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Input Tariffs, Roads and Firm Performance: Evidence from Ethiopia*

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Abstract

A reduction in input tariffs can provide firms with access to cheaper, better quality and a wider variety of intermediate inputs, improving firm performance. This paper investigates the role of road infrastructure in shaping the effects of a reduction in input tariffs on firm productivity. We conceive of a framework where intermediaries transport goods to local markets. Better infrastructure decreases intra-national transport costs, improves competition among intermediaries and increases demand in local markets. Depending on the relative strengths of these channels, improving infrastructure can either amplify or attenuate the positive effects of a reduction in input tariffs on firm productivity. We aim to resolve this ambiguity empirically by exploiting census data on Ethiopian manufacturing firms combined with information on tariff reform and improvements in road infrastructure at the town level. We show that a reduction in input tariffs has a strong positive effect on productivity for firms located in towns with better road infrastructure. Our study underlines the importance of domestic transport infrastructure in ensuring that gains from input tariff liberalization are spread uniformly within developing countries.

Keywords: Input tariffs; transport infrastructure; roads; firms; productivity; Ethiopia
JEL Classification: F14; O14; O18

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1 Introduction

A large literature in international trade focuses on gains from trade liberalization for domestic firms. Studies have established 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). There is also substantial evidence that better transport infrastructure can decrease trade costs and increase interregional and international trade (Donaldson, forthcoming). Better road infrastructure can spur firm activity, encourage the entry of new firms (Shiferaw et al., 2015), facilitate exports (Volpe Martincus and Blyde, 2013; Coşar and Demir, 2016) and increase employment (Volpe Martincus et al., 2017). Moreover, recent research has embedded intranational trade costs (encompassing access and quality of road infrastructure) into models of international trade. This literature has estimated the role of these intra-national barriers in shaping the pattern of comparative advantage among sub-national entities (Coşar and Fajgelbaum, 2016) as well as the intra-national distribution of gains from falling international trade barriers (Atkin and Donaldson, 2015).

Despite this plethora of work, little has been done in the way of a formal assessment of the complementarity between better road infrastructure and trade liberalization effects on firm performance. In this paper, we analyze the role played by road infrastructure in moderating the effects of a fall in input tariffs (the tariff on intermediate inputs used in production) on the productivity of firms. First, we posit that a reduction in input tariffs is associated with lower domestic prices for intermediate inputs, allowing firms access to better quality and a wider range of inputs, boosting firm productivity. Next, we propose a framework where intermediaries operating in an imperfectly competitive market transport goods from the port to local regions in the country.

Intermediaries charge a local price that includes a mark-up. In this framework, we argue that on the one hand, better road infrastructure is associated with better transmission of input tariff reductions to domestic prices at the local level and hence productivity of firms in that region. Or, better road infrastructure amplifies input tariff liberalization effects on firm productivity. On the other hand, better road infrastructure may be associated with greater competition among intermediaries and better demand conditions engendered by greater economic activity in the local region. While the former amplifies trade liberalization effects on firm productivity (via its effect on the price charged by the intermediary), the latter (demand) effect operates in the opposite direction, leading to weaker transmission of tariff reductions to reductions in the local product price because the intermediary can charge a higher mark-up. To summarize, the net effect of road infrastructure in moderating the impact of a reduction in input tariffs is theoretically ambiguous and depends on how each of these three channels play out. An important contribution of our study is our examination of this ambiguity in the empirical analysis.

We use census data on Ethiopian manufacturing firms from 1998 through 2009.[1] The detail in

[1] The data, collected by the Ethiopian Central Statistical Agency (CSA), include detailed information at the

our data allows us to construct measures of physical productivity at the firm level. Specifically, the availability of price data at the firm level allows us to build quantity-based productivity measures, which are not affected by the usual caveats undermining the application of revenue-based productivity in studies of the effects of trade liberalization on firm performance (see for instance De Loecker, 2011; De Loecker et al., 2016). We combine this data with a measure of road infrastructure quality at the town-level constructed by employing GIS techniques on information on the type and quality of roads and on traffic volumes (classified according to the type and capacity of vehicles) on roads connecting Ethiopian towns. Our measure is computed as the sum of the estimated travel distance that can be covered in an hour from a particular town across all roads departing from it. This measure accounts for road quality as well as the impact of road construction and rehabilitation over time.[2]

Simultaneous trade and road infrastructure reforms make Ethiopia an excellent case study for our purpose. Tariffs were reduced progressively starting in the early 1990s continuing into our sample period as part of a trade liberalization agenda initiated externally. Hence, we argue (and check) that tariff reductions were largely exogeneous to domestic firms. Next, Ethiopia embarked on extensive improvements to road infrastructure via the Road Sector Development Programme, 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, providing us with rich variation in road infrastructure across time and space. The Ethiopian case thus offers an excellent setting to explore the role of road infrastructure in moderating the effects of trade liberalization.

Exploiting input tariff reductions over time and improvements in road infrastructure that vary over time and across towns, our empirical strategy relates firm productivity to input tariffs, road infrastructure and an interaction of the two to capture the moderating effect of road infrastructure on the relationship between input tariffs and firm productivity. We find strong complementarity between the effects of a reduction in input tariffs and better road infrastructure. As anticipated in our conceptual framework, this complementarity is augmented when we control for the "demand" effect of road infrastructure which mitigates the transmission of a reduction in input tariffs to a reduction in local prices.

We find that a ten percentage point fall in the input tariff is associated with a 10 percentage point larger increase in productivity for a firm in the 70^{th} percentile of road infrastructure relative to a firm in the 30^{th}. For a majority of firm-years in our data (67%), a fall in the input tariff is associated with an increase in firm productivity. This is primarily because most firms are located in the few Ethiopian towns with adequate road infrastructure. However, for almost 80% town-years in our data, a reduction in tariffs would not result in an increase in firm productivity due to lack of road infrastructure. The moderating role of road infrastructure is magnified once we account for the "demand" effect. At the mean value of total production by firms in a town (our proxy for local demand), a ten percentage point fall in the input tariff is associated with a 19 percentage point larger increase in productivity for a firm in the 70^{th} percentile of road

establishment level, including on location (town), labor use, capital, usage of imported inputs and exports.

[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).

infrastructure relative to a firm in the 30$^{\text{th}}$. The percentage of firm-years for which a fall in the input tariff is associated with an increase in firm productivity rises to 74% and the percentage of town-years for which a fall in the input tariff would not result in an increase in firm productivity due to lack of road infrastructure falls to 71%.

Results are robust to an instrumental variables estimation strategy, alternative measures of both productivity and road infrastructure and various cuts of the data. In an extension of the analysis, we show that our results are also robust to controlling 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. Moreover, we find a negative and economically significant coefficient on the interaction between the output tariff and road infrastructure, suggesting that a reduction in the output tariff is associated with a larger increase (or smaller decrease) in productivity for firms located in areas with better local infrastructure. This is a key finding of our work. Previous literature has found weak effects of a reduction in output tariffs on firm productivity (an exception being recent work by Brandt et al. (2017) on Chinese firms). We show that in the presence of high costs of intra-national trade, the pro-competitive effects of an output tariff reduction are conditional on the quality of local infrastructure.

Our study contributes to the literature in several ways. First, our analysis employs measures of physical firm productivity, relating to the burgeoning literature emphasizing the need to use quantity-based, rather than revenue-based measures of productivity to study the impacts of trade liberalization on firm performance (De Loecker et al., 2016). 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 mark-ups. By estimating physical productivity, we are able to tackle some of these concerns and to better identify some of the underlying mechanisms. Second, we complement existing literature emphasizing the crucial role of intra-national trade costs and infrastructure as drivers of growth in low-income countries (Storeygard, 2016). To some extent, our evidence on a strong polarization of quality infrastructure in a few locations within Ethiopia echoes existing work on investment in railroads in Africa shaping regional disparities (Jedwab and Moradi, 2016).

More importantly, we contribute to an infant literature on the role of domestic trade costs in shaping the effects of international trade (Ramondo et al., 2016; Coşar and Fajgelbaum, 2016) by highlighting the role for domestic transport infrastructure in ensuring gains from access to cheaper intermediate inputs for domestic firms. In this respect, our results complement those by Atkin and Donaldson (2015), since we also show that firms in poorly connected towns do not gain as much from globalization. Finally, we highlight mechanisms whereby intermediaries with market power shape the transmission of gains from trade liberalization domestically, an issue of increasing relevance in the international trade literature (Atkin and Donaldson, 2015; Han et al., 2016; Ishikawa and Tarui, 2017). Specifically, we posit that in an environment where intra-national trade is carried out by intermediaries with market power, the role played by road infrastructure in moderating the effects of a reduction in input tariffs may operate via numerous channels exerting opposing influences on local intermediate input prices and hence firm productivity. Our empirical analysis provides support for the idea that greater local demand spurred by better road infrastructure can dampen the complementarity between the effects of an input tariff reduction and better road infrastructure on firm productivity by inhibiting transmission of tariff changes to changes in local prices.

