17	0.46
Gujarat	65.40	2.74	2.60	-0.48	0.08	0.55
Tamil Nadu	41.67	1.32	1.81	-0.79	-0.01	0.32
Uttar Pradesh	29.91	2.22	2.14	-0.36	-0.07	0.51
Karnataka	26.97	2.87	2.61	-0.21	-0.10	0.57
Andhra Pradesh	21.23	1.78	1.84	-0.34	-0.11	0.39
West Bengal	18.97	3.67	3.04	0.16	-0.14	0.62
Haryana	18.80	0.97	1.55	-0.62	-0.17	0.21
Jharkhand	17.10	4.97	3.44	1.22	0.03	0.29
Rajasthan	12.64	2.84	2.46	0.43	-0.30	0.25
Madhya Pradesh	11.39	1.40	1.55	-0.25	-0.11	0.20
Orissa	10.74	2.31	2.06	-0.02	0.01	0.26
Punjab	10.16	0.41	0.95	-0.69	0.04	0.10
Himachal Pradesh	9.49	0.29	1.07	-0.70	-0.17	0.09
Chattisgarh	9.32	0.28	1.02	-0.84	-0.01	0.11
Kerala	7.42	0.75	1.07	-0.60	0.06	0.22
Uttaranchal	4.62	0.76	1.15	-0.57	0.04	0.14
Delhi	4.58	0.95	1.15	-0.53	0.12	0.21
Assam	3.72	0.28	0.86	-0.72	0.04	0.09
Goa	3.57	7.82	4.89	3.51	-0.60	0.02
Bihar	2.73	5.35	3.54	2.11	-0.37	0.07
Jammu and Kashmir	2.59	-0.41	0.47	-0.74	-0.11	-0.04
Meghalaya	0.62	0.53	0.99	-0.67	0.07	0.13
Tripura	0.26	-1.60	-0.25	-1.63	0.25	0.03
Manipur	0.11	-1.51	-0.20	-1.70	0.34	0.05
Nagaland	0.08	-1.06	0.06	-1.45	0.26	0.07
Sikkim	0.03	3.96	2.47	0.89	0.39	0.22
Mizoram	0.02	-1.07	0.38	-1.68	0.19	0.05
Arunachal Pradesh	0.01	-1.29	0.00	-1.80	0.46	0.05

Table V shows the % change in real income and the decomposition of the [Holmes, Hsu, and Lee \(Forthcoming\)](#) index for the 29 Indian states; η_w represents the % change in labor income component of the index; η_{PE} represents the % change in the *Prod. efficiency* component; η_{ToT} represents the % change in the *terms of trade* component; and η_{ae} represents the % change in the *allocative efficiency* component.

term is negative for the Northeastern states implies that the effect of wages in the states close to the GQ outweighed the benefits of the GQ in terms of lower transportation costs. We discuss this

“*trade diversion*” in detail in Section 7.2.

Next, we examine the pro-competitive and terms of trade effects across states. These two terms are the result of the variable markups feature of the model. First, we find that the pro-competitive effects are positive across all but one state. This means that lower transportation costs generally led to welfare-enhancing changes in markups. As mentioned before, theory is ambiguous as to whether declines in transportation costs lead to gains in allocative efficiency. The range of gains from changes in allocative efficiency is -0.04 to 0.62%. Larger states also see the greatest gains in terms of allocative efficiency.

In order to understand the changes in allocative efficiency and terms of trade, it is necessary to think about the asymmetry of states. In particular, it is necessary to think about the markups charged by firms based on their location. As can be seen in Table VIII, there is large variation in wages across states. Large states tend to have lower wages, which means that, everything else equal, firms located in those states are relatively competitive. Conditional on the productivity draws, the competitiveness of firms located in state o serving market d is $(W_o\tau_d^o)^{-1}$, which is directly related to the marginal cost of serving that market from state o . Thus, firms located in large states have more market power than firms located in small states. This holds true even though firms have exactly the same productivity draws. Figure V shows the distribution of the location of the firms that charge the markups in the top 1% on goods purchased in Arunachal Pradesh and Maharashtra. We see that in both cases, these firms are primarily located in Maharashtra and other big states, where wages tend to be lower. For instance, in Maharashtra, around 60% of the firms charging the 1% biggest markups are domestic firms. It is important to note that, in Arunachal Pradesh, the competitiveness of firms located in Maharashtra decreases due to transportation costs. This implies that, for goods sold in Arunachal Pradesh, only around 24% of the firms charging the highest markups are from Maharashtra.

Thus, under our benchmark calibration, any force that increases the competitiveness of firms in large states will *decrease* allocative efficiency. This is the case because increasing the competitiveness of firms in large states will increase the market power of firms that already have high markups. Likewise, any force that decreases the competitiveness of firms in large states will *increase* allocative efficiency.

Now we will examine changes in allocative efficiency for the states in the Northeast. The lower transportation costs make firms located in large states more competitive in the Northeast, lowering allocative efficiency. On the other hand, Table V shows that large states had the biggest increases wages. The higher wages lower the competitiveness of firms in large states, raising allocative efficiency. In this case, the effect of rising wages is stronger than the decline in transportation costs. For example, the competitiveness of firms located in Maharashtra serving Arunachal Pradesh decreases by 1.90%. This loss in competitiveness is reflected in the changes in markups of those firms with large amounts of market power. Table IX shows the changes in markups charged

by destination market. We see that for Arunachal Pradesh, the markup of the 99th percentile decreases by 0.11%. This fact also explains why small states saw significant increases in terms of trade. Note that the re-adjustment of wages is critical in thinking about changes in misallocation. If wages did not adjust, we would see *increases* in misallocation in the Northeast.

