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Abstract

We examine the complementary role of road infrastructure in determining the impact of a reduction in input tariffs on firm productivity. We combine newly constructed geo-spatial data from Ethiopia on road improvements under the Ethiopian Road Sector Development Program with detailed establishment level data on manufacturing firms. To explore the impact of roads, we construct a measure of market access capturing the intensity of possible road connections between the town in which a firm is located and other intranational markets. Road improvements under the program give us rich spatial and time variation in market access. We find strong complementarity between roads and input tariff liberalization. A reduction in the input tariff is associated with a larger increase in firm productivity in areas with better market access. Our study highlights the role of roads in shaping the effects of trade liberalization on firms.

Keywords

Input tariffs; transport infrastructure; roads; firms; productivity; Ethiopia

JEL Classification: F14; O14; O18

1 Introduction[1]

Trade liberalization has been shown to benefit economies in several ways. Increased competition and better access to intermediate inputs resulting from trade liberalization can spur innovation and lead to productivity enhancements (Topalova and Khandelwal, 2011; Bigsten et al., 2016; Bloom et al., 2016; De Loecker, 2011), while lower product prices can generate welfare improvements for consumers (Ural Marchand, 2012). However, the distribution of gains from trade liberalization is far from uniform within countries and depends on complementary domestic conditions, including the flexibility of labor and credit markets, quality of institutions and provision of public goods and infrastructure (Pavcnik, 2017). Identifying and understanding these complementary conditions and the channels through which they shape the effects of trade liberalization is crucial to inform policy and ensure that trade works for everyone.

In this study, we examine the complementary role of road infrastructure in determining the impact of input tariff (the tariff on intermediate inputs) liberalization on firm productivity. We argue that roads matter for productivity gains from input tariff liberalization. Specifically, we propose that improved roads amplify the impact of a reduction in input tariffs on firm productivity by boosting firms' connectivity to intranational markets. Our empirical analysis combines newly constructed geo-spatial data from Ethiopia on road improvements under the Ethiopian Road Sector Development Program (RSDP) with detailed establishment level data on manufacturing firms.

Overlapping trade and road infrastructure reforms make Ethiopia an excellent case study for our purpose. Tariffs were reduced progressively starting in the early 1990s and continuing into our sample period as part of a trade liberalization agenda initiated externally. Tariff changes were hence largely exogenous to domestic firms. Next, Ethiopia embarked on extensive improvements to roads via the RSDP, aimed at improving connectivity throughout the country. Significant enhancements in road infrastructure were undertaken under this program, including projects to rehabilitate and upgrade the quality of existing roads and to build new ones.

To study the impact of roads, we construct a measure of market access capturing the intensity of possible road connections between the urban area (town) in which a firm is located and other markets in the country. We identify urban areas using contiguous lit spatial units from

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high resolution nocturnal satellite images. Road improvements under the infrastructure program result in differential changes in market access for firms across Ethiopian towns over time, either through increases in the quality of the existing road network or through an expansion of the existing network with the construction of new roads.[2] We exploit census data on Ethiopian manufacturing establishments from 1998 through 2009 to construct measures of firm productivity.[3]

In addition to information on revenues, the Ethiopian manufacturing census records data on quantities, allowing us to compute unit-values at the firm level. This allows us to build quantity-based physical productivity measures that are not affected by the usual caveats undermining the application of revenue-based productivity in studies of trade liberalization and firm performance. As highlighted by a burgeoning literature, focusing on revenue-based productivity introduces biases in the estimation of production function coefficients and may confound the effects of trade liberalization on physical productivity and firm markups (see for instance De Loecker, 2011; De Loecker et al., 2016).

Our empirical strategy relates firm productivity to input tariffs, market access determined by the road network (hereafter referred to simply as roads) and an interaction of the two to capture the complementary effect of roads on the relationship between input tariffs and firm productivity. We find strong complementarity between roads and input tariff liberalization. A ten percentage point decrease in the input tariff is associated with a 19 percentage point larger increase in productivity for a firm with median roads relative to a firm with roads at the 5^{th} percentile. A ten percentage point decrease in the input tariff is associated with a 4 percentage point larger increase in productivity for a firm with roads at the 95^{th} percentile relative to a firm with median roads.

Results survive a battery of robustness checks, including an instrumental variable estimation exercise to tackle the potential endogeneity of road improvements from non-random allocation of road investments. Our findings are further confirmed with alternative measures of both productivity and roads and in various cuts of the data. Finally, results endure after we control for the effects of a reduction in output tariffs (the tariff on the final good produced by the firm) on firm productivity that operate by increasing competition.

An exploration of the mechanisms through which roads complement the relationship between input tariff liberalization and firm productivity shows that with a fall in the input tariff, firms in towns with better roads see an increase in the likelihood of employing new imported intermediate inputs in production. Additionally, in an extension of our empirical analysis, we look at revenue-based firm productivity and the markup charged as additional dependent variables. We find some evidence for complementarity between roads and the impact of input tariff liberalization on revenue-based productivity. However, our results on the markup charged by firms reveal no such complementarity. We argue that two contrasting forces are potentially at work. While amplified gains from an input tariff reduction for firms in towns with better roads mean larger

[2] The raw data to construct this measure and other measures of road infrastructure used in our study are sourced from the Ethiopian Road Authority (ERA).

[3] The data, collected by the Ethiopian Central Statistical Agency (CSA), include detailed information at the establishment level, including on location (town), labor use, capital, usage of imported inputs and exports.

markups, increased competitive pressures from better roads can exert an opposing influence.

Our paper makes several contributions. First, we contribute to the literature studying infrastructure development in the context of international trade. This literature has embedded intranational trade costs into models of international trade to emphasize that better transport infrastructure can impact interregional and international trade (Donaldson, 2018), shape the pattern of comparative advantage among sub-national entities (Coşar and Fajgelbaum, 2016) and determine the intranational distribution of gains from falling international trade barriers (Atkin and Donaldson, 2015; Allen and Atkin, 2016; Ramondo et al., 2016). However, to date, there has been no formal assessment of the role played by roads in determining the impacts of trade liberalization on firm performance. We aim to fill this gap by underscoring the role for transport infrastructure in ensuring gains from better access to intermediate inputs for domestic firms.

Second, our study contributes to the literature demonstrating that lower input tariffs and the resulting access to cheaper, better quality and a wider variety of intermediate inputs is associated with greater firm productivity (Topalova and Khandelwal, 2011; Bigsten et al., 2016), higher markups (Brandt et al., 2017), product quality improvements (Amiti and Khandelwal, 2012) and greater product scope (Goldberg et al., 2010). In this context, we argue that the positive effects of an input tariff reduction are augmented when firms are better connected to markets intranationally by quality transport infrastructure. Indeed, firms in less connected regions may lose out on gains from trade liberalization.

Third, our study broadly relates to the literature emphasizing road infrastructure improvements as crucial for economic development in low-income countries (Storeygard, 2016; Donaldson, 2018). Policy makers have long touted the potential for roads to generate growth and alleviate poverty.[4] While studies have found that good roads are associated with increases in firm activity (Shiferaw et al., 2015), exports (Volpe Martincus and Blyde, 2013; Coşar and Demir, 2016) and employment (Volpe Martincus et al., 2017), recent work casts doubt on the ability of road improvements to substantially transform rural economies in developing countries (Asher and Novosad, 2018). We highlight an important role for roads in ensuring gains from trade liberalization. In fact, our results suggest that initial road investments bring the largest gains for firms, echoing existing work on investment in railroads in Africa (Jedwab and Moradi, 2016).

The remainder of the paper is organized as follows. Section 2 presents our conceptual framework. Section 3 describes the empirical strategy. We describe our measures of tariffs and road infrastructure, the data and productivity estimation. We also discuss the empirical specification, identification issues and estimation strategy. Section 4 presents results, robustness checks and extensions to the baseline analysis. Section 5 concludes.

[4] The World Bank identified "widespread poverty ... linked to, among others, the constraint imposed by the poor road network on economic and social development and the creation of local employment opportunities" as a concern for Ethiopia (World Bank, 2018).

2 Conceptual Framework

The main goal of our study is to analyze the role played by road improvements in determining the impact of an input tariff reduction on physical total factor productivity of firms. In this section we discuss a framework to motivate our empirical analysis. Consider firms that use differentiated intermediate inputs in production. A reduction in the input tariff is associated with a decrease in the price of imported intermediate inputs that are now accessible to the firm at a lower cost. This improved access allows firms to utilize more imported inputs (at both the intensive and extensive margins), which can increase total factor productivity through several potential channels. Imported intermediates may imperfectly substitute domestic inputs and may have higher price-adjusted quality (Halpern et al., 2015). Alternatively, if the production technology displays love-of-variety, access to a larger variety of imported intermediates may be associated with greater efficiency from greater specialization of resources (Colantone and Crinò, 2014).

Improved road infrastructure can moderate the impact of a reduction in input tariffs on firm productivity by boosting firm connectivity to intranational markets. Better roads lower the cost of transporting imported inputs. For any route through which imported intermediates travel from the Ethiopian border to an importing firm, lower travel costs between the firm's location and other intranational markets - including national or regional economic hubs and dry-ports - will decrease the firm's transport cost. This reduction in transport cost magnifies the reduction in the price of imported inputs from a lower input tariff, boosting its impact on firm productivity. Next, better connectivity to intranational markets due to new or upgraded roads means that, on the one hand, firms can access larger demand. Jensen and Miller (2018) show how, when consumers learn about non-local producers, firms gain market share and grow. On the other hand, they compete more intensively with other final good producers, given that an increase in market access allows consumers to access goods produced by firms in other locations.

Greater market access and more competition increase the potential gains for firms from improving total factor productivity and lowering their marginal cost of production (Lommerud et al., 2009). Firms in areas with better roads thus have a greater incentive to switch to imported varieties that improve productivity and lower marginal cost, further magnifying the impact of an input tariff reduction on total factor productivity.[5] To summarize, our hypothesis is that better roads, by improving connectivity to intranational markets, magnify the impact of an input tariff reduction on the total factor productivity of firms. In other words, a reduction in the input tariff is associated with a larger increase in total factor productivity for firms in towns that are better connected to intranational markets through the road network. We examine this hypothesis in our empirical analysis by exploiting detailed geo-spatial information on road improvements under Ethiopia's road development program to construct measures of road connectivity to intranational markets for firms across Ethiopia.

[5] We summarize this discussion in Figure H-1 in Appendix Section H

3 Empirical Framework

This section presents the ingredients of our empirical framework. Section 3.1 discusses Ethiopian infrastructure and tariff reforms and related measures used in the analysis. Section 3.2 describes the database of Ethiopian firms and the methodology we adopt to estimate total factor productivity. Our preferred approach accounts for both output price and input price biases in addition to the standard endogeneity concerns due to simultaneity in input choices. Section 3.3 introduces the empirical specification used to analyze the role of infrastructure in determining the effect of a reduction in input tariffs on firm productivity and discusses our identification strategy. Finally, Section 3.4 introduces the estimation sample and reports summary statistics.