The remaining 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 the results while Section 5 concludes.

2 Conceptual Framework

Our goal is to analyze the differential impact of a decrease in the input tariff on firm productivity in towns with differential quality of road infrastructure. We hypothesize that a fall in the input tariff lowers the cost of obtaining inputs (the intermediate input price), resulting in better and wider access to inputs, which boosts firm productivity. Since this channel operates via its effect on product prices, we propose a stylized framework to analyze the impact of a tariff decline on the product price in local towns (towns in our data) in Ethiopia.

Suppose that intermediaries transport an imported product from the port to the final destination (Ethiopian towns, indexed by r).[3] Intermediaries obtain the product at the port for a price of $p^w + t$ where t is a specific tariff on imports of the product. They incur a transport cost to transport the product from the origin to the destination market. For simplicity, we assume that this transport cost is a per-unit cost $\tau(x_r)$ that is related to x_r, the quality of road infrastructure in town r. Better roads lead to a lower transport cost and hence, $\tau'(x_r) < 0$. Intermediaries then sell the product to firms to be used as an intermediate input in production at a price p_r. We conceptualize Ethiopian towns as local markets. This is consistent with anecdotal evidence from the ground, which documents how firms operate in local markets given high intra-national transport costs.

We assume that the number of intermediaries competing in each town r is given by n_r and it is a positive function of the quality of local infrastructure x_r. Formally, $n_r'(x_r) > 0$, capturing the fact that better infrastructure induces greater competition among intermediaries. The number of intermediaries in each town is fixed (we rule out entry), which is plausible in the Ethiopian context (Atkin and Donaldson, 2015).

Consider the location specific demand function

$$Q_r = a(x_r) - bp_r \tag{2.1}$$

Demand in the town depends on roads via $a(x_r)$, with $a'(x_r) > 0$. This is a core assumption,

[3] The relevance of different types of intermediaries - from companies managing international and domestic transport, to agents dealing with customs clearance procedures - is high in the context of Ethiopia. This has been confirmed in a series of field interviews with various officials at the Ethiopian Customs Authority and with experts of the trade facilitation and logistics division at the Ethiopian office of the World Bank.

unique to our framework. Our rationale behind this assumption is that low cost conditions generated by better access to roads might generate firm entry (or at least reduce firm exit), generate agglomeration economies and more economic dynamism that increases demand for intermediate inputs from firms.

Denote with q_{kr} the quantity sold by intermediary k in location r. The profit function of intermediary k in location r is given by

$$\Pi_{kr}(q_1, \ldots, q_{n_r}) = q_{kr} p_r \Big(\sum_{i=1}^{n_r} q_{ir} \Big) - c_{jr}(q_{jr}) \tag{2.2}$$

where $\sum_{i=1}^{n_r} q_{ir}$ can be denoted as q_r. Location specific marginal cost is given by

$$c_r'(q_{kr}) = p^w + t + \tau(x_r) \tag{2.3}$$

Necessary conditions for the Cournot-Nash equilibrium can be identified in the following system of first order conditions (FOCs):[4]

$$p_r(Q_r) - \frac{1}{b} q_{kr} - p^w - t - \tau(x_r) = 0 \qquad \forall j = 1 \ldots n_r(x_r) \tag{2.4}$$

Summing FOCs across intermediaries, we get

$$n_r(x_r) p_r(Q_r) - \frac{1}{b} q_r - n_r(x_r) \Big(p^w + t + \tau(x_r) \Big) = 0 \tag{2.5}$$

Imposing market clearing $Q_r = q_r$ and using the expression for demand, (2.5) can be rewritten as an expression in p_r. That expression can be solved to obtain the location-specific equilibrium price

$$p_r^* = \frac{a(x_r)}{b(n_r(x_r) + 1)} + \frac{n_r(x_r)}{(n_r(x_r) + 1)} \Big(p^w + t + \tau(x_r) \Big) \tag{2.6}$$

We can now derive a workable expression for $\partial \Big(\frac{\partial p}{\partial t} \frac{1}{p} \Big) / \partial x$ where, for the sake of simplicity, we ignore the r subscript since everything is now intended to be location-specific. We also write p^* as p. This expression tells us how does the proportionate change in the equilibrium price associated with a change in tariffs varies with the quality of road infrastructure. In other words, it is the moderating effect of roads on the transmission of tariff changes to price changes.

$$\frac{\partial \Big(\frac{\partial p}{\partial t} \frac{1}{p} \Big)}{\partial x} = \frac{b}{[a + bn(p^w + t + \tau)]^2} (an' - bn^2 \tau' - na') \tag{2.7}$$

The sign of this expression is determined by the term in the numerator in brackets.

$$\frac{\partial \Big(\frac{\partial p}{\partial t} \frac{1}{p} \Big)}{\partial x} < 0 \iff an' - bn^2 \tau' - na' < 0 \iff \frac{n'}{n} - \frac{b}{a} n \tau' < \frac{a'}{a} \tag{2.8}$$

Hence, for a large enough proportional shift in demand due to better roads (the "demand" effect), $\partial \Big(\frac{\partial p}{\partial t} \frac{1}{p} \Big) / \partial x < 0$, suggesting that towns with better roads may see a weaker transmission of tariff

[4] Functions' differentiability and concavity of the payoff functions make FOCs also sufficient.

declines to price declines. On the other hand, a larger competition effect among intermediaries (the "intermediary competition" effect) captured by n'/n, or a larger effect of roads on the transport cost (the "transport cost" effect) captured by $-(b/a)n\tau'$ will result in $\partial\Big(\frac{\partial p}{\partial t}\frac{1}{p}\Big)/\partial x > 0$ so that towns with better roads will see a stronger transmission of tariff declines to price declines. Finally, if these various effects offset each other, we may observe no moderating effect of roads on the impact of a tariff decrease on the destination price.

From our analysis above and the fact that we expect impacts on firm productivity to occur through product prices, we conclude that the moderating effect of road infrastructure on the impact of a reduction in input tariffs on productivity is ambiguous and depends on the relative strenghts of the "demand", "intermediary competition" and "transport cost" effects on product prices. If the "intermediary competition" and "transport cost" effects dominate, $\partial\Big(\frac{\partial p}{\partial t}\frac{1}{p}\Big)/\partial > 0$ and hence $\partial\Big(\frac{\partial \omega}{\partial t}\Big)/\partial x < 0$ where ω denotes firm productivity. If the "demand" effect dominates, we would expect $\partial\Big(\frac{\partial p}{\partial t}\frac{1}{p}\Big)/\partial x < 0$ and $\partial\Big(\frac{\partial \omega}{\partial t}\Big)/\partial x > 0$. This theoretical ambiguity generates the question of what the net moderating role of infrastructure is. To craft our answer, we turn to the empirical analysis.

3 Empirical Framework

This section presents the ingredients of our empirical framework. As a first step, Section 3.1 discusses Ethiopian infrastructure and tariff reforms and related measures used in the analysis. Second, 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. Third, Section 3.3 introduces the empirical specification used to analyze the role of infrastructure in moderating 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, road infrastructure represents the prevailing dominant transport mode for goods transported within Ethiopia (Iimi et al., 2017).[5] Recognizing this, Ethiopia has planned and implemented various sectoral infrastructure development programmes over the last 15 years. A major such programme is the Road Sector Development Programme (RSDP), which started in 1997 and was implemented in three phases,

[5] 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. When fully operational, it is expected to reduce travel time to Addis from the port of Djibouti to about 6 hours, compared to 3 days by road.

the last of which ended in 2011. A recent 13-year assessment by the Ethiopian Road Authority (ERA) reveals that the programme resulted in substantial improvements in road infrastructure (see Table 1).

Table 1: Improvements in Roads during the RSDP

Indicators	1997	2010
Proportion of Asphalt roads in Good Condition	17%	73%
Proportion of Gravel roads in Good Condition	25%	53%
Proportion of Rural roads in Good Condition	21%	53%
Proportion of Total Road network in Good Condition	22%	56%
Road Density/ 1000 sq. km	24.1	44.4
Road Density/ 1000 Population	0.46	0.58
Road Density/ 1000 sq. km (incl. community roads)	24	136.6
Road Density/ 1000 Population (incl. community roads)	0.49	1.83
Proportion of area more than 5 km from all weather road	79%	64.20%
Average distance to all weather road, km	21.4	11.3

Notes: Raw data sourced from RSDP 13 Years Performance and Phase IV: January 2011.