For the large states we know that local firms have relatively high markups. Thus, increases in the wages of large states improve allocative efficiency, just as in the case of the states in the Northeast. However, declines in transportation costs have the opposite effect on allocative efficiency. This is because it forces local firms to lower their high markups due to the increased competitiveness of firms located in other states, which have relatively low markups. Thus, the forces of changing wages and transportation costs work towards increasing allocative efficiency in large states. Large states saw the biggest increases in allocative efficiency. Furthermore, large states generally saw declines in terms of trade.

These findings highlight the importance of considering asymmetric economies in models of variable markups. In particular, we find that including variable markups in the model generates gains that mitigate the negative Ricardian terms for the states in the Northeast. For example, the state of Manipur gained 0.39% due to changes in markups. This helped reduce the loss of -1.90% from the Ricardian term.

It is interesting to note that there is a wide dispersion in the effects of the terms of trade component. For example, Goa lost 0.60%, while Sikkim gained 0.39%. Thus, although allocative efficiency improves for all but one state, the changes in the terms of trade can result in some states suffering losses due to changing markups. For example, Goa lost more from the changing terms of trade than it did from the improved allocative efficiency. Thus, although almost all states gain from increases in the allocative efficiency, the changes in markups lead to a significant re-shuffling of income across states through changes in the terms of trade.

Figure VI highlights the main pattern of the change in markups after the reduction in transportation costs. Changes in markups are only quantitatively relevant for firms which charged markups above the 90th percentile of the (before) distribution of markups. Interestingly, the 90th and 95th percentiles of the markup distribution actually increase. More importantly, Figure VI shows that the 1% firms in the distribution substantially decrease their markups. The fact that reductions in markups after policy reforms are more pronounced on firms with initially high markups has already been documented in the literature. For instance, [De Loecker, Goldberg, Khandelwal, and Pavcnik \(2014\)](#) find that, for high markup products (above the 90th percentile), the same reduction in tariffs results in an additional 4.40 percent decline in markups.

7.2 The GQ and Trade Diversion and Creation within India

We now study changes in state-to-state trade patterns induced by the construction of the GQ. The fact that reductions in transportation costs are not uniformly distributed across states gives room

TABLE VI

% CHANGE IN TOTAL TRADE BETWEEN i AND j (MODEL)

	mean	median	sd/mean	N
(A) both i and j in GQ	5.35	5.03	1.55	78
either i or j in GQ	1.42	-0.79	7.11	208
neither i nor j in GQ	3.25	3.11	3.54	120
(B) both i and j in (N-EAST+JM)	3.89	2.73	2.40	190
either i or j in (N-EAST+JM)	1.21	0.31	9.72	180
neither i nor j in (N-EAST+JM)	4.08	4.04	1.47	36

Table VI shows the mean, median, and coefficient of variation of the % change in total trade between states i and j after the construction of the GQ; “both i and j in GQ” refers to state pairs in which both of them are crossed by the GQ; “either i or j in GQ” refers to state pairs in which only one of them is crossed by the GQ; “neither i nor j in GQ” refers to state pairs in which none of them are crossed by the GQ; “both i and j in (N-EAST+JM)” refers to state pairs in which both of them belong to the group (N-EAST+JM); “either i or j in (N-EAST+JM)” refers to state pairs in which one of them belong to the group (N-EAST+JM); “neither i nor j in (N-EAST+JM)” refers to state pairs in which none of them belong to the group (N-EAST+JM). N-EAST+JM includes Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and Jammu and Kashmir. N is the number of state pairs that fall into the six different categories.

for trade diversion and creation. To study this possibility, we compute the whole set of bilateral trade flows across Indian states before and after the GQ. We define total trade between state i and state j as

$$\text{Total Trade}_{i,j} = \text{exports}_j^i + \text{exports}_i^j,$$

where exports_j^i and exports_i^j are the total exports from state i to state j and the total exports from state j to state i respectively.

Table VI shows the percentage changes of this variable for different sets of state pairs. In Panel (A) we have divided the state pairs according to their access to the GQ.²² In the first row we include state pairs in which both of the states are crossed by the GQ. In the second row we include state pairs in which only one of the states is crossed by the GQ. In the third row we include state pairs in which none of the states is crossed by the GQ. The Panel (B) is equivalent to Panel (A), but classifying the state pairs according to whether they are way far from the GQ. This set of states include the northeastern states (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura) plus Jammu and Kashmir. With this additional classification, we try to capture the fact that, even if some states were not crossed by the GQ, they were relatively close so that their market access increased. Examples of this include Goa and Madhya Pradesh.

We find that, on average, trade increases considerably more between state pairs in which both states are cross by the GQ or not crossed by the GQ. In other words, the construction of the GQ resulted in an increase in trade flows between states located far away. It also resulted in increases in trade flows between states located close to the GQ. For instance, trade flows between state

²²This analysis is similar in spirit to papers that study trade diversion such as Krueger (1999) and Bayoumi and Eichengreen (1998).

pairs crossed by the GQ increased on average a 5.35%. For state pairs not crossed by the GQ, the increase in trade was of 3.25%. On the other hand, trade between state pairs in which only one of the states was crossed by the GQ increased much less, 1.40% on average. In fact, the median percentage change in trade between these states is negative: -0.79%.

This means that the trade flows in India becomes more regionally concentrated. For instance, the trade between northeastern states increased by 3.89%. The pattern is similar for the non-northeastern states, where trade increased by 4.08% on average.