3.1 Infrastructure and Tariffs in Ethiopia: Reforms and Related Measures

3.1.1 Infrastructure

Being a landlocked country with a poorly developed railway system, Ethiopian road transport represents the dominant mode for intranational movement of people and goods (Iimi et al., 2017).[6] At the end of the nineties, the deteriorated condition of the existing road network spurred the Ethiopian Government to launch a major infrastructural reform program: the Road Sector Development Programme (RSDP). The first three phases of the program, from July 1997 to June 2010 involved construction, rehabilitation, upgrading and maintenance of federal and regional roads by the Ethiopian Roads Authority (ERA) and the Regional Roads Authorities (RRAs).

The official assessment of the first three phases of the program (Ethiopian Roads Authority, 2011) reveals substantial improvements in road infrastructure along multiple dimensions between 1997 and 2010 (see Table 1).

Table 1: Improvements in road infrastructures during the RSDP

Indicators	1997	2010
Proportion of Asphalt roads in Good Condition	17%	73%
Proportion of Total Road network in Good Condition	22%	56%
Road Density/ 1000 sq. km	24.1	44.4

Notes: Raw data sourced from Ethiopian Roads Authority (2011).

The main source of information on Ethiopian road infrastructure we draw upon in this paper is a proprietary geo-spatial database consisting of coded documents by the ERA and the RRAs reporting on all road construction sites that were opened in the context of the first three phases of the RSDP. The resulting database is a time series of shapefiles of the Ethiopian road network, where for each geo-localized road segment, two main attributes are registered: the type of road

[6] The railway connecting Addis to the port of Djibouti was ceased in 2007 in the section between Addis and Dire Dawa. The new railway connecting Addis to Djibouti has been financed by a Chinese concessional loan project and was inaugurated in early 2017, almost ten years after the sample period analyzed in this paper.

surface and the road's condition. There are four types of road surfaces in the data: earth surface, minor gravel (which identifies regional rural roads with a gravel surface), major gravel (federal gravel roads) and asphalt. As for road conditions, the database distinguishes between two categories: not rehabilitated and new or rehabilitated.[7]

Figure 1a presents the network of federal and regional roads in 1996 by type of surface and the cities that are covered in our empirical analysis. Figure 1b shows the network of federal and regional roads in 2010, distinguishing between road segments which existed in 1996 and were not rehabilitated by 2010 (light grey segments on the map) and roads that were either newly constructed or rehabilitated during the first three phases of the RSDP. A visual inspection of the two maps shows a substantial expansion of the road network between 1996 and 2010. This data on road improvements can be aggregated to compute the average travel speed for each road segment at each point in time. This is done in accordance with the speed matrix proposed by the ERA and reported in Table 2.[8]

Figure 1: Federal roads, regional roads and the RSDP

(a) Cities and RSDP roads in 1996 by surface type

(b) New and upgraded RSDP roads between 1996 and 2010

Table 2: The ERA travel speed matrix

Surface	Condition	
	Not rehabilitated	Rehabilitated or new
Asphalt	50	70
Major gravel	35	50
Minor gravel	25	45
Earth	20	30

Notes: The table reports average travel speed as a function of the surface and condition of the road segment. Speed is measured in kilometers per hour.

To identify the role of road improvements in determining the relationship between a reduction

[7] Information on road surface and condition are recorded every two years from 1996 to 2010. The raw data were compiled by a local consultant. The consistency and accuracy of the original documents used for the coding exercise were checked by the authors during a field trip in 2017.

[8] The same speed matrix has been used by Shiferaw et al. (2015) and Storeygard and Jedwab (2018).

in input tariffs and firm performance, we employ an indicator of market access á la Harris (1954). This and alternative versions of the market access indicator have been used by Donaldson and Hornbeck (2016) to measure the economic effects of infrastructural developments in the context of a formal structural gravity trade model. In the context of the present paper and similarly to Storeygard (2016), market access captures the structure of road connections between a geographically defined urban area (city or town) where a firm is located and all other urban markets in the country weighted by the intensity of their economic activity.[9]

Formally, we define the indicator Roads_{rt} for each town r at time t as follows:

$$\text{Roads}_{rt} = \log\Big(\sum_{z \neq r} D_{rz,t}^{-1} L_z\Big) \tag{3.1}$$

where $D_{rz,t}$ is the minimum distance in hours of travel between town r and town z given the road network in place at t, and L_z is an indicator of economic activity based on night-light intensity in z in the pre-sample period (1996).[10] Bilateral distances in travel hours are computed applying the Dijkstra algorithm on the network of Ethiopian urban areas (nodes) connected by federal and regional Ethiopian roads (links).[11] Each link is characterized by its average travel speed, a function of the surface type and condition of the road segment(s) in the link (see Table 2). Hence, the variable Roads_{rt} captures the intensity of the road infrastructure reform treatment received by town r at time t as the capacity of such treatment to affect r's contact with intranational markets in the country.

Following Henderson et al. (2011, 2012) we measure town-level economic activity with night light data. More precisely, L_z is given by the sum of the beginning of sample (1996) night light intensity scores provided by NOAA National Geophysical Data Center (2018) over 0.86km^2 grid cells within the urban area corresponding to town z.[12] Urban areas are defined as contiguous lit areas between 1996 and 2010 intersecting with, or situated within a 5 kilometer distance from the town coordinates as reported in the road network database.[13] Note that since L_z is fixed over

[9] In the computation of market access, we consider all 82 cities recorded in the Ethiopian census of large and medium manufacturing firms for which we have firm data.

[10] While many papers including Donaldson and Hornbeck (2016) use population data in the computation of market access, we employ night light intensity data as in Storeygard (2016). This is particularly appropriate, given our interest in supply-side economic activity.

[11] Starting from the shapefiles with road segments, we create additional ancillary nodes to allow for turns at every intersection between road segments. We have no information on the direction of travel allowed on each road segment. Hence, links are set so that they are not directed, reflecting the underlying assumption that each road segment can be travelled on in both directions. This is a reasonable assumption, given the focus on regional and federal roads which represent the majority of road infrastructure in the country. A road (link) is connected to a town node when it enters the corresponding urban area (definition follows in the main text). Unlike other Ethiopian regions, city or town areas are small and relatively homogeneous. For this reason, we assume zero distance for connections between roads and town nodes. Alternative assumptions do not change the resulting market access indicator.

[12] Following Eberhard-Ruiz and Moradi (2018), we use scores from raw satellite images, instead of processed images with stable nightlights, as more reliable proxies of economic activity in small and medium African towns.

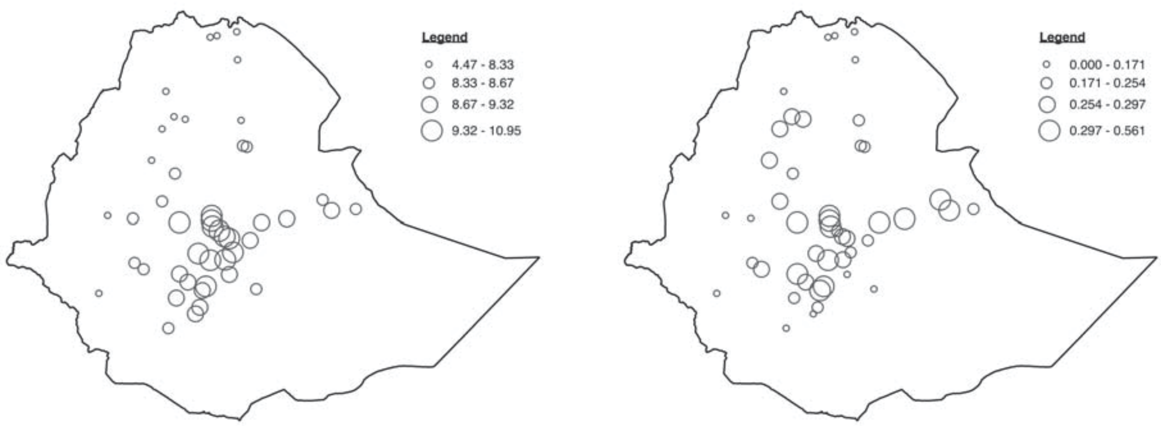
[13] This definition of urban areas follows the approach in other studies, as in Henderson et al. (2017) and Eberhard-Ruiz and Moradi (2018). We thus identify urban areas starting from 69 town coordinates. For 6 of these coordinates, we do not find any corresponding lit area and we exclude these cooridnates from our analysis. Also, the contiguous lit area associated with Addis, the capital city, is associated with 8 town coordinates: Addis, Burayu, Sululta, Sendafa, Akaki, Sebeta, Bishoftu, Modjo. We partition this area into 7 sub-areas consisting of the Voronoi polygons defined around town coordinates. This requires merging Addis and Burayu, whose coordinates

time, the time variation in Roads_{rt} solely reflects the rehabilitation, upgrading and construction of new roads undertaken during the first three phases of the RSDP.

We believe that the market access indicator, Roads_{rt}, captures several dimensions of connectivity that are consistent with the mechanisms identified in our conceptual framework. First, it reflects the ease with which intermediate inputs can be transported to Ethiopian firms. As more remote towns are better connected to regional and central economic hubs via the road network, the cost for intermediaries to transport inputs to them are likely to decline. Second, the measure accounts for both increases in market size and competition from other final good producers that connectivity to intranational markets can bring for remote firms. As we argue in Section 2, lower transport costs and increased market size and competition can magnify the impact of an input tariff reduction on firm productivity.

Figure 2a plots the value of the market access indicator in 1996 for the 46 towns that are covered in the econometric analysis. Figure 2b shows the change in market access between 2010 and 1996 for each town, formally $\text{Roads}_{r,2010} - \text{Roads}_{r,1996}$. Focusing on Figure 2a, bigger circles near the center of the country close to Addis reveal higher market access in this area of the country. Smaller circles away from the center indicate lower market access for these towns. Figure 2b shows a larger increase in market access for less connected towns away from the center, suggesting that they saw improvements in road infrastructure over the time period of our analysis.

Figure 2: Market access (Roads_{rt})



(a) $\text{Roads}_{r,1996}$ (b) $\text{Roads}_{r,2010} - \text{Roads}_{r,1996}$

In Table B-1, we conduct a descriptive analysis of the relationship between roads and firm outcomes at the town level. We find that roads are positively correlated with a range of indicators of economic performance and global engagement in manufacturing, like the total number of firms, labor productivity, capital intensity, total sales, the ratio of skilled to unskilled labor and import-intensity (defined as the ratio of imports to sales). These correlations are consistent with roads broadly benefiting the manufacturing sector in Ethiopia.

are too close to each other to allow for the application of the Voronoi partition. Figure A-1 provides a graphical representation of this partition for Addis (including Burayu), Sululta, Akaki, Bishoftu and Modjo, the towns within the contiguous lit area covered in our estimation sample.

3.1.2 Tariffs

Starting in 1993, the Ethiopian government implemented six rounds of trade reforms, which ended in 2003 with the adoption of a six-band tariff structure with bands now ranging from 0 to 35% (more details are available in World Bank, 2004). We collect data on tariffs from the World Bank's WITS database, which uses the UN's TRAINS database as its source. Data on tariffs for Ethiopia are publicly available for the period 1995-2015, but they report some gaps in coverage, especially for the pre-2000 period. In light of this, we replace missing tariff values with values obtained by linear interpolation.