To identify the role of improvements in road infrastructure in moderating the relationship between a reduction in input tariffs and firm performance, we develop measures of accessibility of economic nodes (towns hosting firms in the census data) which account for rehabilitation, upgrading and construction of new roads from 1996 through 2009 (the start of the programme to the last year of our census data).

The main source of information on Ethiopian road infrastructure is the 19 Year RSDP programme document, which includes a list of federal roads that were rehabilitated, upgraded or newly constructed in the past 19 years (Ethiopian Road Authority, 2016). The document also includes a list of trunk roads in the rehabilitation and upgrading programme, and a list of link roads and new roads for different types of work categories such as asphalt concrete, bituminous treatment surface and gravel surface. We extract information on the year of construction and completion of each road project from physical and financial disbursement documents. Roads are classified by their pavement type such as Asphalt Roads, Major Gravel Roads (Federal Gravel Roads), Minor Gravel Roads (Regional Rural Roads) and Earth surfaced roads. The ERA's design documents provide the target speed for different road classes.

The methodology implemented to construct our measures on quality of road infrastructures relies on standard tools of GIS analysis. In particular we use service coverage analysis, which accounts for improvements in travel time and distance using the expected changes in travel speed due to measured changes in road quality. Each town included in the census data of firms represents a node. We calculate the main indicator used in the empirical analysis as follows. First, for each time period (year) t we estimate the distance that can be covered in one hour's time from a node (town) to neighbouring areas using one particular road. This accounts for the quality of the road in year t, as we are able to calculate the effects of road rehabilitation and upgrading implemented on roads around the node. Second, we sum the estimated distance across all roads that branch out from the node at time t, accounting for new roads accessible through the node. The resulting town-year specific measure is taken as a proxy of quality of road infrastructure.

To summarize, the measure we use as our baseline proxy for the quality of road infrastructure in town r at time t is the travel distance that can be covered in an hour departing from r, summed over all roads which are accessible from r in a given year t. We denote the natural log of this measure as $\text{Infrastructure}_{rt}$.

Figure 1a and Figure 1b report on a map the travel distance that can be covered from the node (town) in 1996 and the percentage increase over the time period 1996-2009 respectively. Focusing on Figure 1a, bigger circles near the center of the country close to Addis show that a larger travel distance can be covered in an hour's travel time around the node for these towns. Smaller circles away from the center indicate that for these towns, a much smaller distance can be covered in an hour's travel around the node. Figure 1b shows larger increases in the distance that can be covered in an hour's travel time around the node for many of these less connected towns, suggesting that they saw improvements in road infrastructure over the time period of our analysis.

Figure 1: Road infrastructure

(a) Total travel distance (km) in 1996

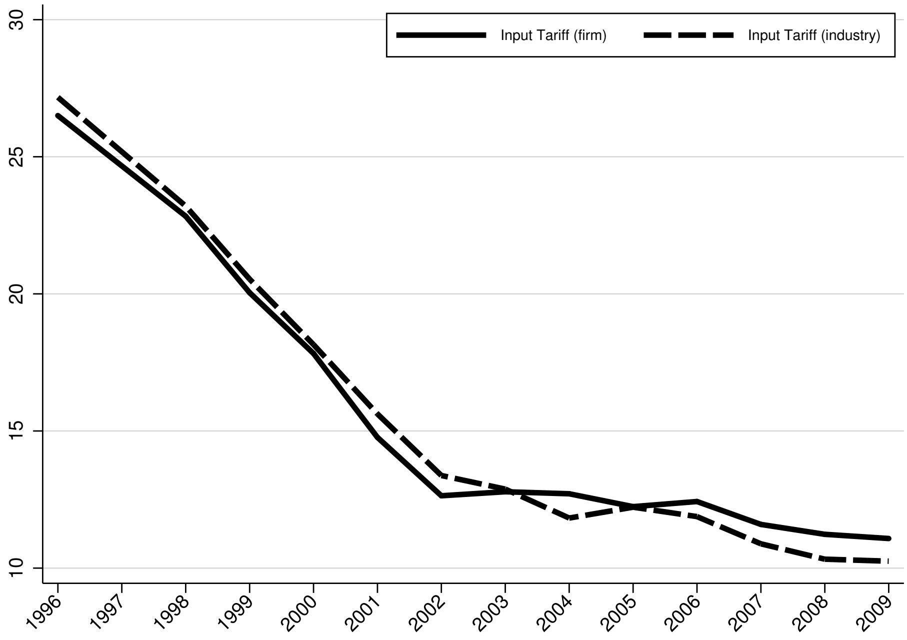
(b) % increase from 1996 to 2009

3.1.2 Tariffs

Starting in 1993, the Government of Ethiopia 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. Figure 2 documents the changes in input tariffs for firms and sectors included in our sample from 1995 to 2009. With trade liberalization, tariffs dropped consistently up to 2003 and got more stable after.

We construct input tariffs directly at the firm level using information on the use of raw materials to construct 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 compute the share of each sector in each firm's

Figure 2: Input tariffs during the sample period



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

total input expenditure: we denote as α_{ijt} the share of sector j input expenditure for firm i at time t.[6] Third, we use these shares as firm-specific coefficients to weight output tariffs using the standard approach.

$$\text{Input-tariff}_{it} = \sum_j \alpha_{ijt} \text{Ouput-tariff}_{jt} \tag{3.1}$$

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

3.2.1 Firm level Data

We use establishment level[7] data from the annual census of Large and Medium Manufacturing firms, published by the Central Statistica Agency (CSA) of Ethiopia. Data cover all firms with at least 10 persons engaged and that use electricity in their production process.[8] All firms need to comply with CSA requirements, and the census is therefore representative of more structured and formal firms in the country.[9] The dataset includes detailed information on the characteristics of

[6] Notably, we have constructed the cost shares on the basis of total input purchases, i.e. including both domestic and imported inputs, to avoid endogeneity bias (see discussion in Amiti and Konings, 2007).

[7] The census data includes information at the level of the single productive establishment. In the rest of the paper we use the terms establishment and firms interchangeably.

[8] The number of person engaged refer to employees as well as working owners.

[9] In 2005, a representative survey of firms was conducted instead of a census. This does not represent a huge 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 the variables as the simple average of the closest years. Results remain robust when dropping 2005 from our data.

each establishment, including on production, employment, capital and inputs, which are needed to estimate production functions. Firms belong to the manufacturing sector, and their industry is defined at the 4-digit level according to the ISIC Rev. 3 classification.

A useful feature of the dataset is that it includes detailed information on (up to 8) 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, our data allow to identify raw materials used at the firm level and their share in total firm expenditure. We use this information to construct the input tariff variable.

Finally, and crucially for our focus on infrastructure, 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 diversifying over time (Mukim, 2016). Nevertheless, we register a strong concentration in the capital, Addis Ababa, which hosts 45.7% of the firms and 52% of total observations in our data respectively.

We use an unbalanced panel of 3,551 establishments covering the period 1998-2009, totalling 12,672 observations. Table 2 reports the number of firms for each year of the sample, showing strong dynamism of the private sector,[10] which is consistent with the overall pattern of economic growth experienced by the country during the last decade (Moller, 2015).

Table 2: 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' elaboration on Ethiopian Census Data.

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 missing in almost 59% of cases in the sample. Other products which are not perfectly identifiable across time have the same product code and the same unit of measure within a firm-year pair. They account for another 20% of the observations in the sample. On average, across firms and years, non-identifiable products account for 63% of total firm sales. This would make a product-level analysis

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

substantially non-representative.[11] For this reason we choose to conduct the TFP estimation and the subsequent econometric analysis at the firm level.

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). Due to lack of information on firm specific prices, it has been argued that a large body of research on the nexus between trade liberalization and firm performance has been unable to capture improvements in physical efficiency, but mostly captures gains in profitability. In our study, we exploit information on values and physical quantities at the product level to construct a measure of physical productivity (Eslava et al., 2004; Smeets and Warzynski, 2013).

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

$$y_{ijrt} = \beta_1 \ k_{ijrt} + \beta_2 \ l_{ijrt} + \beta_3 \ m_{ijrt} + \omega_{ijrt} + \epsilon_{ijrt} \tag{3.2}$$

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} labour and m_{ijrt} the costs of materials, respectively. The random component ω_{ijrt} is the unobservable productivity or technical efficiency and ϵ_{ijrt} is an idiosyncratic output shock distributed as white noise.