7.3 The GQ and the Evolution of Prices

The model has an important implication which is behind the differential effect of the construction of the GQ across regions: prices fall more in states crossed by the GQ. We use the time dimension of the data to evaluate the ability which the model has to predict the different responses of prices in GQ vs non-GQ locations. In order to do this, we examine the impact of the GQ on prices using a reduced form approach and we compare it with the outcome of the model.²³ In the model, the prices paid for goods are endogenous and depend on both changes in transportation costs, wages, and markups. These changes in wages and markups depend on complex general equilibrium effects. Thus, it is necessary to simulate the model in order to compare the changes in prices paid for goods with the data.

One of the major issues to tackle when studying the impact of transportation infrastructure is the fact that the placement of infrastructure is not random. In the case of India, the GQ was built with the goal of connecting the major urban centers. In order to deal with this identification problem, we use the strategy adopted by several authors such as [Atack, Bateman, Haines, and Margo \(2010\)](#) and [Banerjee, Duflo, and Qian \(2012\)](#) who have exploited the fact that the goal of infrastructure projects is usually to connect historical cities or large economic centers. The causal effect of transportation infrastructure is identified by applying a difference-in-difference approach comparing non-nodal areas that differ in their distance to the transportation network before and after the infrastructure is constructed. We follow this approach in order to study the impact of transportation costs on prices, making use of the natural experiment provided by the GQ. We run the following difference-in-difference regression in particular:

$$\Delta \log P_{jd} = \sum_j \alpha_j + \beta_1 \Delta \text{GQ}_d + \sum_s \delta_s + \epsilon_{jd}, \quad (23)$$

where P_{jd} is the price of input j in district d between 2001 and 2006, and GQ_d is a dummy variable taking the value 1 if district d is within a certain distance of the GQ, and ϵ_{jd} is an error term.

²³The difference-in-difference strategy we use to identify how the GQ affected prices is similar to the one used in recent work that investigates the impact of transportation infrastructure in development. These papers include [Atack, Bateman, Haines, and Margo \(2010\)](#), [Banerjee, Duflo, and Qian \(2012\)](#), and [Faber \(Forthcoming\)](#). This strategy has also been applied to investigate the impact of the GQ by [Datta \(2012\)](#) and [Ghani, Goswami, and Kerr \(Forthcoming\)](#).

Distance is calculated as the shortest straight-line distance between the district and a treated portion of the GQ. Thus, $\Delta GQ_d = 1$ if a district is within the specified distance of a treated portion of the GQ in 2006 and not in 2001. We use the following categories for distance: 15, 50, 100, 150, 200, and 300 km. We include input fixed effects and state fixed effects in order to account for input-specific price trends and aggregate shocks affecting prices at the state level. Standard errors are clustered at the district level in order to account for possible serial correlation of price shocks within districts.

TABLE VII
PRICES AND THE GOLDEN QUADRILATERAL: DIFFERENCES-IN-DIFFERENCES

	(1)	(2)
<u>Dep. Variable: Log change in input prices between 2001 and 2006</u>		
District within 15 km from GQ	-0.3219** (0.1395)	-0.3293** (0.1406)
District within 50 km from GQ	-0.3484** (0.1363)	-0.3604*** (0.1367)
District within 100 km from GQ	-0.2036 (0.1659)	-0.2171 (0.1697)
District within 150 km from GQ	0.0711 (0.1357)	0.0768 (0.1416)
District within 200 km from GQ	0.0916 (0.1591)	0.0973 (0.1767)
Input fixed-effects	YES	YES
State fixed-effects	YES	YES
Nodal districts	YES	NO
Observations	5,123	5,037
Average R-squared	0.44	0.44
Number of products	929	912

Table VII shows the estimation of equation (23). The dependent variable is the log change in the price of input j between 2001 and 2006 in district d . The variable of interest is the connectivity of the district, defined as whether the district is within a certain distance from the GQ in 2006 and 2001. Each row corresponds to a different regression, where different distances are considered. The treatment variable at distance x takes value 1 if district d is within x km from the GQ in 2006 and was not in 2001, and zero otherwise. Columns (1) includes all districts whereas column (2) excludes nodal districts. Input and state fixed effects are included in all specifications. Robust standard errors are in parenthesis, clustered at the district level. Significance levels: *: 10%; **: 5%; ***: 1%.

The estimates of equation (23) can be found in Table VII. We find that districts located within 15 km and 50 km of the GQ in 2006 experienced statistically significant declines in input prices. For districts located within 15 km, input prices were 33 percentage points lower relative to districts located further away from the GQ. The first coefficient of column (1) includes nodal districts and column (2) excludes nodal districts. For districts within 50 km of the GQ in 2006, we find an even stronger effect, a decrease of 36 percentage points in input prices relative to districts further away. Extending the treatment group beyond 50 km makes the effect disappear. The evolution of input prices was not significantly different between districts that within 100 km of the GQ and

those beyond 100 km. This implies that prices in “GQ” districts decreased 1.57 times as much as in the average district. The model predicts a stronger effect. The decrease in prices charged in states through which the GQ passes are 2.70 times bigger than in the average state. Although we find this evidence supportive for the differential evolution in prices predicted by the model, these comparisons have to be taken with caution for several reasons. First, while we calibrate the model at the state level, we carry out the difference-in-difference exercise at the district level. We do this in order to exploit as much as possible the variation in the data. Second, we are looking at a short span of time in the data (2001-2006). However, one could think that it would take longer for the Indian economy to converge to the new equilibrium after the construction of the GQ.

8 Alternative Scenarios

In this section, we evaluate the aggregate and state-level welfare under various scenarios.