We construct input tariffs using information on the use of raw materials to construct industry weights. First, we match the code attributed by the CSA to each raw material used by the firm with a (4-digit) HS code. Second, we aggregate the information at the industry level (4 digit ISIC Rev. 3). Third, we compute the share of each input in each industry's total input expenditure: we denote as α_{jzt} the share of expenditure on input z in total input expenditures of sector j at time t.[14] Fourth, we use these shares as industry-specific coefficients to weight output tariffs using the standard approach:

$$\text{Input-tariff}_{jt} = \sum_{z} \alpha_{jzt} \text{Ouput-tariff}_{zt} \tag{3.2}$$

Figure 3 traces changes in the (sector) average input tariff for the period of our estimation sample (from 1998 to 2009). With trade liberalization, input tariffs dropped sharply up to 2003 and more gradually thereafter.

3.2 Firm-level Data and the Estimation of Total Factor Productivity

3.2.1 Firm level Data

We use establishment level data from the annual census of Large and Medium Manufacturing firms, published by the Central Statistical Agency (CSA) of Ethiopia.[15] Data cover all firms with at least 10 persons engaged and that use electricity in their production process.[16] All firms need to comply with CSA requirements, and the census is therefore representative of more structured and formal firms in the country.[17] The dataset includes detailed information on the characteristics of each establishment that are needed to estimate production functions, including

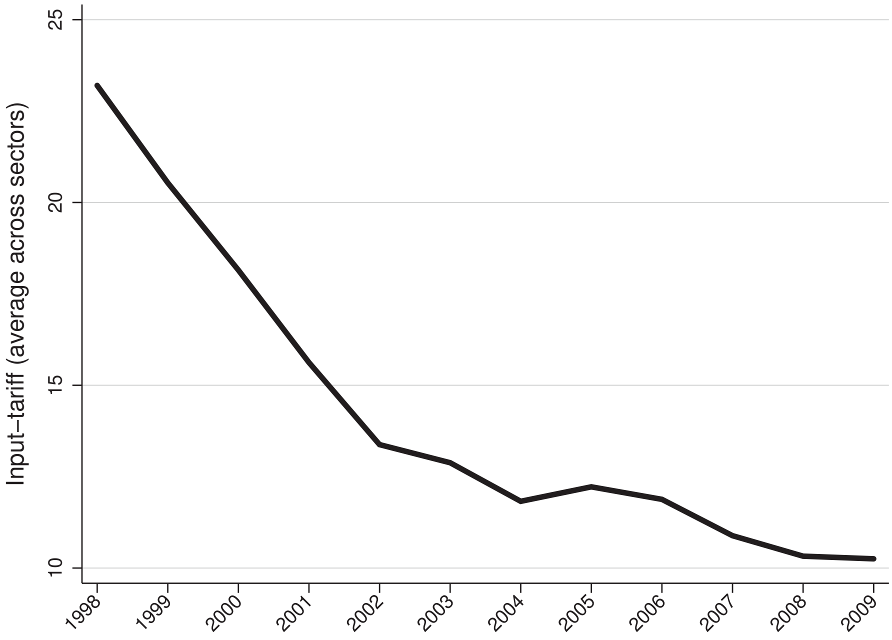
[14] We construct these cost shares on the basis of total input purchases, including both domestic and imported inputs to avoid endogeneity bias (see discussion in Amiti and Konings, 2007).

[15] The census data includes information at the level of the single productive establishment. We use the terms establishment and firms interchangeably in the paper.

[16] The number of persons engaged refer to employees as well as working owners.

[17] In 2005, a representative survey of firms was conducted instead of a census. This does not represent a critical bias for our analysis, since we do not focus explicitly on entry and exit rates (except when adjusting our TFP estimates for attrition), or on generating aggregate figures. Yet, we make an adjustment for those firms that are in the data in both 2004 and 2006, but not in 2005, filling in information for all variables as the simple average of the closest years. Results remain robust when dropping 2005 from our data.

Figure 3: Input tariff reduction



Notes: Authors' calculations from World Bank's WITS data.

output, employment, capital and inputs. Firms belong to the manufacturing sector, and their industry is defined at the 4-digit level according to the ISIC Rev. 3 classification.

Information on sales values and physical quantities is given for (up to eight) specific products produced by each firm. Products are recorded according to a CSA (Ethiopian Statistical Agency) classification and information available includes the value and quantity produced for the domestic and export markets for each product. As discussed earlier in the section on input tariffs, our data also allow us to identify raw materials used at the firm level, sourced domestically and imported, and their share in total firm expenditure.[18]

Finally, and crucially for our focus on roads, we have information on the region, woreda (district) and town for each firm. While firms are located in about 90 towns in the country, their growth is geographically divergent over time. Nevertheless, we register a strong concentration in the capital, Addis Ababa, which hosts 47% of the firms and 54.3% of total observations in our data respectively.

The firm census dataset is an unbalanced panel of 3,551 establishments covering the period 1998-2009, totalling 12,672 observations. Table 3 reports the number of firms for each year, showing strong dynamism in the private sector,[19] which is consistent with the overall pattern of economic

[18] Though our database has a multi-product structure, it has a limitation which undermines the application of a multi-product empirical framework to the analysis. In particular, the product code which is necessary to identify the observation at the product-time level is often missing in the data (58% of product-time level observations in the estimation sample have a missing product code). On average, across firms and years in our estimation sample, non-identifiable products account for 21% of total firm sales. This would make a product-level analysis substantially non-representative.

[19] The sector has experienced rapid growth, with an annual average of 10% over the period considered.

growth experienced by the country over the last decade (Moller, 2015).

Table 3: Number of firms in census years

Year	Firms	Share (%)
1998	701	5.53
1999	712	5.62
2000	704	5.56
2001	732	5.78
2002	866	6.83
2003	923	7.28
2004	980	7.73
2005	978	7.72
2006	1,131	8.93
2007	1,301	10.27
2008	1,696	13.38
2009	1,948	15.37
Total	12,672	100

Notes: Authors' summary of Ethiopian Census Data on firms.

3.2.2 TFP Estimation

To construct our dependent variable, we follow the existing literature and use a measure of firm performance based on estimated Total Factor Productivity (TFP). A large body of research on the nexus between trade liberalization and firm performance has been unable to distinguish improvements in physical efficiency from gains in profitability due to lack of information on firm specific prices. In our study, we exploit information on values and physical quantities to construct a measure of physical productivity at the firm level in the spirit of Eslava et al. (2004) and Smeets and Warzynski (2013).

We start from a basic production function linking the output produced by firm i to inputs adopted in the production process:

$$y_{ijrt} = \beta_1\ k_{ijrt} + \beta_2\ l_{ijrt} + \beta_3\ m_{ijrt} + \omega_{ijrt} + \epsilon_{ijrt} \tag{3.3}$$

where y_{ijrt} denotes the output of firm i producing in sector j, located in town r at time t. k_{ijrt} denotes capital, l_{ijrt} labor and m_{ijrt} intermediate inputs respectively. The random component ω_{ijrt} is unobservable productivity or technical efficiency and ϵ_{ijrt} is an idiosyncratic output shock.

Standard approaches adopt industry price deflators, when available, to adjust both output and inputs for price variation common to all firms in a given industry j. This introduces a so-called output price bias, resulting in a possible downward bias on the input coefficients, which is due to the likely correlation between firm specific variation in output prices and expenditure on inputs (De Loecker and Goldberg, 2014; De Loecker, 2011). For instance, firms producing products of high quality are likely to use high quality inputs that are priced higher. Similarly, lack of information on firm specific variation in input prices can introduce a downward bias in the estimated coefficients, given that higher input prices will raise input expenditure, while not increasing physical output (De Loecker et al., 2016).

Our data allow us to eliminate the output price bias given that we can calculate firm level price indices from information on the quantity and value of a firm's product. We aggregate product-level unit values at the firm level to calculate a firm-level price index P_{it}, using the approach suggested by Eslava et al. (2004) and Smeets and Warzynski (2013). The steps followed to calculate P_{it} are described in Appendix C.[20]

While deflating output with firm specific prices eliminates the output price bias, we follow a simplified version of the approach developed by De Loecker et al. (2016) to address input price bias. The assumption here is that the source of input price variation at the firm level can be captured by the quality of inputs adopted in the production process. Another assumption is that output quality is complementary to input quality and therefore, the quality of inputs is a function of the quality of output. This assumption allows us to control for the input price bias by including the output price index in the control function to account for unobserved input price variation.

We estimate production functions at the sector level (aggregating sectors at the 2 digit of the ISIC classification, and combining sectors sharing similar technologies when sample sizes are too small). Since OLS coefficients will be biased in equation (3.3) due to simultaneity and selection biases, we apply the approach by Levinsohn and Petrin (2003) (LP) that uses the costs of raw material as a proxy for unobservable productivity shocks to correct for simultaneity bias. We also address potential collinearity in the first stage due to simultaneity bias in the labor coefficient by adopting the correction suggested by Ackerberg et al. (2015). Finally, we adjust our estimates for attrition in the second stage of our productivity estimation. Physical output is total production at the level of the firm deflated using the index P_{it} described in Appendix C. We use the book value of fixed assets at the beginning of the year to measure capital stock, the total number of permanent employees to measure labor and the total cost of materials to measure intermediate inputs. Table D-1 in Appendix D reports production function coefficients at the industry level.

3.3 Econometric Specification and Identification Strategy

The basic empirical strategy used in this paper consists of a standard interaction model, where the main regressor of interest is the product of the input tariff and the moderator variable, roads. The empirical model is given by

$$\log \text{TFP}_{ijrt} = \beta \text{ Input-tariff}_{jrt} + \gamma \text{ Input-tariff}_{jrt} \times \text{Roads}_{rt} + \boldsymbol{\delta}'\mathbf{z}_{ijrt} + \mu_i + \nu_{rt} + \varepsilon_{ijrt} \qquad (3.4)$$

The dependent variable is the natural logarithm of TFP estimated for firm i active in sector j, town r at time t. Input tariffs in equation (3.4) vary at the industry-year level. The second regressor consists of the interaction between the input tariff and our measure of market access

[20] This comes with measurement issues, given that product-level prices are measured by unit values. In addition, we make assumptions concerning product homogeneity or the way products are aggregated across firms. See Appendix C for details.

determined by the road network as described in Section 3.1. The latter varies at the town level and over time. The model includes a vector of firm-specific characteristics varying over time ($\mathbf{z}_{ijrt}$): this includes a control for the firm's age (age_{ijrt}), a dummy for exporter status ($\text{Exporter dummy}_{ijrt}$) and one for foreign ownership ($\text{Foreign ownership dummy}_{ijrt}$). The baseline specification also contains firm fixed effects (μ_i), town-year fixed effects (ν_{rt}) and the idiosyncratic error term (ε_{ijrt}). Standard errors are clustered at the level of the (four-digit) industry.