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 the firm-specific variation in output prices and expenditures 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 input price variation 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 prices at the product level, since firms report information on quantity and values of products they produce (see Section 3.2.1 above).[12] We aggregate product prices at the firm level calculating a firm-level

[11] A similar issue of non-identifiability applies to raw materials which are identified with a code similar to that used for products. About 56% of all raw-material-time observations have a missing raw material code and therefore are non-identifiable across time. Moreover 12% of the observations have the same (non-missing) raw material code and the same unit measure within a firm-year. Fortunately the problem here is less relevant from an economic point of view as non-identifiable raw materials account only for about 30% of all raw material expenditures on average across firms and years. This is why the input tariff variable at the firm-level built on these data remains our preferred measure of input tariffs.

[12] This comes with measurement issues, given that prices are measured by unit values. In addition, we make assumptions concerning product homogeneity or the way products are aggregated across firms (see De Loecker and Goldberg, 2014, for more discussion).

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 A.

While deflating output with firm specific prices eliminates the output price bias and allows us to compute physical TFP more precisely, to address the input price bias we follow a simplified version of the approach developed by De Loecker et al. (2016). 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. With this assumption, we can 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 (3.2) 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 the simultaneity bias. We also address potential collinearity in the first stage due to simultaneity bias of the labour 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 the total production at the level of the firm deflated using P_{it} described in Appendix A. 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 labour input and the total cost of raw materials to measure intermediate inputs.

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 policy treatment (input tariff) and a moderator variable (quality of insfrastructure). The empirical model is given by

$$\log \mathrm{TFP}_{ijrt} = \beta \text{ Input-tariff}_{ijrt} + \gamma \text{ Input-tariff}_{ijrt} \times \text{Infrastructure}_{rt} + \boldsymbol{\delta}'\mathbf{z}_{ijrt} + \mu_i + \nu_{rt} + \varepsilon_{ijrt} \quad (3.3)$$

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 (3.3) vary at the firm level. The second regressor consists of the interaction between the input tariff and our measure of the quality of infrastructure. 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-time 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 infrastructure. This would be reflected in a negative sign for the coefficient β when the moderator variable $\text{Infrastructure}_{rt}$ is demeaned. By construction, the proposed specification allows the productivity effect of the input tariff to vary linearly with the quality of infrastructure. The role of infrastructure in shaping the effect of tariff liberalization is identified by the coefficient γ.

The different theoretical channels determining the moderating role of infrastructure exert opposing influences. As discussed in Section 2, better infrastructure improves economic dynamism in a town encouraging greater firm activity via entry or expansion of firms. Overall, better infrastructure is likely to be correlated with greater aggregate demand at the local level. Intermediaries can take advantage of higher local demand to internalize some of the gains from lower trade barriers without passing them on to firms in local markets. This can result in better infrastructure jeopardizing/attenuating the positive effects of trade liberalization on firm productivity. In other words, if the "demand" effect offsets the "transport cost" and "interemediary competition" effects, we may observe a zero or positive sign for γ. However, if the two latter effects dominate the "demand" effect, the sign of γ will be negative.

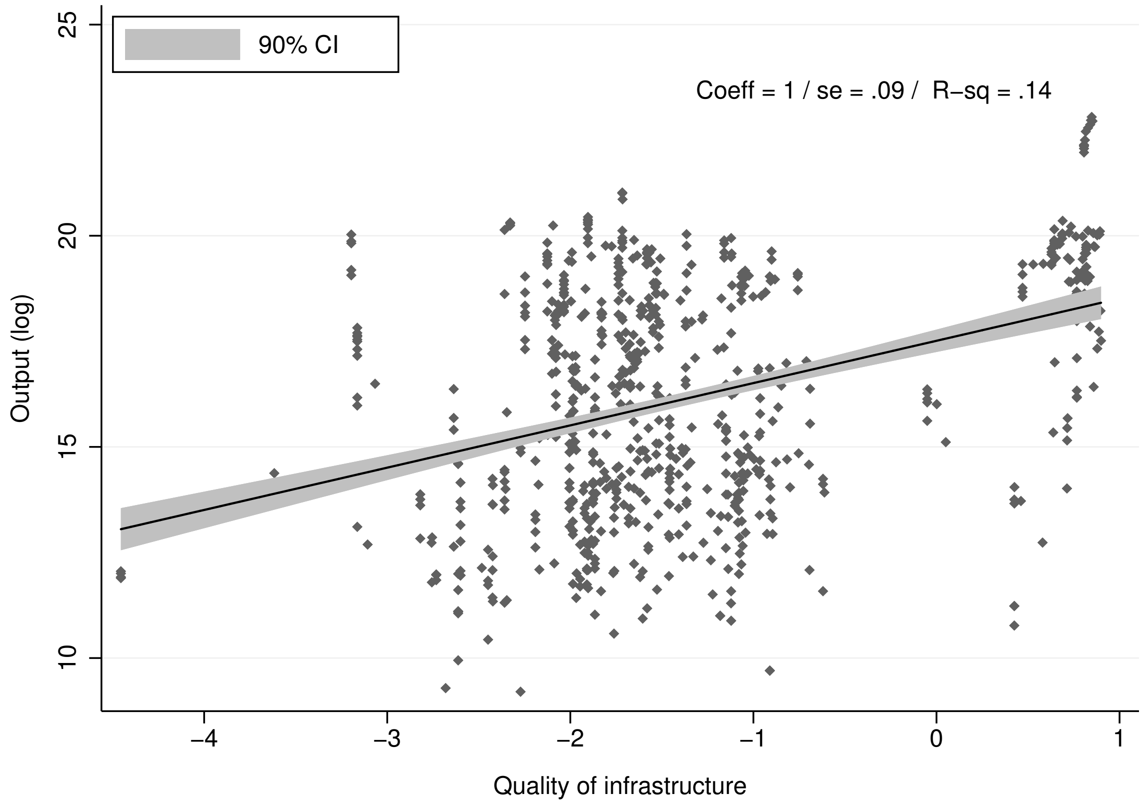
The sign of γ is ultimately an empirical matter. To examine these channels empirically, we estimate equation (3.3) including an interaction between the input tariff and a measure of local demand conditions in the town. This additional term should control for the moderating role of infrastructure operating through the "demand" channel, isolating the moderating role of infrastructure operating through the "transport cost" and "intermediary competition" channels. To capture demand, we use total firm production (output) in the town in our baseline model and the total number of firms and night-light intensity (capturing overall economic activity) in the town in further robustness checks. Figure 3 shows a positive correlation between quality of road infrastructure and local demand as measured by our proxy, supporting the idea that better road infrastructure spurs economic activity in the town.

Once we control for the "demand" effect that acts against the "transport cost" and "intermediary competition" effects, we expect the negative coefficient on the interaction term between the input tariff and road infrastructure to be much larger, indicating stronger complementarity between the input tariff and road infrastructure. We estimate

$$\begin{aligned} \log \text{TFP}_{ijrt} = \beta \text{ Input-tariff}_{ijrt} + \gamma \text{ Input-tariff}_{ijrt} \times \text{Infrastructure}_{rt} + \\ + \eta \text{ Input-tariff}_{ijrt} \times \text{Production}_{rt} + \boldsymbol{\delta}'\mathbf{z}_{ijrt} + \mu_i + \nu_{rt} + \varepsilon_{ijrt} \end{aligned} \tag{3.4}$$

Identification in this empirical setting requires the policy treatment to be as good as randomly assigned in each equation. The included battery of fixed effects accounts for any confounding heterogeneity originating from firm-specific as well as town-time-specific shocks/characteristics. In sections below, we address further concerns pertaining to our empirical strategy.

Figure 3: Quality of infrastructure and demand at the local level



Notes: The figure plots the logarithm of output against the quality of infrastructure as captured by the variable Infrastructure for each town-year environment where both variables take a non missing value (734 town-year observations). The figure also reports the fit from a linear regression model. The estimated slope of the linear fit is 1 with standard error equal to 0.09.

3.3.1 Endogeneity of Infrastructure

The literature has long debated the potential endogeneity of infrastructure investments, claiming that new infrastructure is often placed where it will have the biggest economic impact (Coşar and Demir, 2016; Duflo and Pande, 2007). The endogeneity concern in our specific context is that the decision on where to place new roads or to improve existing ones is somehow related to the presence of more productive firms in given towns. If this was the case, the moderating effect of roads on the relationship between input tariff reductions and firm productivity would be confounded with the moderating effects of related but unobserved town-specific factors, including economic and political conditions, which are in turn correlated with firm productivity. We do not expect potential endogeneity of road placement to present a major concern in our context. While the economic potential of the area is, along with other criteria, among the priorities listed by the Ethiopian Road Authority (ERA) for allocating new infrastructure investments, there is little evidence on the effective criteria used to determine investments in practice. As argued by Shiferaw et al. (2015), who use the same data we employ, the risk of endogenous road placement decisions should be marginal given that plans of road constructions are taken on a 5-year basis and this can hardly affect 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.