8.1 Perfect Competition

We first examine the implications of changing the market structure to perfect competition for all firms. Under perfect competition, there is no misallocation or dispersion in MRPL across firms.

The allocative efficiency component of welfare gives us a sense of the welfare losses due to the misallocation resulting from market power. The allocative efficiency component ranges from 0.967 to 0.925, meaning that real income would increase by 3.3-7.5% under constant markups across firms. Furthermore, we find that larger states consistently have more misallocation than smaller states. Overall, the levels of misallocation that the model generates are low compared to the ones found by [Hsieh and Klenow \(2009\)](#).

To understand the quantitative importance of market power on firm size distribution, we simulate an equilibrium in which all firms charge marginal cost. In the new equilibrium, all parameters remain the same except firms charge marginal cost. Since productive firms charge higher markups in the calibration, they will be larger in the new equilibrium with perfect competition. We find that the top 5% of firms comprise 97% of all sales in India compared to 89% previously. In addition, the top 1% of firms go from having 42% to 55% of sales. In the case of perfect competition, there is no variance in the MRPL.

9 Conclusions

The goal of this paper is to quantitatively evaluate the welfare effects of improving the transportation infrastructure in a setting of internal trade and variable markups. Hence, we determine the extent to which misallocation is driven by high transports costs and decompose the welfare effects into Ricardian and pro-competitive gains, and we can thus gauge the distribution of gains across locations. We apply this framework to the construction of the Golden Quadrilateral in India, a

major highway project spanning 5,800 km. We find large gains from the infrastructure project, amounting to more than 2% of real income, 1/5 of which come from pro-competitive gains. Nevertheless, there is wide variation in income gains across Indian states, and even some negative effects after the project. These findings highlight the quantitative significance of the aggregate gains from the GQ, the size of pro-competitive gains, as well as the heterogenous effects across states.

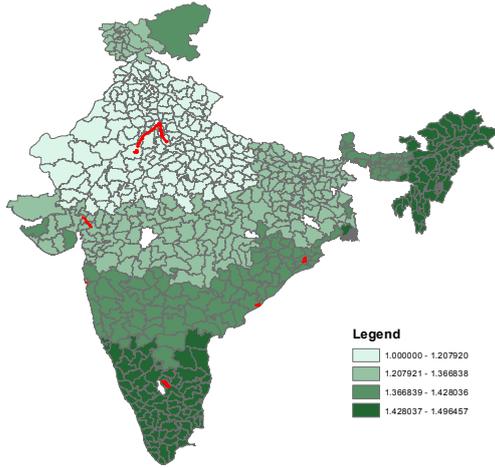
TABLE VIII
QUANTITATIVE RESULTS

state	w_n		$\frac{1}{P_n^{pc}}$		$\frac{\mu_n^{sell}}{\mu_n^{buy}}$		$\frac{P_n^{pc}}{P_n} \mu_n^{buy}$	
	before	after	before	after	before	after	before	after
Maharashtra	0.4286	0.4370	0.0143	0.0142	1.0233	1.0250	0.9210	0.9252
Gujarat	0.4276	0.4388	0.0137	0.0137	1.0124	1.0132	0.9275	0.9325
Tamil Nadu	0.4431	0.4512	0.0134	0.0133	0.9990	0.9989	0.9342	0.9371
Uttar Pradesh	0.4695	0.4796	0.0131	0.0130	1.0025	1.0018	0.9462	0.9510
Karnataka	0.4659	0.4782	0.0131	0.0131	0.9822	0.9813	0.9462	0.9516
Andhra Pradesh	0.4838	0.4928	0.0129	0.0128	0.9929	0.9918	0.9508	0.9545
West Bengal	0.4740	0.4886	0.0127	0.0127	0.9890	0.9876	0.9443	0.9501
Haryana	0.4775	0.4849	0.0130	0.0129	0.9834	0.9818	0.9572	0.9592
Jharkhand	0.4034	0.4175	0.0125	0.0127	0.9906	0.9909	0.9519	0.9547
Rajasthan	0.4925	0.5047	0.0127	0.0128	0.9928	0.9899	0.9582	0.9607
Madhya Pradesh	0.4862	0.4938	0.0127	0.0126	0.9746	0.9736	0.9572	0.9591
Orissa	0.4571	0.4667	0.0125	0.0124	0.9715	0.9715	0.9541	0.9567
Punjab	0.5078	0.5126	0.0126	0.0125	1.0021	1.0026	0.9590	0.9599
Himachal Pradesh	0.4660	0.4710	0.0125	0.0124	0.9832	0.9815	0.9560	0.9569
Chattisgarh	0.4396	0.4441	0.0124	0.0123	0.9609	0.9608	0.9554	0.9565
Kerala	0.5171	0.5227	0.0124	0.0123	0.9971	0.9978	0.9548	0.9569
Uttaranchal	0.4991	0.5048	0.0124	0.0123	0.9913	0.9916	0.9624	0.9638
Delhi	0.5505	0.5568	0.0130	0.0129	0.9727	0.9739	0.9606	0.9626
Assam	0.4812	0.4854	0.0116	0.0116	0.9889	0.9894	0.9563	0.9571
Goa	0.5002	0.5253	0.0123	0.0128	0.9601	0.9543	0.9580	0.9582
Bihar	0.5033	0.5214	0.0122	0.0124	0.9762	0.9726	0.9602	0.9609
Jammu and Kashmir	0.5144	0.5168	0.0118	0.0117	1.0157	1.0146	0.9622	0.9618
Meghalaya	0.4854	0.4903	0.0115	0.0114	0.9250	0.9256	0.9613	0.9626
Tripura	0.5692	0.5678	0.0112	0.0110	1.0497	1.0522	0.9664	0.9666
Manipur	0.6503	0.6490	0.0111	0.0110	1.0870	1.0907	0.9663	0.9668
Nagaland	0.6683	0.6687	0.0112	0.0110	1.0824	1.0852	0.9650	0.9657
Sikkim	0.7360	0.7544	0.0116	0.0117	1.0011	1.0050	0.9649	0.9670
Mizoram	1.0857	1.0898	0.0111	0.0109	1.1790	1.1812	0.9672	0.9677
Arunachal Pradesh	1.0000	1.0000	0.0111	0.0109	1.4065	1.4130	0.9669	0.9674