Consistent with the large literature on the productivity effects of tariff liberalization, lower tariffs are expected to have a positive impact on TFP at the average quality of roads. This would be reflected in a negative sign for the coefficient β when the moderator variable Roads_{rt} is demeaned. By construction, the proposed specification allows the productivity effect of the input tariff to vary linearly with the quality of roads. The role of roads in shaping the effect of tariff liberalization is identified by the coefficient γ. As discussed in Section 2, we hypothesize that γ is less than zero. In other words, the negative relationship between input tariffs and TFP is magnified for firms in towns with better roads.

Identification in this empirical setting requires the policy treatment (input tariffs in our case) to be as good as randomly assigned in each equation. The included battery of fixed effects account for any confounding heterogeneity originating from firm specific as well as town and year specific shocks/characteristics. In sections below, we address further concerns pertaining to endogeneity. Finally, one might argue that the moderating role of roads is confounded with the moderating effect of other town specific economic factors. In order to identify the specific contribution of roads, we augment the baseline model by adding an interaction between input tariffs and town-level economic activity proxied by local night-light intensity. This additional interaction term partials out the moderating effect of other dimensions of economic development.

3.3.1 Endogeneity of Tariffs

A standard argument in the literature has to do with the potential endogeneity of trade policy. Mechanisms related to political economy (Grossman and Helpman, 1994), including the targeting of more (or less) productive industries for protection or lobbying by firms and industries might influence both the timing and the size of trade protection, introducing a bias in our estimates. In the case of Ethiopia, trade reforms were largely exogeneous, shaped by international institutions under liberalization programs implemented beginning in the early '90s (Jones et al. (2011) and Bigsten et al. (2016)) . Nevertheless, we tackle this potential concern in two main ways.

First, as in Topalova and Khandelwal (2011), Ahsan (2013) for India and Bas (2012) for Argentina, we aggregate our firm data at the industry level to test for the political protection argument. Specifically, we construct aggregates of production, employment, exports, capital intensity and agglomeration for each 4-digit industry and test the correlation among pre-sample levels (1996) of these variables and changes in the input tariff between 1996 and 2003.[21]

[21] For this exercise we use the change in input tariffs between 1996 and 2003, since this is the year of the latest trade reform. Results do not change if we replicate the same exercise using the change in tariffs from 1996 to

Results from these regressions show that there is hardly any correlation between changes in input tariffs and pre-sample industry characteristics, bolstering our argument that tariff reform in Ethiopia was largely exogeneous to firm outcomes.

Second, following Topalova and Khandelwal (2011) and Brandt et al. (2017), we check whether input tariff adjustments were made in response to productivity levels. To do this we regress input tariffs at time $t+1$ on firm productivity at t, controlling for firm and year fixed effects. We repeat the same exercise using levels of productivity at $t-5$. Results of these exercises show that changes in input tariffs were not correlated with previous levels of firm productivity, implying that policy makers did not adjust trade policy in response to observed productivity levels.

Due to space considerations, we present and discuss results from these exercises in Appendix E. Overall, we find strong empirical support against endogeneity of input tariff liberalization in Ethiopia.

3.3.2 Endogeneity of Roads

In this section, we address potential endogeneity of the moderator variable of interest, Roads_{rt}. It is possible that investments in road improvements were allocated systematically across towns. The high costs and potential benefits of road improvements can lead policy makers to select locations in which they will have the biggest economic impact (Coşar and Demir, 2016; Duflo and Pande, 2007; Asher and Novosad, 2018). In our specific context, road improvement decisions may be related to the presence of productive firms or firms that can lobby for protection or roads effectively. A mitigating factor in the Ethiopian context, as argued by Shiferaw et al. (2015), is that road improvement plans under the program were made on a 5-year basis. It is hence unlikely that they were affected by annual changes in firm performance. In addition, given the small weight of the manufacturing sector in the Ethiopian economy, it is hard to speculate that its current performance could affect long-term investment decisions in the road sector.

We proceed to address this concern in three steps. First, we regress town-specific changes (log differences) in Roads_{rt} during each phase of the RSDP against town-level average productivity at the beginning of each phase and we find no significant relationship between the two variables. We replicate the exercise after replacing average TFPQ with the town-level proxy for economic activity based on night-light data (L_{rt} defined above). Again, there is no evidence that suggests that towns with higher economic performance receive disproportionate infrastructure investments in the context of the RSDP. Results of these exercises are reported in Appendix F.

Second, as in Donaldson and Hornbeck (2016), we exploit the fact that variation in each town's market access (Roads_{rt}) is determined by improvements to the whole road network in the country. Therefore we can partial out the moderating role of changes in local roads, the source of the endogeneity concern. We do this by augmenting the baseline model (3.4) with an additional interaction between $\text{Input-tariff}_{jrt}$ and a measure of the quality of local road infrastructure at the town level.

2009.

Third, we employ an instrumental variable (IV) approach to tackle the endogeneity of roads. Following recent studies (Duflo and Pande, 2007; Iimi et al., 2017; Faber, 2014; Storeygard, 2016), we instrument for road improvements Roads_{rt} using variables that capture construction and transport costs. To do this, we use the geophysical condition of the terrain as a plausibly exogenous proxy for the costs of building road infrastructure. We use the slope of the terrain in the district in which each town is based interacted with input tariffs as an instrument for $\text{Input-tariff}_{jrt} \times \text{Roads}_{rt}$. The relevance of the instrument lies in the underlying assumption that investing in new roads in districts where the terrain is steep is more costly.[22] Turning to the exclusion restriction, it is easy to argue that terrain slope is as good as randomly assigned. Note, however, that terrain slope is time invariant. Hence, we refine the instrument to additionally reflect the costs of infrastructure investments over time. Specifically, we interact terrain slope with the global oil price index. As discussed by Storeygard (2016), fluctuations in global oil prices cause exogenous changes in transport costs, especially for remote locations. This composite variable provides us with a time varying measure of the cost of building roads at the town level. We ensure that our results are qualitatively robust to employing this new variable interacted with the input tariffs as an instrument for $\text{Input-tariff}_{jrt} \times \text{Roads}_{rt}$.

We present the results of these exercises after a discussion of our baseline estimates.[23]

3.4 Estimation Sample

We assemble data from the sources described to obtain our final estimation sample. The final sample consists of an unbalanced panel covering up to 1544 establishments located in 46 towns and observed across the period 1998-2009, yielding a total of 7740 observations. Summary statistics for the variables used to obtain baseline results are reported in Table 4.

[22] Our field interviews with ERA senior officers confirm that investments in roads are based on cost-benefit analyses, and that areas with difficult terrain conditions are less likely to be targeted due to higher costs.

[23] As a final note to this section, we argue that endogeneity of Roads_{rt} can actually be irrelevant for the consistent estimation of our parameter of interest - the coefficient of the interaction between roads and tariffs. To do so we appeal to an econometric result recently highlighted by Nizalova and Murtazashvili (2016). These authors show that in estimating the coefficient of an interaction between an exogenous treatment (in our case input tariff reduction) and an endogenous moderator (roads), consistent OLS estimates are obtained when the moderator and the unobservable omitted variable determining the endogeneity of the moderator (firms' lobbying capacity, for instance) are jointly independent of the treatment. Given exogeneity of tariffs discussed above, the absence of any correlation between roads and tariffs would guarantee consistent estimates for γ (as well as for β). This is strongly the case in our exercise, where exogenous tariff policy action at the national level is independent of town-level infrastructure improvements. Indeed, in our setting, the correlation between roads and tariffs is very close to zero. Computed on firm-year observations, the correlation between Roads and Input-tariff is equal to -0.032 on the estimation sample defined below and equal to -0.005 on all available observations. Finally, this is confirmed by the robustness of our results to the various checks proposed in this section and further discussed in Section 4.2.1. A similar application of Nizalova and Murtazashvili (2016) can be found in Beverelli et al. (2018).

Table 4: Summary statistics

Variable	mean	median	sd	min	max
log TFP_{ijrt}	2.484	2.267	1.518	-4.999	9.081
Input-tariff_{jrt}	14.376	10.032	9.480	0	60.236
Roads_{rt}	9.188	9.463	1.060	4.470	11.004
Night light intensity_{rt}	8.802	9.669	1.461	3.807	10.035
$\log(\text{age}_{ijrt}+1)$	2.436	2.398	0.891	0	4.736
Exporter dummy_{ijrt}	0.045	0	0.208	0	1
Foreign ownership dummy_{ijrt}	0.040	0	0.196	0	1

Notes: The table reports summary statistics for the main variables used in the analysis as described in equation 3.4.

4 Results

4.1 Baseline Results

Section 2 outlines our hypothesis that road infrastructure, by improving connectivity, magnifies the relationship between input tariff reductions and firm productivity. We examine this hypothesis in our empirical analysis. We report our main estimation results in Table 5. Column (1) excludes the interaction of the input tariff and roads, which is then included in column (2), along with the roads variable. Our measure of roads captures connectivity to economic hubs and tracks improvements in connectivity as roads were developed under the RSDP. Models in columns (1) and (2) do not control for potentially confounding heterogeneity across towns, but only for firm and year fixed effects. Column (3) reports estimates for the specification in column (2) with town-year fixed effects introduced to account for unobserved town-specific shocks correlated with firm productivity. Note that in this case we cannot estimate the impact of roads on firm productivity, since this effect is subsumed by the town-year effects. In column (4), we include an interaction of the input tariff and night-lights, a control variable for local economic activity, to address the concern that an input tariff reduction may be moderated by local factors correlated with better roads. Column (4) is our preferred specification and we employ it for all subsequent estimations.

Column (1) shows a negative relationship between the input tariff and firm productivity, however, this effect is not statistically significant. In column (2), we find that the interaction term between the input tariff and roads is negative and statistically significant. A decrease in the input tariff is associated with a larger increase in productivity in firms located in towns with better roads. Put together, results in columns (1) and (2) emphsize the role for roads in determining the effects of a reduction in the input tariff on firm productivity. Without quality roads, there is no evidence that a reduction in the input tariff is associated with gains in total factor productivity for Ethiopian firms. These results continue to hold in column (3), which includes town-year fixed effects to account for time-varying town-specific heterogeniety. Column (4) controls for the moderating role of local economic activity in driving the relationship between a reduction in input tariffs and firm productivity. Our results from Table 5 confirm that roads matter for how input tariff liberalization impacts firm productivity.