Yet, for robustness, we account for the potential endogeneity of road infrastructure by employing an instrumental variable (IV) approach. First, note that we do not look at the direct effect of road infrastructure on firm productivity, since our focus is on its moderating role. Hence, we account for time-varying town-specific shocks with town-year fixed effects in our baseline regressions, thereby ruling out potential simultaneity bias between firm productivity and road construction. Next, we address the endogeneity in the moderating role of road infrastructure. Following recent studies (Duflo and Pande, 2007; Iimi et al., 2017; Wang et al., 2016), we use the geophysical condition of the terrain as a plausible exogenous proxy for the higher costs of building road infrastructure. We use the slope of the terrain in the district in which each town is based, weighted by the distance of each town to the capital as an instrument for road infrastructure. The assumption here is that investing in new roads in areas more isolated from Addis (the capital and geographical center) is more costly [13]. We use an interaction of this instrument with the input tariff as an instrument for our interaction term of interest. Given that we use the instrument interacted with the tariff variable that varies by year, we do not worry about the time invariant nature of the proposed instrument.

We present the results from this IV exercise after the discussion of our baseline estimates.

3.3.2 Endogeneity of Tariffs

A standard argument in the literature has to do with the potential endogeneity of trade policy. Political economy mechanisms (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, we are confident about the exogeneity of trade policy since, as also argued by Jones et al. (2011) and Bigsten et al. (2016), trade reforms were largely shaped by international institutions under liberalization programmes implemented starting with the early '90s. Yet, since we cannot completely rule out endogeneity of input tariffs on the basis of this argument, we try to address 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, export, 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.[14] Results from these regressions show that there is hardly any correlation between changes in input tariffs

[13] Personal communications with a senior officer of the Road Authority 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.

[14] To do this exercise we use input tariffs computed at the industry, rather that at the firm level. We use the change until 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 2009.

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 (calculated at the firm level) 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 productivity of firms and industries, thus implying that policymakers did not adjust trade policy in response to observed productivity levels of local firms and industries.

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

3.4 Estimation Sample

Assembling data from the different sources we obtain the estimation sample which consists of an unbalanced panel covering up to 1430 establishments located in 56 towns and observed across the period 1998-2009, yielding a total of 7527 observations. Summary statistics for the variables used to obtain the baseline results are reported in Table 3.

Table 3: Summary statistics

Variable	mean	median	sd	min	max
log TFP$_{ijrt}$	2.490	2.267	1.507	-4.999	9.081
Input-tariff$_{ijrt}$	13.964	10.000	9.924	0	66.667
Infrastructure$_{rt}$	7.604	8.330	1.086	4.361	8.423
log Production$_{rt}$	20.651	22.120	2.439	11.108	22.813
log(age$_{ijrt}+1$)	2.423	2.398	0.894	0	4.736
Exporter dummy$_{ijrt}$	0.048	0	0.213	0	1
Foreign ownership dummy$_{ijrt}$	0.039	0	0.193	0	1

Notes: The table reports summary statistics for the main variables used in the analysis.

4 Results

4.1 Baseline Results

Section 2 outlines our hypothesis that the role of road infrastructure in moderating the relationship between input tariff reductions and firm productivity that operates through product prices is ambiguous and depends on the relative strenghts of the "trasnport cost" and "intermediary competition" effects on the one hand and the "demand" effect on the other. If the first two effects dominate, we expect the coefficient on the interaction term between the import tariff and road infrastructure to be negative, suggesting that a reduction in the input tariff is associated with relatively higher productivity for firms in towns with better road infrastructure. If the latter effect dominates, we expect the coefficient on the interaction term between the input tariff and road infrastructure to be positive.

We report the main estimation results in Table 4. Columns (1) through (3) present results for a preliminary version of our baseline model. The first column excludes the interaction of the input tariff and road infrastructure, which is then included in Column (2). In Column (3), we include a control for the "demand" effect and estimate equation (3.4). These models do not control for potentially confounding heterogeneity across towns, but only for firm and year fixed effects. Columns (4) and (5) report estimates for the specifications in Columns (2) and (3) but with town-year fixed effects introduced to account for unobserved town-specific shocks correlated with firm productivity.

Table 4: Main Estimation Results

Dependent variable:	log TFP$_{ijrt}$				
	(1)	(2)	(3)	(4)	(5)
Input-tariff$_{ijrt}$	-0.007**	-0.006**	-0.059*	-0.003	-0.052
	(0.003)	(0.003)	(0.032)	(0.003)	(0.032)
Input-tariff$_{ijrt}$×Infrastructure$_{rt}$		-0.005**	-0.010***	-0.006**	-0.011***
		(0.003)	(0.003)	(0.003)	(0.003)
Input-tariff$_{ijrt}$×Log Production$_{rt}$			0.003		0.002
			(0.002)		(0.002)
Infrastructure$_{rt}$		0.065	0.103		
		(0.111)	(0.114)		
Log Production$_{rt}$			-0.016		
			(0.040)		
Observations	7527	7527	7527	7527	7527
Adjusted R^2	0.673	0.673	0.673	0.671	0.671
Firm FE	√	√	√	√	√
Year FE	√	√	√		
Town-year FE				√	√
Firm-year controls	√	√	√	√	√

Notes: Data are for the years 1998 through 2009. Input tariffs are constructed as outlined in Section 3.1.2. Variable Infrastructure refers to distance covered in 1hr travel time around firm node. Variable Log Production is the natural log of total output of firms in the town. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parenthesis are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Column (1) shows a significant and negative relationship between the input tariff and firm productivity, suggesting that a fall in the input tariff is associated with an increase in firm productivity. In column (2) we include the interaction term between the input tariff and road infrastructure. We find evidence for a significant role for road infrastructure in moderating the effects of a reduction in the input tariff on firm productivity. A decrease in the input tariff is associated with higher productivity in firms located in regions with better road infrastructure. Column (3) partials out the "demand" effect by adding an interaction term between the input tariff and total production in the town capturing firm activity. We find that as hypothesized, once we control for the "demand" effect, the role of road infrastructure in moderating the impact of a reduction in the input tariff on firm productivity is stronger. The coefficient on the interaction term between the input tariff and road infrastructure is negative and doubles in size.

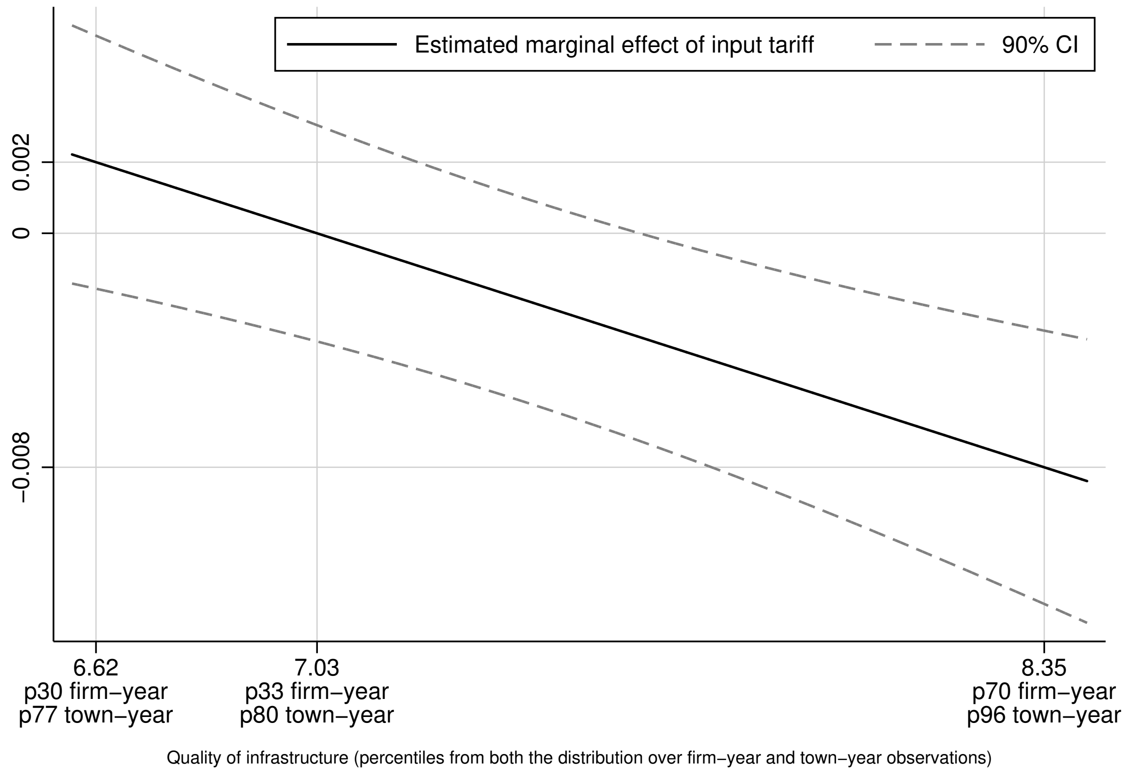
Put together, results in Columns (2) and (3) provide support for the idea proposed in Section 2 that the role of road infrastructure in moderating the effects of a reduction in input tariffs on firm productivity works through several channels operating in opposing ways. Theoretically, if the "demand" effect counters the "transport cost" and "intermediary competition" effects, a reduction in the input tariff may not be associated with higher firm productivity in towns with better roads. Empirically, our result in Column (3) provides evidence for the "demand" effect, while the result in Column (2) suggests that the "transport cost" and "intermediary competition" effects dominate, yielding strong complementarity between the effects of a reduction in the input tariff and better road infrastructure on firm productivity.