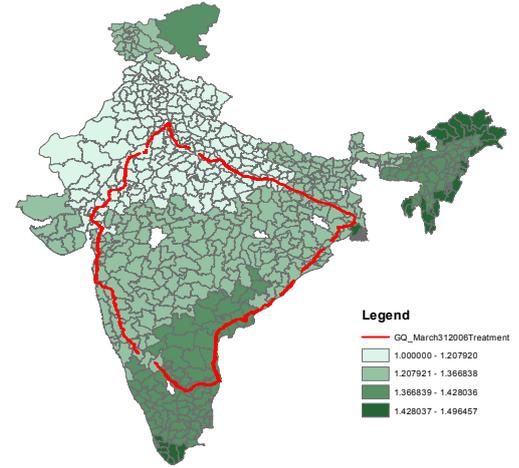
Table V shows the level of the four different components of the [Holmes, Hsu, and Lee \(Forthcoming\)](#) index for the 29 Indian states for before and after the construction of the GQ; w_n is the relative wage (note that we have excluded labor endowment for presentation purposes); P_n^{pc} is the aggregate price index in state n if all firms charged marginal cost; μ_n^{buy} represents the expenditure-weighted average markup charged on goods purchased in state n ; μ_n^{sell} represents the revenue-weighted average markup charged on goods produced in state n ; P_n is simply the aggregate price index in state n .

FIGURE II
ESTIMATED TRANSPORTATION COSTS FROM DELHI

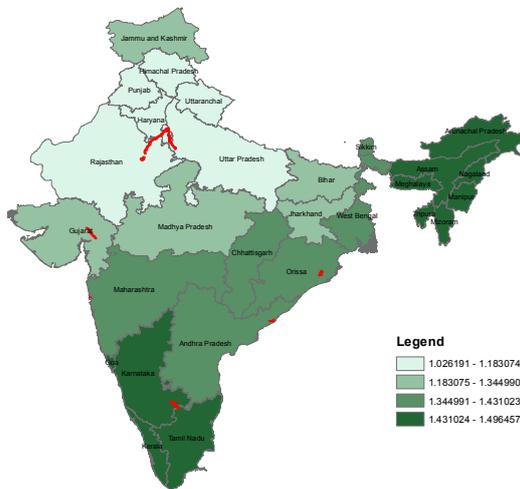
A: 2001 (District level)



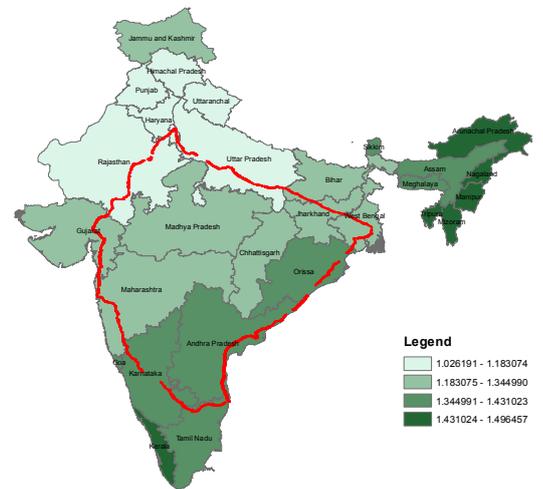
B: 2006 (District level)



C: 2001 (State level)



D: 2006 (State level)



Panel A of Figure II shows the estimated transportation costs from Delhi at the district level for 2001; Panel B of Figure II shows the estimated transportation costs from Haryana at the district level for 2006; Panel C of Figure II shows the estimated transportation costs from Delhi at the state level for 2001; Panel D of Figure II shows the estimated transportation costs from Delhi at the state level for 2006. The transportation costs have been estimated as explained in section 6.1.