Figure 4 uses estimates from column (4) to plot the effect of the input tariff on firm productivity

Table 5: Main Estimation Results

Dependent variable:	log TFP_{ijrt}			
	(1)	(2)	(3)	(4)
Input-tariff$_{jt}$	-0.008	-0.008	-0.009	-0.009
	(0.007)	(0.007)	(0.007)	(0.006)
Input-tariff$_{jt}$×Roads$_{rt}$		-0.006**	-0.007**	-0.009***
		(0.003)	(0.003)	(0.003)
Input-tariff$_{jt}$×Night light intensity$_{rt}$				0.006*
				(0.003)
Roads$_{rt}$		0.369***		
		(0.132)		
Observations	7740	7740	7740	7740
Adjusted R^2	0.664	0.664	0.661	0.662
Firm FE	√	√	√	√
Year FE	√	√		
Town-year FE			√	√
Firm-year controls	√	√	√	√

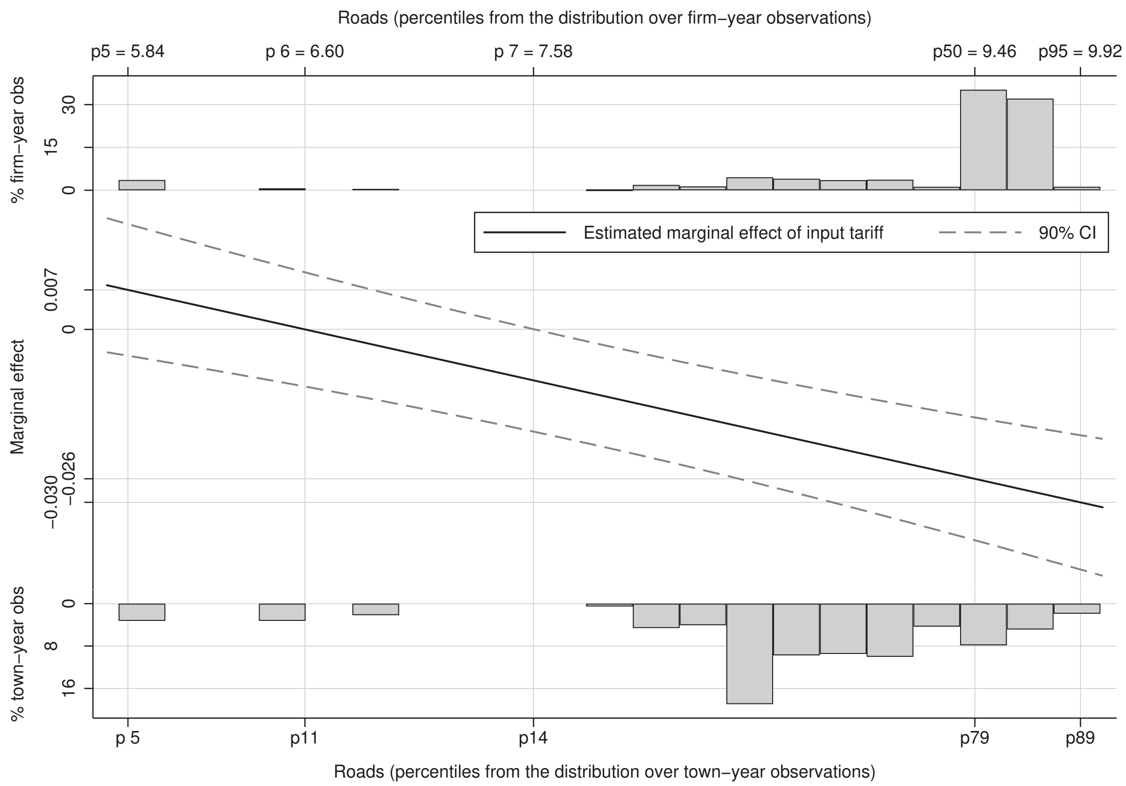
Notes: Roads$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

at various levels of roads (holding local economic activity - Night light intensity$_{rt}$ - fixed at the sample mean) with 90 percent confidence intervals on each side. The horizontal axis presents percentiles of roads in the data based on firm-year and town-year observations.

We make the following observations from Figure 4. First, the downward sloping line at the center of the figure shows that the coefficient on the input tariff is more negative for larger values of roads. In other words, a fall in the input tariff is associated with a larger increase in firm productivity as road quality improves. From the figure, a ten percentage point decrease in the input tariff is associated with a 19 percentage point larger increase in productivity for a firm with median roads relative to a firm with roads at the 5$^{\text{th}}$ percentile. A ten percentage point decrease in the input tariff is associated with a 4 percentage point larger increase in productivity for a firm with roads at the 95$^{\text{th}}$ percentile relative to a firm with median roads. Note from the confidence intervals in Figure 4 that moving from roads at the 5$^{\text{th}}$ percentile to the median level of roads results in a statistically larger effect of an input tariff reduction on firm productivity. This is not true for moving from the median to the 95$^{\text{th}}$ percentile of roads.

Our results hence suggest that roads built to connect towns at the left tail of the roads distribution can bring larger gains to firm productivity from input tariff liberalization. Second, the estimated marginal effect of the input tariff is negative and statistically significant for 94% of firm-year observations and 89% of town-year observations. This suggests that for a majority of firms in our data (but not for all firms), a fall in the input tariff is associated with an increase in productivity since they are located in regions well connected by roads.

Figure 4: The effect of input tariffs moderated by road infrastructures



Notes: The central panel in this figure plots the estimated marginal effect of input tariffs on log TFP_{ijrt} from column (4) of Table 5 (on the vertical axis) as a function of Roads_{rt} (on the horizontal axis) and fixing the value of Night light intensity_{rt} at its sample mean level denoted by $\overline{\text{Night light intensity}}$. Considering the regression equation (3.4) augmented with the additional term η $\text{Input-tariff}_{jt} \times \text{Night light intensity}_{rt}$, the point estimate plotted as a solid black line in the figure is given by $\hat{\beta} + \hat{\gamma} \times \text{Roads}_{rt} + \hat{\eta} \times \overline{\text{Night light intensity}}$. Corresponding confidence intervals at the 90% level of statistical significance have been estimated for each value of Roads_{rt} in the estimation sample of 7740 observations used in Table 5. The upper and lower panel of the figure plot the distribution of Roads_{rt} over firm-year observations and town-year observations respectively. Point estimates for the marginal effect of the input tariff are negative for values of Roads_{rt} bigger than 6.60. 94% (89%) of firm-years (town-years) covered in the estimation sample score a value of Roads_{rt} bigger than that threshold. After the 7^{th} (14^{th}) percentile of the distribution of Roads_{rt} over firm-years (town-years), the estimated marginal effect is negative and also statistically different from zero.

4.2 Identification and Robustness

In this section, we address several empirical concerns. First, we present results from the exercises to tackle endogeneity of roads discussed in Section 3.3.2. Next, we test for robustness of our results to alternative productivity and road measures. Finally, we ask if our results are robust to excluding the largest city and capital Addis from the sample and controlling for the effect of the output tariff (the tariff on the final good produced by the firm) on productivity and its complementarity with road infrastructure. We find that across all robustness tests, our results qualitatively support baseline results.

4.2.1 Addressing Endogeneity of Road Infrastructure

The quality of road infrastructure might be endogenous to firm productivity. Even though descriptive evidence discussed in Section 3.3.2 suggests that this is unlikely in our empirical setting, we present results from a number of additional exercises to address endogeneity of roads in Table 6.

Table 6: Additional interactions and IV

Dependent variable:	log TFP_{ijrt}		
Exercise:	Adding interactions		IV
	(1)	(2)	(3)
Input-tariff$_{jt}$	-0.009	-0.008	-0.010*
	(0.006)	(0.006)	(0.006)
Input-tariff$_{jt}$×Roads$_{rt}$	-0.009***	-0.010***	-0.018**
	(0.003)	(0.003)	(0.009)
Input-tariff$_{jt}$×Night light intensity$_{rt}$	0.004	0.012	0.009**
	(0.004)	(0.010)	(0.004)
Input-tariff$_{jt}$×Local roads$_{rt}$	0.006	0.014	
	(0.015)	(0.016)	
Input-tariff$_{jt}$×Log number of firms$_{rt}$		-0.012	
		(0.010)	
Input-tariff$_{jt}$×Production$_{rt}$		0.004	
		(0.005)	
Observations	7740	7740	7740
Adjusted R^2	0.662	0.662	0.661
Firm FE	√	√	√
Town-time FE	√	√	√
Firm-time controls	√	√	√
KP LM stat			9.250
P-val			.01
KP F stat			7.447

Notes: Roads$_{rt}$, its instruments and Night light intensity$_{rt}$ are demeaned using the mean over the estimation sample. Firm-time controls include exporter and FDI dummies and firm age. The slope (in degrees) is the average of each wereda in which the town is located, it is derived from Shuttle Radar Topography Mission (SRTM) dataset (v4.1) at 500m resolution, and it comes from Aiddata Geospatial statistics. The Oil price index (2000=100) measures the annual change of the spot price (FOB UK ports, dollar/barrel) in the UK Brent of Crude petroleum sourced from UNCTAD commodity statistics. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The Kleibergen-Paap (KP) LM statistic (and related p-value) tests for under-identification under the assumption of heteroskedasticity. The KP Wald F test tests for weak identification.

In Column (1) of Table 6 we augment the baseline model with the additional interaction between input tariffs and a measure of the quality of local (town-level) roads denoted as Local roads$_{rt}$. We construct this variable as the sum of all distances that can be travelled in an hour from a town node over all possible road links connected to that node. As argued by Donaldson and Hornbeck (2016) in their seminal contribution, partialling out the local component of the market access measure would not undermine its variability, which crucially depends on the whole road network. However, it will help to purge it of local variation that is the source of endogeneity. We find that after partialling out the moderating role of improvements to local road infrastructure, our market access variable Roads_{rt} capturing road infrastructure retains its role in shaping the effect of an input tariff reduction on firm productivity.

In the spirit of Ahsan (2013), column (2) augments the specification with additional interactions between the input tariff and measures of economic performance at the town level, in particular the number of firms and total production. This exercise reinforces our interpretation of γ as the productivity premium due to better road connectivity with intra-national markets as it controls for other town-level factors generating a differential effect of input tariff liberalization.

Column (3) presents results from the instrumental variables estimation. We instrument for the key interaction variable of interest with an interaction of the input tariff, the slope of the terrain in the district that the firm is located in and the oil price index (see Section 3.3.2 for a discussion). First-stage statistics reported in the table assure us that our instruments are strong and we find that they are negatively related to our road infrastructure variable as expected. From Table 6, we find that second-stage results confirm our baseline result presented in column (4) of Table 5. Note that even though the IV point estimate for γ is larger, the associated 95% confidence interval fully overlaps with the 95% confidence intervals associated with the coefficient estimates for γ in columns (1) and (2) of Table 6 (see Figure G-1 for a graphical representation). We conclude that the evidence presented in this section resoundingly supports our baseline result.

4.2.2 Robustness Checks

Finally, we undertake a series of checks to ensure the robustness of our results to (1) alternative measures of the dependent variable; (2) alternative measures of roads; (3) alternative sub-samples and (4) the inclusion of additional control variables.

First, we calculate alternative measures of firm productivity, to check if results are affected by the TFP estimation methods used and described in Section 3.2. In column (1) of Table 7, we present results for the baseline model with productivity estimated after accounting for a range of variables in the control function.[24] In columns (2) and (3), productivity is estimated with a one-step GMM method proposed by Wooldrigde (Wooldridge, 2009) and simply as labor productivity respectively. Across the three columns, we find that our results remain stable and qualitatively consistent with the baseline.