In Columns (4) and (5), we estimate the specifications in Columns (2) and (3), but with town-year fixed effects to account for time-varying town-specific heterogeniety. Column (4) shows that the interaction term between the input tariff and road infrastructure is negative and statistically significant, providing evidence for complementarity between the effects of a reduction in the input tariff and better road infrastructure on firm productivity. In Column (5), we control for the "demand" effect. The qualitative story remains. Controlling for the "demand" effect increases the magnitude of the coefficient on the interaction between the input tariff and road infrastructure nontrivially. Hence, while Column (5) provides evidence for the "demand" effect, results in Column (4) suggest that the "transport cost" and "intermediary competition" effects dominate to yield a strong complementary role for road infrastructure in mediating the effects of a reduction in input tariffs on firm productivity.

Figure 4 plots the effect of the input tariff on firm productivity at various levels of road infrastructure quality with 90 percent confidence intervals on each side. The horizontal axis presents percentiles of road infrastructure 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 road infrastructure. In other words, a fall in the input tariff is associated with a greater increase (or smaller decrease) in firm productivity as the quality of road infrastructure improves. From the figure, a ten percentage point decrease in the input tariff is associated with a 10 percentage point greater increase in productivity for a firm in the 70^{th} percentile of access to road infrastructure relative to a firm in the 30^{th}. Second, the coefficient on the input tariff is negative for 70% of firm-year observations and 23% of town-year observations. This suggests that for a majority of firm-years in our data, a fall in the input tariff is associated with an increase in productivity since they are located in regions with quality access to road infrastructure. Specifically, for 30% of firm-years in our data, a 10 percentage point fall in the tariff is associated with an increase in productivity of at least 8%. However, very few town-years have the level of infrastructure that would be associated with an increase in firm productivity with a fall in the input tariff.

Figure 5 presents similar results, but for the model that controls for the "demand" effect. Once we partial out the "demand" effect, the role of road infrastructure in moderating the impact of a fall in the input tariff is magnified. Setting total firm production (capturing the "demand" effect) at its mean, a ten percentage point fall in the input tariff is associated with a 19 percentage point greater increase in productivity for a firm in the 70^{th} percentile of access to road infrastructure relative to a firm in the 30^{th}. A fall in the input tariff is associated with an increase in firm productivity for a majority of firm-years, but for very few town-years. For 30% of firm-years in our data, a 10 percentage reduction in the output tariff is associated with an increase of at least 20% in firm productivity. To summarize, the two figures highlight three salient points. There is a strong moderating role for road infrastructure under input tariff liberalization, the role is magnified once we account for road infrastructure being associated with improved local demand conditions and there is substantial scope to improve local road infrastructure in Ethiopia, thereby spurring firm activity and performance uniformly across towns.

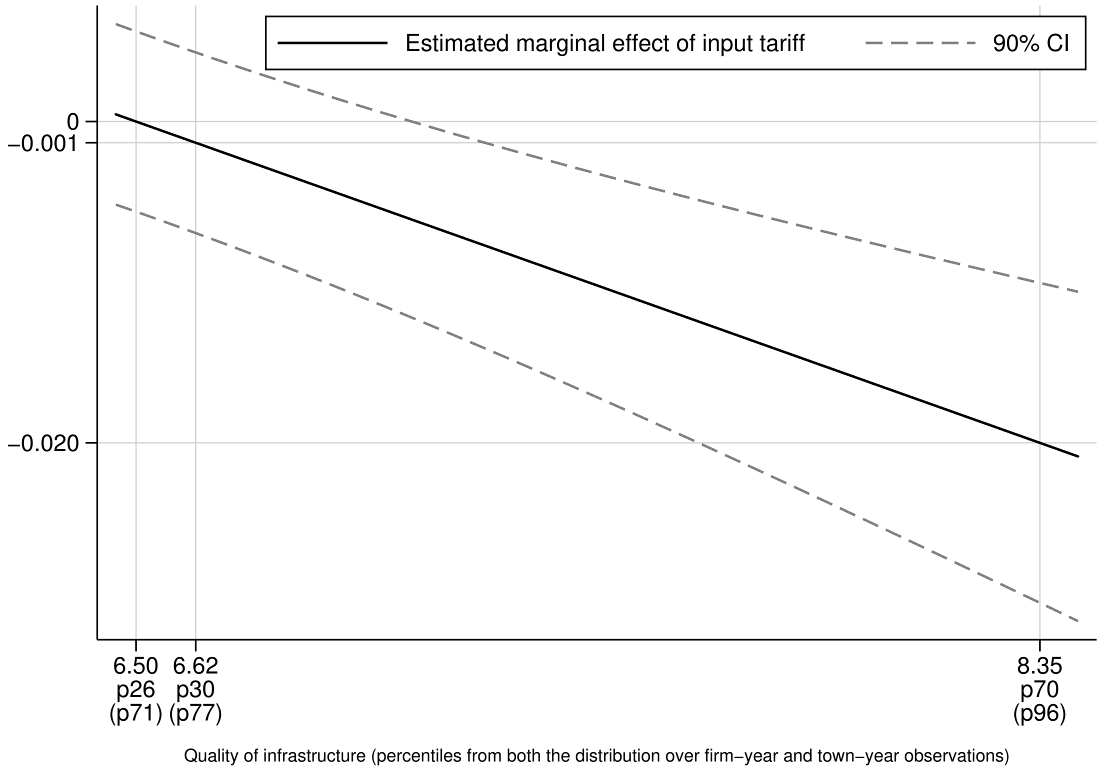
Figure 4: The effect of input tariffs moderated by the quality of infrastructure



Notes: This figure plots the estimated marginal effect of input tariffs on log TFP_{ijrt} from column (4) of Table 4 (on the vertical axis) as a function of $\text{Infrastructure}_{rt}$ (on the horizontal axis). p30 (p77) and p70 (p96) on the horizontal axis refer to the 30^{th} (77^{th}) and 70^{th} (96^{th}) percentiles of the distribution of $\text{Infrastructure}_{rt}$ over firm-years (town-years). Using the notation in equation (3.3), the point estimate plotted as a solid black line in the figure is given by $\hat{\beta} + \hat{\gamma} \times \text{Infrastructure}_{rt}$. Corresponding confidence intervals at the 90% level of statistical significance have been estimated for each value of $\text{Infrastructure}_{rt}$ in the estimation sample of 7527 observations used in Table 4. Point estimates for the marginal effect of the input tariff are smaller than 0 for values of $\text{Infrastructure}_{rt}$ bigger than 7.03. 67% (20%) of firm-years (town-years) covered in the estimation sample score a value of $\text{Infrastructure}_{rt}$ bigger than that threshold. At the 70^{th} (96^{th}) percentile of the distribution of $\text{Infrastructure}_{rt}$ over firm-years (town-years), the estimated marginal effect of the input tariff is equal to -0.008 and it is statistically different from zero.