FIGURE III
PERCENTAGE CHANGE IN TRANSPORTATION COSTS FROM DELHI

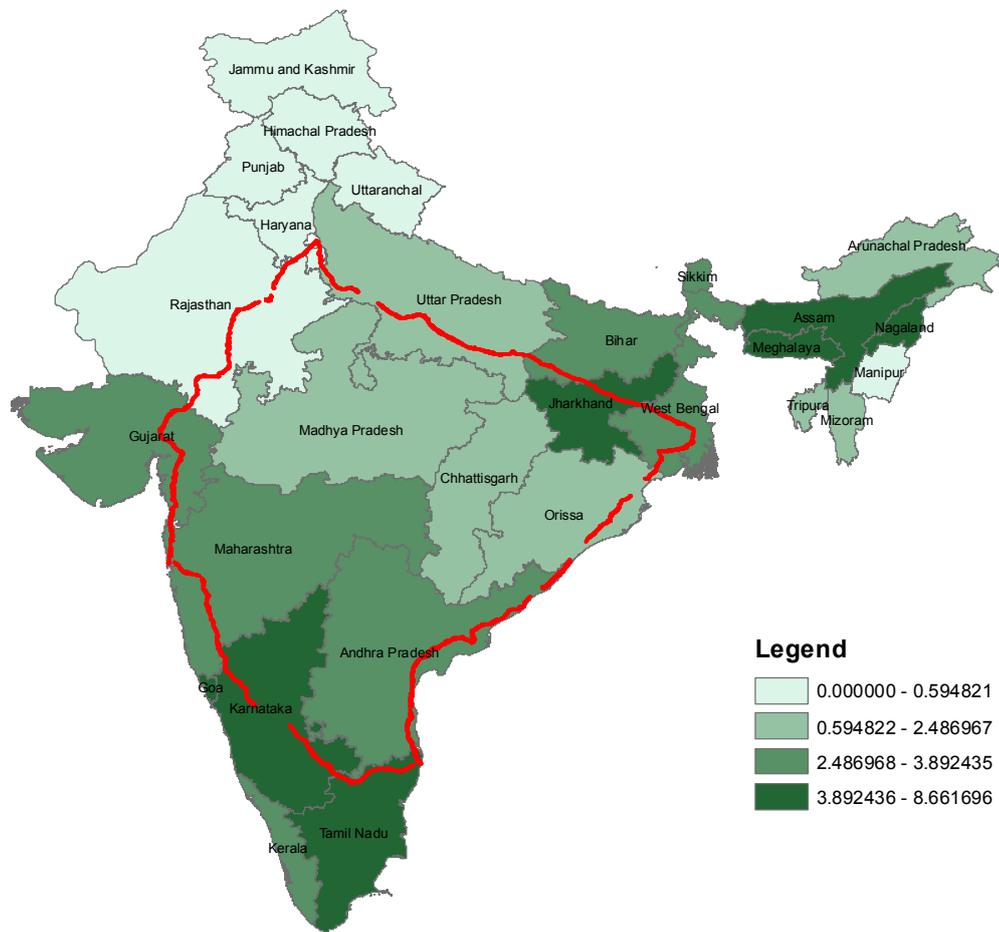


Figure III shows the % change in transportation costs due to the construction of the GQ at the state level.

FIGURE IV
PERCENTAGE CHANGE IN REAL INCOME AFTER GQ

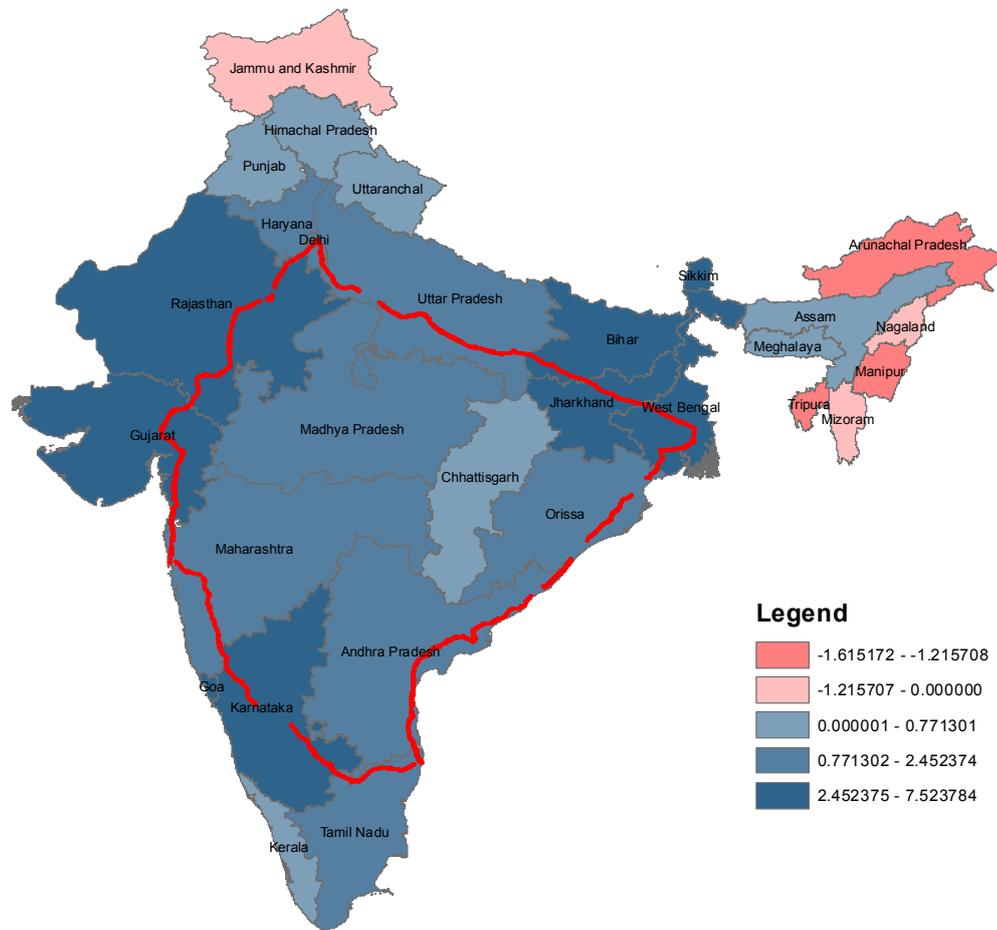


Figure IV shows the % change in real after the decrease in transportation costs due to the construction of the GQ. The numbers represented in this map correspond to the ones presented in column 2 of Table V.