Second, results may be affected by the choice of variable measuring road infrastructure. We use two alternate measures of roads and present results in Table 8. First, we use an alternative measure of market access. In particular we take the model based formula derived in Donaldson and Hornbeck (2016) and applied to the East African context by Eberhard-Ruiz and Moradi (2018) (henceforth ERM). Using the night-light intensity variable L and bilateral travel times D, the model based formula of market access for town r can be written as $\sum_{z \neq r} L_z / \exp\{\sigma D_{rz,t}\}$. We follow the parametrization in ERM where σ is the product of trade elasticity - fixed at 8.4 - and the average per unit cost of transporting a good for one hour over the road network relative

[24] The control function approach is based on the methodology proposed by De Loecker et al. (2016), and consists of augmenting the set of variables affecting a firm's demand for materials. We do this by adding the input tariff as well as the export status of the firm.

Table 7: Robustness to Alternate Measures of Productivity

Productivity measure (in logs):	Control F	W-GMM	Lab Prod
	(1)	(2)	(3)
Input-tariff$_{jt}$	-0.009	-0.010	-0.006
	(0.006)	(0.007)	(0.007)
Input-tariff$_{jt}$×Roads$_{rt}$	-0.009***	-0.010**	-0.006*
	(0.003)	(0.005)	(0.004)
Input-tariff$_{jt}$×Night light intensity$_{rt}$	0.006*	0.008**	0.009**
	(0.003)	(0.003)	(0.003)
Observations	7740	7740	7738
Adjusted R^2	0.633	0.983	0.621
Firm FE	√	√	√
Town-time FE	√	√	√
Firm-time controls	√	√	√

Notes: The dependent variable in column (1) is TFP estimated with a modified control function; in column (2) with the Wooldridge GMM approach; and labor productivity (measured as value added over employees) in column (3). Roads$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

to the good's overall value. The value of this parameter has been estimated by ERM at 0.005 using monthly petrol prices for seven Ugandan cities. We plug the resulting value (0.042) of the distance decay parameter σ in the market access formula, take the log and denote it as Roads(ERM)$_{rt}$. Results using this alternative measure of market access are presented in column (1) of Table 8. As an alternate measure, we use the distance from each town r to Addis Ababa, the national capital and largest city. Results are reported in column (2).

Table 8: Robustness to Alternate Measures of Quality of Infrastructure

Dependent variable:	log TFP$_{ijrt}$	
	(1)	(2)
Input-tariff$_{jt}$	-0.009	-0.008
	(0.006)	(0.006)
Input-tariff$_{jt}$×Roads(ERM)$_{rt}$	-0.010**	
	(0.005)	
Input-tariff$_{jt}$×Distance to Addis$_{rt}$		0.011**
		(0.005)
Input-tariff$_{jt}$×Night light intensity$_{rt}$	0.005	0.024***
	(0.003)	(0.008)
Observations	7740	7214
Adjusted R^2	0.662	0.660
Firm FE	√	√
Town-time FE	√	√
Firm-time controls	√	√

Notes: Roads(ERM)$_{rt}$, Distance to Addis$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Results from columns (1) and (2) confirm our baseline patterns. A reduction in the input tariff is associated with a larger increase in firm productivity for firms in regions with better roads. The coefficient on the interaction term between the input tariff and Distance to Addis in column (2) is positive and statistically significant as expected, since greater distance to Addis in this case measures poorer road quality.

Third, in column (1) of Table 9, we address the concern that our results are driven by firms in Addis, the largest city in Ethiopia that hosts a majority of firms in our sample. We estimate our baseline specification after excluding Addis and find that our results hold qualitatively.

Table 9: Excluding firms in Addis and including the output tariff

Dependent variable:	log TFP_{ijrt}		
Robustness exercise:	No Addis	Output tariffs	
	(1)	(2)	(3)
Input-tariff$_{jt}$	0.038*		-0.009
	(0.019)		(0.007)
Input-tariff$_{jt}$×Roads$_{rt}$	-0.008**		-0.007**
	(0.003)		(0.003)
Input-tariff$_{jt}$×Night light intensity$_{rt}$	0.024***		0.006
	(0.009)		(0.004)
Output-tariff$_{jt}$		-0.007	-0.003
		(0.009)	(0.010)
Output-tariff$_{jt}$×Roads$_{rt}$		-0.014*	-0.010
		(0.007)	(0.008)
Output-tariff$_{jt}$×Night light intensity$_{rt}$		-0.001	-0.004
		(0.006)	(0.006)
Observations	2833	7740	7740
Adjusted R^2	0.754	0.662	0.662
Firm FE	√	√	√
Town-time FE	√	√	√
Firm-time controls	√	√	√

Notes: Roads$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. Output-tariff$_{jt}$ measures the applied tariff on imports and is measured at the 4-digit ISIC level based on data from the World Bank's WITS database. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

As a final step, we include output tariffs in our estimation. In fact, it is conceivable that the output tariff (the tariff on the final product produced by firms) is correlated with the input tariff and independently affects firm productivity by spurring firms to improve efficiency in the face of competition. If this is true, our estimates of the effect of the input tariff on firm productivity and its complementarity with roads will not be consistently estimated without accounting for output tariff effects. In addition, some of the mechanisms linking infrastructure development to trade liberalization could also work through changes in the output tariff. We thus introduce controls for the output tariff and its interaction with roads in our baseline regression. Results are presented in columns (2) and (3). The qualitative story on the input tariff remains. However, we do not find a significant interaction effect between the output tariff and road infrastructure.

Overall, our analyses in this section show that our results are robust to a range of checks, boosting confidence in our baseline finding.

4.3 Mechanisms

We have so far established a significant moderating role for roads in determining the impact of input tariff reductions on firm productivity. We have argued that better roads magnify the impact of a reduction in the input tariff on firm productivity. In this section, we explore evidence for potential mechanisms by leveraging the strength of our data that allows us to differentiate between domestic and intermediate inputs, calculate the price (unit-value) of imported inputs and track their use over time.[25]

We begin by looking at the impact of an input tariff reduction on the price of imported intermediate inputs utilized by firms. Column (1) of Table 10 estimates the relationship between input tariffs and the price (unit-value) of imported intermediate inputs at the firm level using our baseline specification. We find the expected relationship - a reduction in the input tariff is associated with a statistically significant decrease in the price that firms pay for their imported intermediate inputs. In column (2), we introduce an interaction term between the input tariff and roads to examine the moderating role of roads in determining this relationship. While a reduction in the input tariff may be associated with a larger decrease in the price of intermediate inputs for firms in regions with better roads, they may use these differential cost savings to switch more aggressively to imported inputs that imperfectly substitute domestic ones or have higher price-adjusted quality. The net moderating role played by roads on the average price of intermediates employed by firms is thus ambiguous. Indeed, we find no complementarity between input tariffs and roads in column (2).

One of the main channels we emphasize in our conceptual framework is that a reduction in the input tariff allows firms to use imported intermediate inputs that imperfectly substitute domestic ones. To explore this idea, we study the relationship between input tariffs and the likelihood that a firm employs a new imported input in production in column (3). We find no significant effect of an input tariff reduction on the likelihood of employing new imported inputs. The flavor of this result is similar to our baseline result in column (1) of Table 5, where we find no effect of a reduction in the input tariff on total factor productivity. In column (4), we delve into the moderating role played by roads in this context. Both columns estimate a linear probability model. Results in column (4) suggest a statistically significant moderating role played by roads in determining the relationship between an input tariff reduction and the likelihood of employing a new imported input.

A ten percentage point reduction in the input tariff is associated with a ten percentage point greater likelihood of a firm introducing a new imported input in towns with roads at the median relative to the 5^{th} percentile. A ten percentage point reduction in the input tariff is associated with a one percentage point greater likelihood of a firm introducing a new imported input in

[25] A limitation of our data is that firms are asked to report their seven most important intermediate inputs. This means that we are unable to accurately capture changes in the scope or variety of intermediate inputs used by firms following input tariff liberalization.

towns with roads at the 95th percentile relative to the median. This finding is qualitatively borne out in column (5), which estimates a conditional logit model with firm and year fixed effects. Finally, column (6) ensures that this result is robust to restricting our sample exclusively to inputs whose product code is recorded in the data.

Taken together, columns (3) through (6) provide strong support for the idea that roads differentially afford firms with the opportunity to utilize new imported inputs following a reduction in input tariffs. In a framework where imported intermediates imperfectly substitute domestic inputs, improved access to foreign intermediate inputs is a plausible explanation for the differential gains in total factor productivity from input tariff liberalization experienced by firms in towns with better roads. In fact, without quality roads, there is no evidence that a reduction in input tariffs increases the likelihood that firms employ new imported inputs or see an increase in total factor productivity.

Table 10: Mechanisms

Dependent variable:	input p	input p	newii	newii	newii clogit	newii
	(1)	(2)	(3)	(4)	(5)	(6)
Input-tariff$_{jt}$	0.029**	0.025*	-0.004	-0.004	-0.030	-0.010
	(0.014)	(0.014)	(0.004)	(0.004)	(0.021)	(0.007)
Input-tariff$_{jt}$×Roads$_{rt}$		0.019		-0.003*	-0.024**	-0.025*
		(0.026)		(0.002)	(0.011)	(0.014)
Input-tariff$_{jt}$×Night light intensity$_{rt}$		0.004		-0.001	0.003	0.008
		(0.009)		(0.002)	(0.010)	(0.009)
Infrastructure$_{rt}$					0.477	
					(0.313)	
Night light intensity$_{rt}$					0.101	
					(0.194)	
Observations	1755	1755	7222	7222	5043	1755
Adjusted R^2	0.282	0.281	0.178	0.179		0.270
Firm FE	√	√	√	√	√	√
Year FE					√	
Town-year FE	√	√	√	√		√
Firm-year controls	√	√	√	√	√	√

Notes: Roads$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. The dependent variable in columns (1)-(2) is the price index of imported inputs. The dependent variable in columns (3)-(6) is a dummy variable taking the value of 1 each time a new variety of imported input is reported by the firm. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.4 Extensions

A key contribution of this study is our ability to analyze gains in physical total factor productivity (denoted as TFP in our paper but often called TFPQ in the literature) from input tariff liberalization. A growing body of research has emphasized the need to focus on physical total factor productivity as opposed to revenue-based total factor productivity (TFPR), which conflates impacts on productivity and the markup. Furthermore, there is rising interest in looking at the how firms' pricing strategies respond to trade liberalization, including via input tariff reductions (Brandt et al., 2017; Fan et al., 2018). In an extension of our analysis, we probe the effects of input tariff liberalization and the complementary role of roads on the markup charged by firms and on TFPR.[26]

We hypothesize that by reducing marginal cost, an input tariff reduction will ceteris paribus result in an increase in the markup charged by firms (as found, for instance by De Loecker et al., 2016). Whether this increase in the markup resulting from input tariff liberalization is exacerbated or attenuated in areas with better road infrastructure is less clear. On the one hand, a reduction in marginal cost from the input tariff reduction is likely to result in a smaller increase in the markup in areas with better roads due to stronger competitive pressures. On the other hand, the fact that these firms can also access a larger market and have a greater incentive to employ imported inputs and increase TFPQ may influence markups in the opposite direction. The direction in which roads affect the impact of input tariff liberalization on markups will depend on the effect that dominates, with the possibility of observing no role for roads if these effects play out equally. Figure H-1 in the Appendix Section H summarizes the channels at work.