In Table 5 we employ alternate measures of demand conditions in the town to account for the "demand" effect. In Column (1) we use the total number of firms in the town. In Column (2), we use night-light intensity, which captures overall economic activity in the town. Results from both

Figure 5: The effect of input tariffs moderated by the quality of infrastructure: Partialling out the "demand" effect



Notes: This figure plots the estimated marginal effect of input tariffs on log TFP_{ijrt} from column (5) of Table 4 (on the vertical axis) as a function of $\text{Infrastructure}_{rt}$ (on the horizontal axis) with Production_{rt} set at its mean value. p30 (p77) and p70 (p96) on the horizontal axis refer to the 30^{th} (77^{th}) and 70^{th} (96^{th}) percentiles of the distribution of $\text{Infrastructure}_{rt}$ over firm-years (town-years). Using the notation in equation (3.4), the point estimate plotted as a solid black line in the figure is given by $\hat{\beta} + \hat{\gamma} \times \text{Infrastructure}_{rt} + \hat{\eta} \times \overline{\text{Production}}_{rt}$. Corresponding confidence intervals at the 90% level of statistical significance have been estimated for each value of $\text{Infrastructure}_{rt}$ in the estimation sample of 7527 observations used in Table 4. Point estimates for the marginal effect of the input tariff are smaller than 0 for values of $\text{Infrastructure}_{rt}$ bigger than 6.5. 74% (29%) of firm-years (town-years) covered in the estimation sample score a value of $\text{Infrastructure}_{rt}$ bigger than that threshold. At the 70^{th} (96^{th}) percentile of the distribution of $\text{Infrastructure}_{rt}$ over firm-years (town-years), the estimated marginal effect of the input tariff is equal to -0.02 and it is statistically different from zero.

columns echo our results in Column (5) of Table 4, both in terms of significance and magnitude of the coefficients. Once we account for the "demand" effect, the magnitude of the coefficient on the interaction between the input tariff and road infrastructure increases.

4.2 Identification and Robustness

In this section, we address several empirical concerns. First, we tackle endogeneity of our main independent variable using an instrumental variable estimation strategy. Next, we test for robustness of our results to alternate productivity and road infrastructure measures. Finally, in an extension of our main specification, we ask if our results are robust to controlling for the effect of the output tariff on the final good produced by the firm on productivity and its complementarity

Table 5: Alternative Controls for the Demand Effect

Dependent variable:	log TFP_{ijrt}	
	(1)	(2)
Input-tariff$_{ijrt}$	-0.024**	-0.013**
	(0.011)	(0.006)
Input-tariff$_{ijrt}$×Infrastructure$_{rt}$	-0.012***	-0.011**
	(0.004)	(0.004)
Input-tariff$_{ijrt}$×Log number of firms$_{rt}$	0.004*	
	(0.002)	
Input-tariff$_{ijrt}$×Night light intensity$_{rt}$		0.000*
		(0.000)
Observations	7527	7516
Adjusted R^2	0.671	0.671
Firm FE	√	√
Town-time FE	√	√
Firm-time controls	√	√

Notes: Data are for the years 1998 through 2009. Input tariffs are constructed as outlined in Section 3.1.2. Variable Infrastructure refers to distance covered in 1hr travel time around firm node. Variable Log number of firms is the total number of firms in the town in log terms. The variable Night light intensity is measured as the average light intensity within a circle of a 10 kilometer ray centered around the point coordinate associated with each town in our sample. Raw data on night light have been extracted with QGIS from the raster files available at `https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html`. In particular we have used geo referenced images which contain the lights from cities, towns, and other sites with persistent lighting, including gas flares. Ephemeral events, such as fires have been discarded. Then the background noise takes value zero while data values range from 1-63. Areas with zero cloud-free observations are represented by the value 255 in the raw data and have been recoded as missing for the purpose of this exercise. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parenthesis are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

with road infrastructure. We find that across all robustness tests, our results qualitatively support baseline results. In addition, we find evidence for complementarity between the effects of a reduction in the output tariff and better road infrastructure on firm productivity. This result highlights the role played by road infrastructure in moderating the effects of trade liberalization through reductions in both input and output tariffs.

4.2.1 Instrumental Variables Estimation

As we argue in Section 3.3.1, the quality of road infrastructure might be endogenous to firm productivity. To tackle this concern, we instrument for road infrastructure with the slope of the terrain in the district that the firm is located in, weighted by the distance to Addis, the capital city. Our IV is composed of geographical factors that we argue are largely exogenous. We present results in Table 6. First-stage statistics reported in the table assure us that our instrument is strong and we find that it is negatively related to our road infrastructure variable as expected. From Table 6, we find that second-stage results closely match our baseline results presented in columns (5) and (6) of Table 4.

Table 6: Instrumenting for Road Infrastructure

Dependent variable:	log TFP_{ijrt}	
	(1)	(2)
$\text{Input-tariff}_{ijrt}$	-0.003	-0.061
	(0.003)	(0.038)
$\text{Input-tariff}_{ijrt}\times\text{Infrastructure}_{rt}$	-0.006**	-0.012**
	(0.003)	(0.005)
$\text{Input-tariff}_{ijrt}\times\text{Log Production}_{rt}$		0.003
		(0.002)
Observations	7527	7527
Adjusted R^2	0.671	0.671
Firm FE	$\surd$	$\surd$
Town-time FE	$\surd$	$\surd$
Firm-time controls	$\surd$	$\surd$
KP LM stat	8.4	11.766
P-val	.004	.001
KP F stat	1419.392	43.107

Notes: Data are for the years 1998 through 2009. Input tariffs are constructed as outlined in Section 3.1.2. Variable Infrastructure refers to distance covered in 1hr travel time around firm node. Variable Log Production is the natural log of total output of firms in the town. Firm-time controls include exporter and FDI dummies and firm age. The instrument for Infrastructure is terrain slope weighted by distance to Addis. Standard errors in parenthesis are clustered at the sector-year level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The Kleibergen-Paap (KP) LM statistic and related p-value test for under-identification under the assumption of heteroskedasticity. The KP Wald F test tests for weak identification.

4.2.2 Robustness Checks

Finally, we undertake a battery of checks to ensure the robustness of our results to (1) alternative measures of the dependent variable; (2) alternative measures of road infrastructure; (3) alternative sub-samples.

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 Columns (1) and (2) of Table 7, we present results for the baseline model without and with the "demand" effect with productivity estimated after accounting for a range of variables in the control function.[15] Similarly, in Columns (3) and (4), productivity is estimated with a one-step GMM method proposed by Wooldrigde (Wooldridge, 2009). Across the four Columns, we find that our results remain stable and consistent with the baseline.

Second, results may be affected by the choice of variable measuring road infrastructure. We use two alternate measures of road infrastructure and present results in Table 8. First, we use the total area accessible by road in an hour's travel time (computed using a buffer zone of 5 kilometers on both sides of a road) as an alternative indicator of local accessibility and report results in Columns (1) and (2) without and with the "demand" effect. We call this variable 'Area'. Second, in Columns (3) and (4) we use an alternative indicator of road infrastructure that we construct using a different GIS tool: Origin-Destination (O-D) matrix analysis. The

[15] 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	
	(1)	(2)	(3)	(4)
Input-tariff$_{ijrt}$	-0.003	-0.052	-0.002	-0.098**
	(0.003)	(0.032)	(0.004)	(0.040)
Input-tariff$_{ijrt}$×Infrastructure$_{rt}$	-0.006**	-0.011***	-0.005*	-0.014***
	(0.003)	(0.004)	(0.003)	(0.004)
Input-tariff$_{ijrt}$×Production$_{rt}$		0.002		0.005**
		(0.002)		(0.002)
Observations	7527	7527	7527	7527
Adjusted R^2	0.649	0.649	0.983	0.983
Firm FE	√	√	√	√
Town-time FE	√	√	√	√
Firm-time controls	√	√	√	√

Notes: Data are for the years 1998 through 2009. The dependent variables in Columns (1) and (2) are TFP estimated with a modified control function and in Columns (3) and (4) with the Wooldridge GMM approach. Input tariffs are constructed as outlined in Section 3.1.2. Variable Infrastructure refers to distance covered in 1hr travel time around firm node. Variable Log Production is the natural log of total output of firms in the town. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parenthesis are clustered at the sector-year level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Robustness to Alternative Measures of Quality of Infrastructure

Dependent variable:	log TFP$_{ijrt}$			
	(1)	(2)	(3)	(4)
Input-tariff$_{ijrt}$	-0.004	-0.030	-0.004	-0.011
	(0.003)	(0.028)	(0.003)	(0.033)
Input-tariff$_{ijrt}$×Area$_{rt}$	-0.014*	-0.019*		
	(0.008)	(0.009)		
Input-tariff$_{ijrt}$×Distance$_{rt}$			0.001*	0.001
			(0.001)	(0.001)
Input-tariff$_{ijrt}$×Log Production$_{rt}$		0.001		0.000
		(0.001)		(0.002)
Observations	7527	7527	7527	7527
Adjusted R^2	0.671	0.671	0.671	0.671
Firm FE	√	√	√	√
Town-time FE	√	√	√	√
Firm-time controls	√	√	√	√

Notes: Data are for the years 1998 through 2009. Input tariffs are constructed as outlined in Section 3.1.2. Variable Area refers to area covered in 1hr travel time around the firm node. Variable Distance refers to the travel distance to Galafi (border with Djibouti and port) via Addis for all Ethiopian towns different from Addis and distance to Galafi for Addis. Variable Log Production is the natural log of total output of firms in the town. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parenthesis are clustered at the sector-year level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

O-D matrix analysis is a tool used to test the impact of road construction or rehabilitation and upgrading on travel time to a specific destination. In the service coverage analysis described earlier, the impact of road infrastructure can only be observed if roads around the selected node are improved. The O-D matrix analysis can capture improvements in road infrastructure along road segments between the node and economic hubs. Specifically, we measure improvements in travel time to the town of Galafi (the last Ethiopian town by road to the port of Djibouti, which handles about 95% of Ethiopia's trade) via Addis, the capital city. For firms in Addis, we measure improvements in travel time to Galafi. We call the resulting variable 'Distance'.