FIGURE V

SPATIAL DISTRIBUTION OF THE TOP 1% FIRMS IN TERMS OF MARKUPS (MODEL)

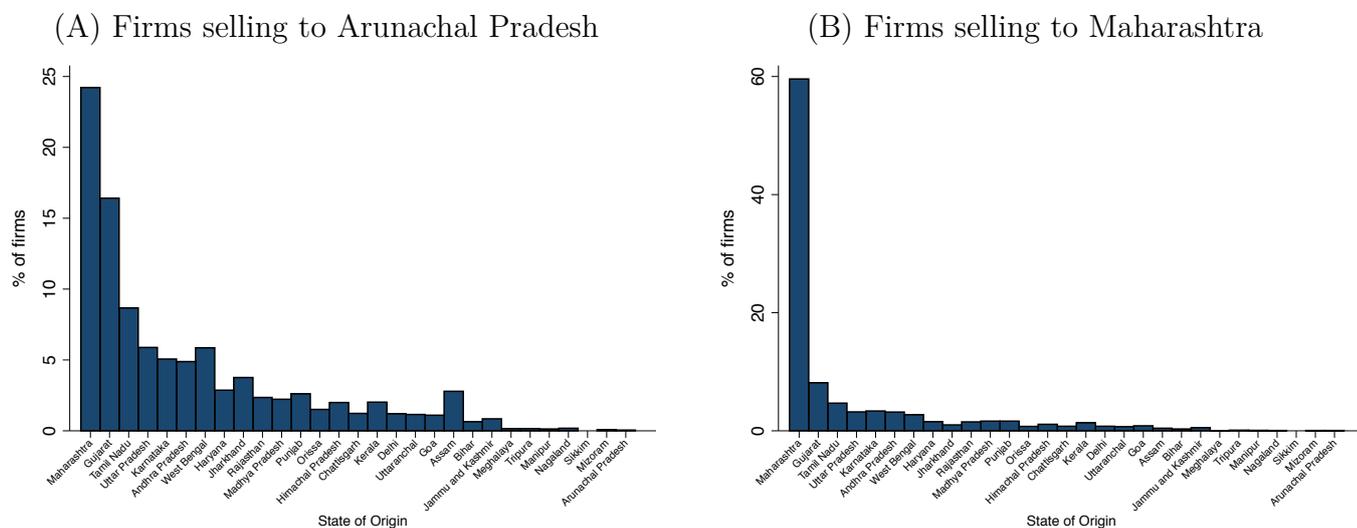


Figure (V) shows the distribution of states in which the top 1% of firms in terms of markups operate. Panel (A) refers to the markups charged on goods sold in Arunachal Pradesh. Panel (B) refers to the markups charged on goods sold in Maharashtra.

FIGURE VI

DISTRIBUTION OF THE CHANGE IN MARKUPS (MODEL)

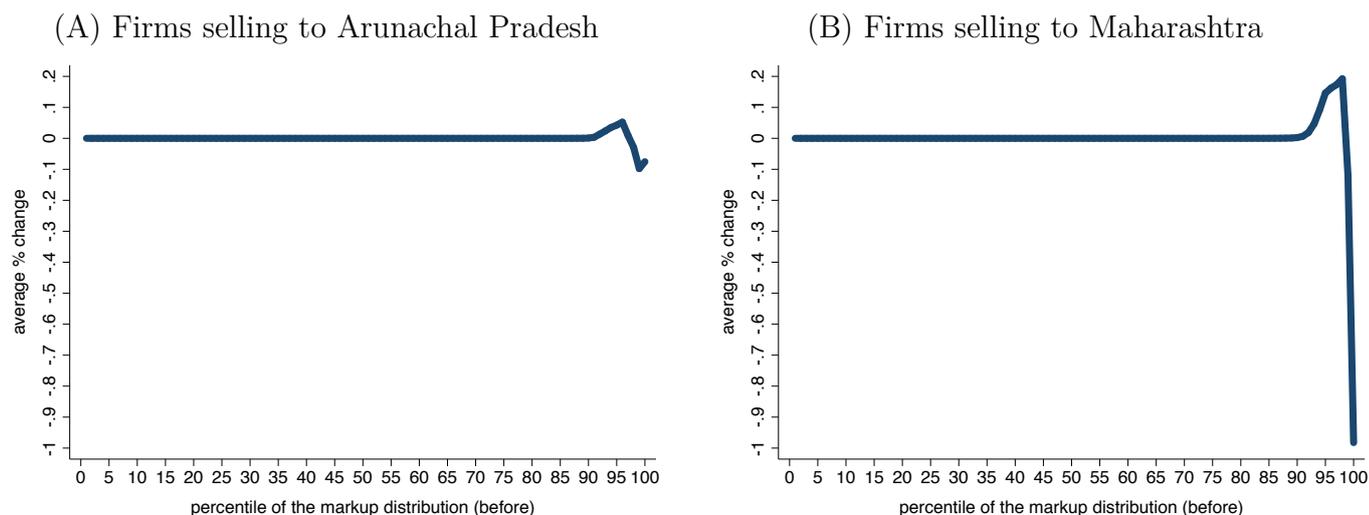


Figure (VI) shows the average percentage change in markups across firms across different percentiles of the distribution of markups before the construction of the GQ in the model. Panel (A) refers to the markups charged on goods sold in Arunachal Pradesh. Panel (B) refers to the markups charged on goods sold in Maharashtra.