We present results for TFP, TFPR and the markup (μ) in Table 11. All columns estimate the baseline specification with firm and town-year fixed effects and firm controls. Columns (1) and (4) replicate columns (1) and (4) of our baseline table Table 5 [27]. Columns (2) and (5) and columns (3) and (6) look at the relationship between the input tariff and TFPR and the markup and the moderating role of roads in each instance respectively. As hypothesized, from column (3), we confirm that a reduction in the input tariff is associated with higher markups charged by firms. From column (6), we find no moderating role for roads in determining the relationship between the input tariff and the markup. This is consistent with the two forces in areas with better road infrastructure acting in opposite directions - more competition in connected regions exerts downward pressure on the markup, while better market access and efficiency gains from physical productivity (TFP) enhancements work the other way. Finally, columns (2) and (4) focus on revenue productivity (TFPR) and show that a reduction in the input tariff is associated with an increase in TFPR, driven by the reduction in marginal cost for firms. The increase is magnified in cities with better road infrastructure, driven primarily by gains in TFP.

Overall, our results in this section are consistent with the idea that while input tariff liberalization is associated with greater improvements in efficiency in areas with better roads, it is not associated

[26] We calculate price-cost margin following the approach by De Loecker and Warzynski (2012), which rests on the idea that markups generate a wedge between an input's elasticity and revenue share. The markup μ_{it} is calculated as the ratio of price to marginal cost, i.e., $\mu_{it} = \frac{P_{it}}{\lambda_{it}}$, where P_{it} is firm's output price. We can derive an expression for markup as:

$$\mu_{it} = \beta^m_{it}(\alpha^m_{it})^{-1},$$

in which $\beta^m_{it} = \frac{\partial Q_{it}(\cdot)}{\partial M_{it}}\frac{M_{it}}{Q_{it}}$ is the output elasticity of material inputs and $\alpha^m_{it} = \frac{p^m_{it}M_{it}}{P_{it}Q_{it}}$ is the share of expenditure in materials in total revenue. We recover the output elasticity of materials β^m_{it} directly from the production function estimated in equation (3.3) and then adjust the share of expenditure on materials, α^m_{it} to account for productivity shocks to revenue, i.e. $\alpha^m_{it} = \dfrac{exp(m_{it})}{exp(r_{it} - \hat{\epsilon}_{it})}$.

[27] The minor difference between column (1) of Table 11 and column (1) of Table 5 is due to the inclusion of town-year fixed effects (instead of year fixed effects only)

Table 11: Extentions - Revenue productivity and markups

Dependent variable:	log TFP	log TFPR	μ	log TFP	log TFPR	μ
	(1)	(2)	(3)	(4)	(5)	(6)
Input-tariff$_{jt}$	-0.009	-0.024*	-0.020***	-0.009	-0.025*	-0.020***
	(0.007)	(0.014)	(0.006)	(0.006)	(0.014)	(0.006)
Input-tariff$_{jt}$×Roads$_{rt}$				-0.009***	-0.012*	-0.003
				(0.003)	(0.006)	(0.003)
Input-tariff$_{jt}$×Night light intensity$_{rt}$				0.006*	0.002	-0.000
				(0.003)	(0.004)	(0.002)
Observations	7740	7740	7567	7740	7740	7567
Adjusted R^2	0.661	0.703	0.433	0.662	0.703	0.433
Firm FE	√	√	√	√	√	√
Town-year FE	√	√	√	√	√	√
Firm-year controls	√	√	√	√	√	√

Notes: Roads$_{rt}$ and Night light intensity$_{rt}$ are demeaned using the sample mean over the estimation sample. TFPR is computed following the procedure described in Section 3.2.2, the only difference being that output is now deflated using the country-wide deflator (sourced from the IMF). Markups (μ) are estimated following the approach by De Loecker and Warzynski (2012), which is described earlier in this Section. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parentheses are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

with equivalent increases in the markup charged by firms. The latter finding can be explained by the presence of competitive pressures from economic dynamism spurred by better roads. The flavour of these results underscores the important role for improved roads in delivering gains from trade liberalization to local firms.

5 Conclusion

In this paper, we examine the role of roads in determining the effect of a reduction in input tariffs on the productivity of Ethiopian firms. We find that a reduction in input tariffs is associated with a larger increase in productivity for firms in towns with better roads that connect them to other intranational markets. Our result thus emphasizes a role for transport infrastructure in ensuring gains from trade. We find supportive evidence that road improvements facilitate adoption of new imported intermediate inputs from a reduction in input prices. Resutls also suggest that increased competition from better connectivity to other markets can ensure that firms do not increase markups differentially more in towns with better roads.

We belive that our analysis has implications for both trade and infrastructure policy in developing economies. While trade liberalization can improve firm performance by affording domestic firms better access to intermediate inputs, poor infrastructure can mitigate these gains from trade, particularly for very remote regions. This may exacerbate regional inequality with trade liberalization. We highlight that road improvements can complement the beneficial effects of trade liberalization on firm performance.

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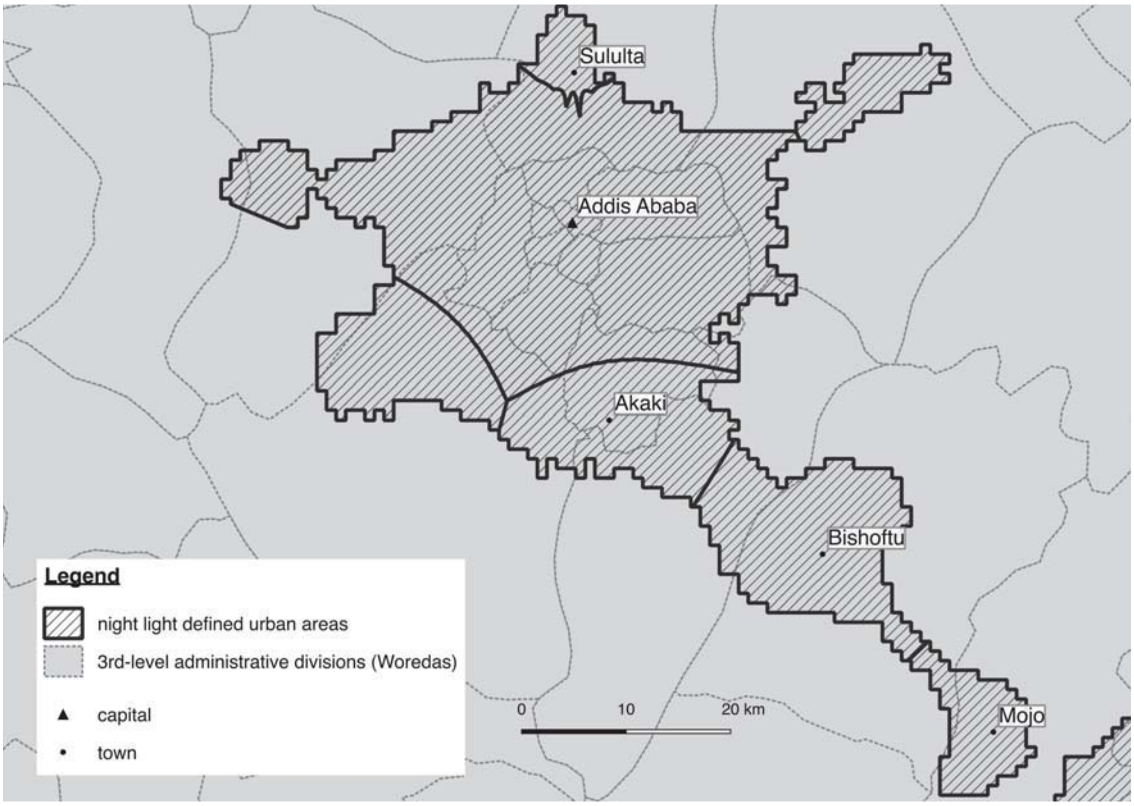
Appendices

A Ethiopian towns within a contiguous lit area

Figure A-1: Voronoi partition of the contiguous lit area



Notes: The figure plots urban areas defined by night-lights corresponding to Addis (including Burayu), Sululta, Akaki, Bishoftu and Modjo, all lying within a contagious lit area. We partition the area into sub-areas consisting of the Voronoi polygons defined around town coordinates.

B Roads and aggregate firm performance

Table B-1: Correlation between roads and town-level aggregate firm performance

Dep var:	N firms$_{rt}$	Lab productivity$_{rt}$	Capital intensity$_{rt}$	Sales$_{rt}$	Import on sales$_{rt}$	Skill ratio$_{rt}$
	(1)	(2)	(3)	(4)	(5)	(6)
Roads$_{rt}$	0.019*	0.108***	0.143***	0.127***	0.011***	0.050***
	(0.011)	(0.028)	(0.021)	(0.038)	(0.004)	(0.013)
Observations	638	591	624	638	635	615
R^2	0.903	0.490	0.568	0.719	0.416	0.383
Town FE	√	√	√	√	√	√
Year FE	√	√	√	√	√	√

Notes: The dependent variables are constructed by adding up firm level information at the town and year level. N firms$_{rt}$ is the log number of firms; Lab productivity$_{rt}$ is the log of labor productivity, constructed as total value added on total number of employees; Capital intensity$_{rt}$ is the log of the share of total fixed assets on total number of employees; Sales$_{rt}$ is the log of total sales; Import on sales$_{rt}$ measures the value of imported raw materials on total sales; and the Skill ratio$_{rt}$ is the share of the total number of administrative (and other non-production) workers on the total number of production workers. Robust standard errors in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

C Firm-level price index

The estimation of firm level productivity in the present paper builds on Eslava et al. (2004) and Smeets and Warzynski (2013). These two studies propose an empirical model of the production function where, instead of deflating revenues with the standard vector of sector-level price indices, a firm-level price index P_{it} is used. This Appendix discusses the procedure to adapt the methodology applied in Eslava et al. (2004) and Smeets and Warzynski (2013) to the specificities of our data.

Step 1

First, we account for the fact that in the Ethiopian firm census data, many products within firms are not consistently identifiable across time due to the lack of a product category as identifier. Second, multiple line entries within a firm-year record the same product code and unit measure. The solution we adopt is as follows. All products with missing product code are grouped in an aggregate product category (denoted with nim 'non identifiable missing'). Products within a firm-year that have the same values for both product code and unit measure are grouped in aggregate product categories depending on their product code ($onih$ 'other non identifiable with product code h').

Next, we derive a product-level price index as a weighted average of the prices of domestic sales and exports:

$$P_{hit} = \sum_{\nu=d,x} s^{\nu}_{hit} P^{\nu}_{hit} \tag{C-1}$$

where the superscripts d and x stand respectively for the domestic and export market, and s^{ν}_{hit} is the share of market ν in the total sales of product h by firm i at time t.