The construction of this variable is motivated by the way goods were cleared in Ethiopia until 2012, when a unimodal trade regime governed intra-national trade. Goods were transported from the port of Djibouti to the dry port of Kaliti (close to Addis), processed there and dispatched to all other destinations within the country [16]. With this variable, we are able to capture connectivity to a major port for imports, an additional dimension of road infrastructure relevant to international trade. This analysis complements our baseline focus on road improvements occurring in the immediate surroundings of a firm.

Results from Columns (1) and (2) confirm our baseline results. A reduction in the input tariff is associated with higher firm productivity for firms in regions with better road infrastructure and this complimentarity effect is magnified once we account for the "demand" effect (Column (2)). In Columns (3) and (4) we present results without and with the "demand" effect respectively with the Distance variable measuring road infrastructure. The coefficient on the interaction term between the input tariff and Distance is positive and statistically significant in Column (3) as expected, since greater distance to Galafi in this case measures lower connectivity. In Column (4), we see that the magnitude of the coefficient on the interaction term does not change once we account for the "demand" effect in the town. This is as anticipated. Since the "demand" effect is likely to operate in the local region, we expect it to be relevant for measures that capture road infrastructure locally and not for the Distance measure that captures connectivity to the port.

Third, we estimate our regressions without the year 2005, when the census was run as a representative survey, as discussed in Section 3.2. We also exclude years for which tariffs were imputed rather than directly obtained from the source. Our results in both cases remain qualitatively robust. Overall, our analysis in this section shows that our results are robust to alternate measures and samples, increasing confidence in our baseline results.

As a final step, we run an extension of our analysis by including 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 phase of competition. It is then possible that our estimates of the effect of the input tariff on firm productivity and its complementarity with road infrastructure are not consistently estimated if we do not account for output tariff effects. In addition, some of the mechanisms linking infrastructure development to trade liberalization could also work through output tariffs. We thus introduce controls for the output tariff and its interaction with road infrastructure in our baseline regressions. Results are presented in Table 9. Column (1) presents results for the baseline specification including the output tariff and its interaction with road infrastructure. Column (2) accounts for the "demand" effect.

The qualitative story on the input tariff remains. A reduction in the input tariff is associated

[16] From 2012, Ethiopia switched to a multi-modal mode of intra-national trade, such that most goods transited in Djibouti and were cleared across a number of dry ports (of which the one in Mojo is currently the largest) all over the country

with higher productivity for firms in towns with better road infrastructure and this effect is stronger in magnitude and statistical significance once we account for the "demand" effect. We also find that a reduction in the output tariff is associated with higher productivity for firms in towns with better road infrastructure and that this effect is stronger once we account for the "demand" effect. This is a notable finding in itself since it shows that the quality of local infrastructure plays a crucial role in facilitating access of imported goods in remote locations, potentially forcing local firms to improve their production efficiency to face competition from imported goods. Our results therefore point to a role for road infrastructure in moderating the effects of a reduction in both input and output tariffs on firm productivity.

Table 9: Including output tariff

Dependent variable:	log TFP$_{ijrt}$	
	(1)	(2)
Input-tariff$_{ijrt}$	-0.004	-0.030
	(0.003)	(0.031)
Output-tariff$_{jt}$	0.003	-0.038
	(0.007)	(0.094)
Input-tariff$_{ijrt}$×Infrastructure$_{rt}$	-0.005*	-0.007**
	(0.003)	(0.003)
Output-tariff$_{jt}$×Infrastructure$_{rt}$	-0.017**	-0.019**
	(0.008)	(0.009)
Input-tariff$_{ijrt}$×Log Production$_{rt}$		0.001
		(0.001)
Output-tariff$_{jt}$×Log Production$_{rt}$		0.002
		(0.005)
Observations	7527	7527
Adjusted R^2	0.671	0.671
Firm FE	✓	✓
Town-time FE	✓	✓
Firm-time controls	✓	✓

Notes: Data are for the years 1998 through 2009. Input and Output tariffs are constructed as outlined in Section 3.1.2. Variable Infrastructure refers to distance covered in 1hr travel time around firm node. Variable Log Production is the natural log of total output of firms in the town. Firm-time controls include exporter and FDI dummies and firm age. Standard errors in parenthesis are clustered at the sector level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5 Conclusion

In this paper, we examine the role of road infrastructure in moderating 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 higher productivity for firms in towns with better road infrastructure. Our result thus emphasizes a role for transport infrastructure in ensuring gains from trade. Finally, in an environment where access to goods in local regions depends on intermediaries or transport agents with market power, better road infrastructure, by invigorating local demand, may provide incentives for agents to capture and retain some of the gains from input tariff liberalization, mitigating benefits for firms. Transmission of input tariff reductions to domestic prices may not necessarily be stronger with better road infrastructure.

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 lead to weak transmission of tariff reductions to domestic prices. This may hamper gains from trade, particularly for remote regions, exacerbating concerns of regional inequality. Our study suggests that road infrastructure can complement the effects of trade liberalization on firm performance. Finally, greater competition in the intermediary sector can yield better transmission of tariff reductions to domestic prices, ensuring that the benefits of trade are spread more uniformly.

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Appendices

A Firm-level price index

The estimation of firm level productivity in the present paper build on Eslava et al. (2004) and Smeets and Warzynski (2013). These two studies propose an empirical model of the production function where firm-level revenues are used in the left hand side. 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 need to 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 or to the fact that more than one product for the same firm in the same year have identical product code and unit measure. The solution we propose consists in treating non perfectly identifiable products as the elements of an aggregate product category that will be used alongside perfectly identifiable individual product categories. More precisely, all products with missing product code will be grouped in an aggregate product category (denoted with nim 'non identifiable missing') and all products with non-missing product code but still non identifiable (because they have the same values for both product code and unit measure within a firm-year pair) will be grouped in aggregate product categories depending on the non missing product code ($onih$ 'other non identifiable with product code h'). In order to aggregate the information contained in product-level observations we proceed as follows. We derive a product-level price index as a weighted average of the prices of domestic sales and exports:

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

where the superscripts d and x stand respectively for domestic and export market, and s^{ν}_{hit} is the share of the ν market in the total sales of product h by firm i at time t. We also perform some intuitive inputation in case some activity is reported but not all the required information is available. The approach we follow for inputing the data is 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 when we have 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 the minority of cases) the shares s^{ν}_{hit} cannot be computed. We correct for this by replacing the missing observation of 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 different years. 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. We create a database where products are actually product-aggregates but will be treated as individual products from now on.

Step 2

Second, 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 Step1. Then, we apply a Tornqvist formula to get the variation in firm-level prices. Notice that the dynamic structure of the Tornqvist formula requires that each product h is perfectly identifiable across time.

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

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, select as a base year the one where the number of active firms is at its maximum, i.e. the end of the time span (2009), we set $P_{i,2009} = 1$, and we proceed recursively (backward) to retrieve the firm-level prices:

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

We first apply (A-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 which 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 (A-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 which is between two time intervals where it is potentially possible to apply the recursive formula (A-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 the series of firm-level price indices P_{it} which will be used to deflate firm-level revenues.

B 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 2009. Results are presented in Table B-1. Across columns, we find no statistically singificant relationship between initial sector characteristics and input tariff changes, assuring us that tariff changes are plausibly exogenous.

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 the tariff reforms were targeted across sectors. In Table B-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

Table B-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, exports and employees 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 the 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. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

performance and subsequent changes in input tariffs (with the exception of a weak negative correlation between tariff changes and total employment), lending some credence to our claim that input tariff changes are exogenous to firm performance.

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

Dependent variable:	Input-tariff$_{ijt}$	
	(1)	(2)
log TFP$_{ijt-1}$	-0.078	
	(0.087)	
log TFP$_{ijt-5}$		0.129
		(0.092)
Observations	6856	2858
R^2	0.257	0.024
Firm FE	√	√
Year FE	√	√

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

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