TABLE IX
MARKUPS IN THE MODEL

state	std			mean			p95			p99			log p99/p50		
	before	after	% change	before	after	% change	before	after	% change	before	after	% change	before	after	% change
Maharashtra	0.0606	0.0596	-1.5851	1.0617	1.0617	-0.0062	1.068	1.070	0.142	1.322	1.315	-0.575	0.227	0.222	-2.560
Gujarat	0.0595	0.0585	-1.6906	1.0616	1.0616	-0.0064	1.071	1.072	0.154	1.304	1.299	-0.434	0.214	0.209	-2.052
Tamil Nadu	0.0586	0.0580	-1.0850	1.0616	1.0615	-0.0042	1.070	1.072	0.161	1.297	1.294	-0.266	0.208	0.206	-1.284
Uttar Pradesh	0.0565	0.0560	-0.8449	1.0614	1.0614	-0.0032	1.077	1.078	0.151	1.273	1.265	-0.654	0.190	0.183	-3.504
Karnataka	0.0576	0.0569	-1.2247	1.0615	1.0615	-0.0048	1.071	1.073	0.175	1.286	1.275	-0.900	0.200	0.191	-4.607
Andhra Pradesh	0.0566	0.0563	-0.6110	1.0614	1.0614	-0.0024	1.074	1.075	0.098	1.272	1.265	-0.522	0.189	0.183	-2.808
West Bengal	0.0570	0.0563	-1.2698	1.0615	1.0614	-0.0048	1.075	1.077	0.211	1.278	1.268	-0.748	0.193	0.186	-3.947
Haryana	0.0560	0.0556	-0.7170	1.0614	1.0614	-0.0028	1.079	1.081	0.196	1.260	1.255	-0.411	0.179	0.175	-2.320
Jharkhand	0.0563	0.0559	-0.6933	1.0614	1.0614	-0.0024	1.079	1.080	0.081	1.255	1.256	0.053	0.175	0.176	0.304
Rajasthan	0.0558	0.0555	-0.4845	1.0614	1.0614	-0.0019	1.078	1.079	0.058	1.257	1.252	-0.397	0.177	0.173	-2.273
Madhya Pradesh	0.0556	0.0555	-0.2840	1.0614	1.0614	-0.0011	1.079	1.079	0.025	1.257	1.254	-0.249	0.177	0.174	-1.417
Punjab	0.0558	0.0556	-0.3927	1.0614	1.0614	-0.0015	1.078	1.079	0.082	1.256	1.253	-0.265	0.176	0.173	-1.518
Orissa	0.0560	0.0557	-0.5797	1.0614	1.0614	-0.0022	1.078	1.079	0.120	1.265	1.260	-0.374	0.183	0.179	-2.069
Himachal Pradesh	0.0558	0.0557	-0.2677	1.0614	1.0614	-0.0010	1.079	1.080	0.065	1.260	1.257	-0.229	0.179	0.177	-1.284
Chattisgarh	0.0559	0.0557	-0.3167	1.0614	1.0614	-0.0012	1.079	1.080	0.061	1.258	1.256	-0.177	0.178	0.176	-1.002
Kerala	0.0564	0.0562	-0.4464	1.0614	1.0614	-0.0018	1.074	1.075	0.087	1.265	1.261	-0.341	0.183	0.180	-1.878
Delhi	0.0559	0.0555	-0.7572	1.0614	1.0614	-0.0029	1.079	1.081	0.196	1.256	1.250	-0.477	0.176	0.171	-2.752
Uttaranchal	0.0554	0.0552	-0.4423	1.0614	1.0613	-0.0017	1.080	1.082	0.127	1.249	1.246	-0.276	0.170	0.168	-1.632
Goa	0.0564	0.0563	-0.1093	1.0614	1.0614	-0.0005	1.074	1.074	-0.002	1.262	1.260	-0.170	0.181	0.179	-0.941
Assam	0.0555	0.0553	-0.3053	1.0614	1.0614	-0.0012	1.080	1.081	0.107	1.256	1.253	-0.206	0.176	0.174	-1.179
Bihar	0.0553	0.0553	-0.0719	1.0614	1.0614	-0.0003	1.081	1.081	0.013	1.252	1.251	-0.038	0.173	0.172	-0.219
Jammu and Kashmir	0.0550	0.0551	0.1177	1.0613	1.0613	0.0004	1.083	1.083	-0.017	1.246	1.247	0.086	0.168	0.169	0.512
Meghalaya	0.0551	0.0549	-0.3836	1.0613	1.0613	-0.0015	1.081	1.083	0.145	1.251	1.247	-0.269	0.172	0.169	-1.579
Tripura	0.0547	0.0546	-0.1151	1.0613	1.0613	-0.0004	1.084	1.085	0.044	1.241	1.240	-0.099	0.164	0.163	-0.603
Manipur	0.0547	0.0546	-0.1229	1.0613	1.0613	-0.0005	1.084	1.085	0.055	1.240	1.240	-0.059	0.163	0.163	-0.362
Nagaland	0.0548	0.0546	-0.2146	1.0613	1.0613	-0.0008	1.084	1.084	0.066	1.243	1.241	-0.163	0.165	0.164	-0.990
Sikkim	0.0548	0.0547	-0.2210	1.0613	1.0613	-0.0009	1.084	1.085	0.121	1.243	1.239	-0.282	0.166	0.163	-1.721
Mizoram	0.0546	0.0545	-0.1266	1.0613	1.0613	-0.0005	1.085	1.085	0.042	1.239	1.238	-0.068	0.163	0.162	-0.422
Arunachal Pradesh	0.0546	0.0546	-0.1252	1.0613	1.0613	-0.0005	1.084	1.085	0.032	1.240	1.238	-0.112	0.163	0.162	-0.693

Notes: Table IX shows some moments of the unconditional markup distribution generated by the model; std, mean, p95, p99, and log p99/p50 refer to the simple mean, standard deviation, 95th percentile, 99th percentile and the percentage difference between the 99th percentile and the median of the markups charged to the goods purchased by each state respectively.

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