We deal with missing information in line with Eslava et al. (2004). In a nutshell: we compute sector-year level averages of P^{ν}_{hit} for $\nu \in \{d, x\}$ and we replace missing values of P^{ν}_{hit} with the respective sector-year average in case of a zero or missing value for sales or export quantity (value) and a non-missing, strictly positive value for sales or export value (quantity). Notice that when the value is missing (this is actually a minority of cases) the shares s^{ν}_{hit} cannot be computed. We correct for this by replacing the missing value of domestic and/or export sales for a product-firm-time level observation with the average value of domestic and/or export sales across available observations of the same product in the same firm but in alternate years.

Finally, we compute $P_{nim,it}$ and $P_{onih,it}$ as the weighted average of P_{hit} for all h belonging to the respective group of non-identifiable products, with weights computed as the h share of the total value (sales value plus export value) in the group. In this newly created database, these product-aggregates will be treated as individual products.

Step 2

We focus on product-level observations with perfectly identifiable products. We compute P_{hit} as before and append the results to the database created in Step 1. Then, we apply a Tornqvist formula to obtain firm-level prices. Notice that the dynamic structure of the Tornqvist formula requires that each product h is perfectly identifiable across time.

$$\Delta log(P_{it}) = \sum_{h} \frac{s_{hit} + s_{hi(t-1)}}{2} \times \left[log(P_{hit}) - log(P_{hi(t-1)}) \right] \tag{C-2}$$

where s_{hit} is the share of product h total (both domestic and export) sales value over total sales value of the firm i at time t.

Finally, we select 2009 as our base year (the number of active firms is at its maximum in this year) and set $P_{i,2009} = 1$. We then proceed recursively (backward) to retrieve firm-level prices:

$$log(P_{i(t-1)}) = log(P_{it}) - \Delta log(P_{it}) \ \forall t \leq 2009 \tag{C-3}$$

We first apply (C-3) only for those firm-year pairs (i,t) such that, for every year $t \leq k \leq 2009$, $\Delta log(P_{it})$ is non missing.

There are two potential computational caveats that we address following the approach laid out by Eslava et al. (2004). First, a firm might not be observed in the base year. Consider the following example which illustrates the proposed solution. Take firm i and assume that the last year where it is observed is 2006. In that case the last $\Delta log(P_{it})$ that we can compute using (C-2) is $\Delta log(P_{i2006})$. We will set $log(P_{i2006})$ as the sector-level average for 2006, i.e. $\sum_j log(P_{j2006})/|J^{S(i)_{2006}}|$, where $|\cdot|$ is a cardinality operator, J^{k_t} is the set of firms j belonging to sector k for which we were able to retrieve $log(P_{jt})$, and $S(i)$ is the sector to which firm i belongs. Second, a firm i might have a missing value for $\Delta log(P_{it})$ at a certain time t in between two time intervals where it is potentially possible to apply the recursive formula (C-3). This would cause a break in the formula (this is the case for year 2004 and panel_id 6 for instance). Again, we solve this issue by replacing the missing observation of $log(P_{i(t-1)})$ with the sector-level average for that year. The result is a series of firm-level price indices P_{it} which will be used to deflate firm-level revenues.

D TFP coefficients

Table D-1: TFP coefficients

Sector	Labor	Capital	Materials
15	0.4126489	0.0486334	0.8142029
17	0.0830094	0.0317496	0.6806585
18	0.1221208	-0.0289049	0.9153442
19	0.0679566	0.0752514	0.8331738
20	0.4058325	0.0115141	0.7583169
22	0.4919236	-0.010469	0.5968748
24	0.0809411	0.1088803	0.8244199
25	0.4396779	0.0269117	0.7720901
26	0.3447249	0.0431832	0.6823554
28	0.1844413	0.1293488	0.7633256
34	0.3015625	0.0996745	0.7081328
36	0.1963425	0.038197	0.8051757

Notes: The table reports coefficients of the production function estimated for each 2-digit industry following the methodology described in Section 3.2.2. Sectors are specified as 2-digit ISIC Rev 3 categories.

E Addressing potential endogeneity of tariff reforms

In this section, we ensure that input tariff changes are largely exogenous to initial industry characteristics. If input tariff changes are endogenous to initial industry characteristics, it is possible that our results on the impact of input tariff reductions on firm productivity are inconsistently estimated. To do this, we estimate relationships between initial sector characteristics in 1996 including production, employment, exports, capital intensity and agglomeration and input tariff changes at the sector level between 1996 and 2003. Results are presented in Table E-1. Across columns, we find no statistically significant relationship between initial sector characteristics and input tariff changes, assuring us that tariff changes are plausibly exogenous.

Table E-1: Correlation between initial sectoral characteristics and trade policy change

Dependent variable:	Production	Employment	Export	Capital intensity	Agglomeration
	(1)	(2)	(3)	(4)	(5)
ΔInput-tariff	-1.005	-1.093*	-1.085	0.514	0.008
	(1.243)	(0.547)	(3.219)	(0.811)	(0.025)
Observations	36	41	41	41	41
R^2	0.020	0.081	0.003	0.015	0.005

Notes: The dependent variables are constructed by aggregating firm level data at the 4-digit sector and year level and using pre-sample information from the census year 1996. Variables "Production", "Employment" and "Export" are the sum of the values of output, employees and exports of the firm by sector and year; "Capital Intensity" is constructed as the sum of fixed asset divided by the total employment by sector and year; "Agglomeration" is given by the number of firms in each sector and year. After aggregation, all variables have then been transformed in logs. Input tariffs are computed at the 4-digit sector level and the variable report their changes between 1996 and 2003. Robust standard errors in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Next, we ask if input tariff changes are related to initial performance, measured by productivity. If they are, then the relationship we estimate between reductions in input tariffs and firm productivity might be driven by how tariff reforms were targeted across sectors. In Table E-2, we estimate correlations between lagged values of productivity and input tariff changes in each year in our sample period. Again, we find no evidence of a strong correlation between initial performance and subsequent changes in input tariffs, lending further credence to our claim that input tariff changes are exogenous to firm performance.

Table E-2: Correlation between initial sectoral performance and trade policy change

Dependent variable:	Input-tariff$_{jt}$	
	(1)	(2)
log TFP$_{ijt-1}$	-0.038	
	(0.063)	
log TFP$_{ijt-5}$		-0.024
		(0.055)
Observations	7367	3107
R^2	0.456	0.055
Firm FE	√	√
Year FE	√	√

Notes: The dependent variable in both regressions is the input tariff computed at the industry level. The regressors are firm productivity lagged one and five years respectively. All regressions include firm and year fixed effects. Robust standard errors clustered at the sector level are reported in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

F Addressing potential endogeneity of roads

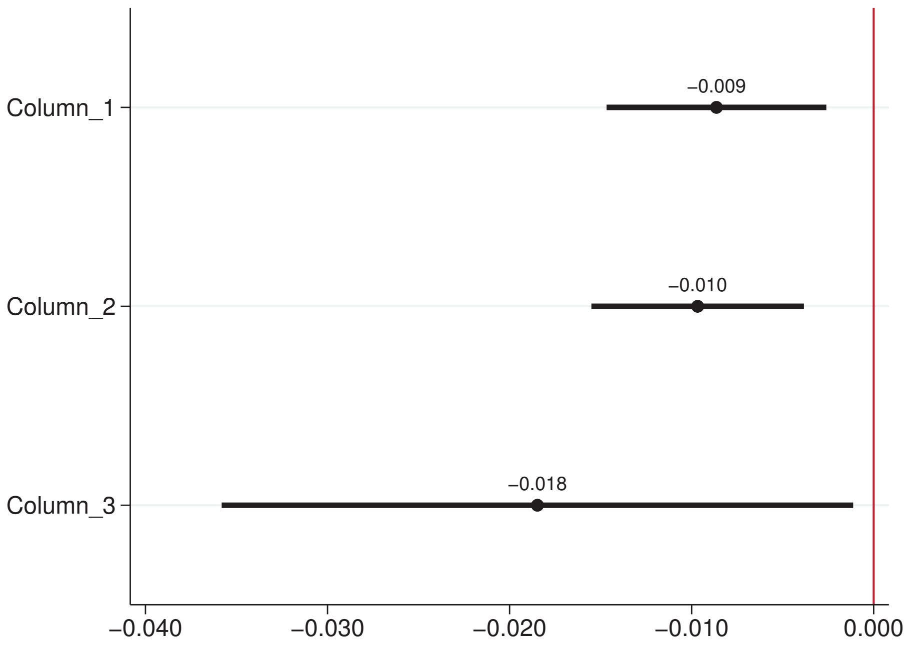
Table F-1: Correlation between town-level economic outcomes and change in roads

Dep var:	ΔRoads_{rp}					
	(1)	(2)	(3)	(4)	(5)	(6)
log TFP_{rp}	0.016		0.016	-0.004		-0.004
	(0.010)		(0.010)	(0.013)		(0.013)
Night light intensity_{rp}		0.007	0.003		0.013	-0.007
		(0.009)	(0.011)		(0.073)	(0.080)
Observations	117	138	117	109	138	109
Adjusted R^2	0.012	-0.003	0.004	0.350	0.328	0.341
Town FE				√	√	√
RSDP phase FE				√	√	√

Notes: The dependent variable ΔRoads_{rp} is constructed as the difference between the value of Roads_r at the end and beginning of each of the three phases (indexed by p) of the RSDP covered in your sample. log TFP_{rp} is constructed by averaging firm level data at the town level for the year at the beginning of each RSDP phase. Night light intensity_{rp} is also measured at the town level for the year at the beginning of each RSDP phase. Robust standard errors in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

G IV estimates: a graphical representation

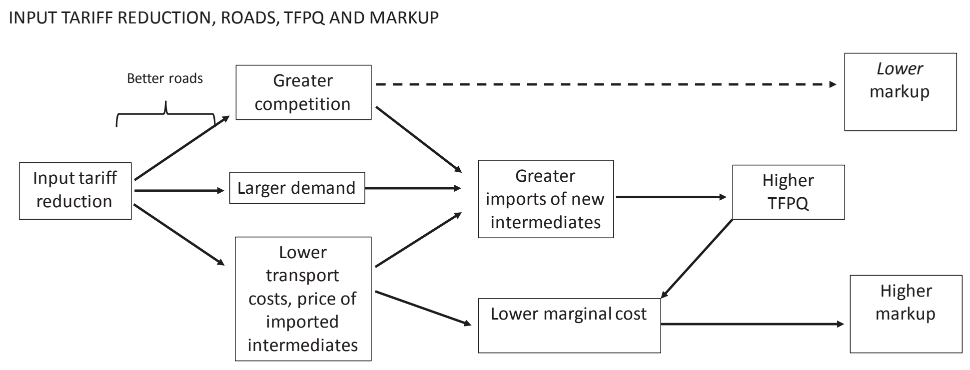
Figure G-1: Estimates of γ and related 95% CIs across the three models of Table 6.



Notes: The figure reports point estimates for γ, the coefficient of the interaction between the input tariff and roads, across the three models of Table 6. Column numbers on the vertical axis correspond to the models in Table 6.

H Conceptual framework: a diagram

Figure H-1: Conceptual framework



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