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Roads, exports and employment: Evidence from a developing country

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ABSTRACT

Domestic road programs are often justified on the basis of their presumed positive effects on firms' exports and accordingly on firms' employment. In this paper we evaluate this policy claim for Peru, a developing country whose regions were exposed to an asymmetric infrastructure shock. In so doing, we take advantage of detailed geo-referenced data on firm-level trade for the period 2003–2010 as well as on recent and historical road infrastructure. In particular, to identify the impacts of interest, we first exploit the dimensions of this dataset to account for regional-sectoral and even firm-level confounding factors through extensive sets of fixed effects. In addition, we conduct placebo exercises and carry out instrumental variable estimations whereby we instrument recent changes in the road network with the pre-Columbian Inca road network. Estimates concur in suggesting that improvements in transport infrastructure had a significant positive impact on firms' exports and thereby on firms' job growth.

1. Introduction

A series of recent papers have assessed the effects of domestic transport infrastructure on a number of economic outcomes across both developed and developing countries typically in cross-region settings (see Redding and Turner, 2014 for an excellent survey of this literature).[1] Overall, this body of research conveys a consistent message: infrastructure seems to have been an important driving force for the variables considered in these studies. When it comes to how transport networks affect trade, evidence from this literature based on data at the level of geographical units is relatively more scarce (e.g., Duranton et al., 2014; Donaldson 2016; and Cosar and Demir 2016).[2] This paper contributes to this growing literature by showing the impact of road infrastructure on international trade using micro data from a developing country as opposed to the more aggregated data utilized previously.[3]

More specifically, we address one main question: *What are the effects of domestic road infrastructure on firms' exports*? As a byproduct and admittedly in a more indicative manner, we also tackle a second related question: *If anything, how do these additional exports affect firms' employment?* In answering these questions, we use highly disaggregated firm-level export data from Peru that include

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[1] With only a few exceptions (see, e.g., Gibbons et al., 2012 and Garcia López et al., 2013), most studies on developed countries focus on the United States. These studies examine the impact of transport infrastructure on: productivity (see Fernald, 1999); relative demand for skilled workers (see Michaels, 2008); suburbanization (see Baum-Snow, 2007); urban growth (see Duranton and Turner, 2012); counties' earnings and market access (see Chandra and Thompson, 2000 and Donaldson and Hornbeck, 2016, respectively). Papers on developing countries primarily look at the experience of Asian and African countries. In particular, these papers assess the effects of transport infrastructure on: urban growth in Ghana (see Jedwab and Moradi, 2013); urban economic activity in Sub-Saharan Africa (see Storeygard, 2013); regional development and concentration of economic activity in China (see Banerjee et al., 2012 and Faber, 2014); firms' inventories and sourcing patterns and performance of the formal manufacturing sector in India (see Datta, 2012 and Ghani et al. 2012, respectively); and households' incomes in Nepal, Madagascar, and Indonesia (see Jacoby, 2000; Jacoby and Minten, 2009 and Gertler et al., 2014, respectively). As for Latin American countries, a recent paper investigates the impact of road access on the spatial distribution of population and economic activities across Brazilian municipalities (see Bird and Straub, 2014).

[2] Duranton et al. (2014) use plans for the United States' Interstate Highway System, historical railroad networks and early exploration routes as instruments to estimate the effects of highways on bilateral trade between large cities. Donaldson (2016) concentrates on colonial India and investigates the impact of the railroad network construction on price gaps, real income levels, and a compound of interregional and international trade, without being able to distinguish among them. In both cases, identification primarily comes from the fact that the design of infrastructure projects was determined by factors unrelated to international trade (e.g., defense or military reasons). Cosar and Demir (2016) exploit the cross-regional variation in upgrading to Turkey's road infrastructure to assess its effects on the level and composition of regions' foreign trade. For recent theoretical contributions on the relationship between infrastructure and trade, see Cosar and Fajgelbaum (2013), Allen and Arkolakis (2014), and Fajgelbaum and Redding (2014).

[3] There is also an incipient literature that looks at the impact of infrastructure across countries on economic outcomes (see, e.g., Feyrer 2009; Akerman, 2009 and Volpe Martincus et al., 2014).

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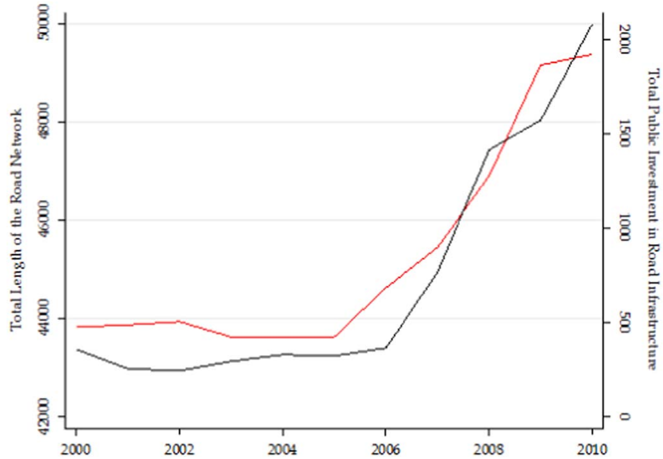

Fig. 1. Evolution of the Total Length of the Road Network and Public Investment in Road Infrastructure. *Source*: Authors' calculations based on data from MTC (2012) and MEF (2013). Length is measured in kilometers (red line, left axis). Investment is reported in millions of US dollars (black line, right axis) (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper).

the exact geographical origin of exports and the location of the ports through which each transaction exited the country in 2003 and 2010 along with detailed geo-referenced information on road infrastructure for Peru. In order to identify the effects of interest, we first exploit the spatial differences in the degree of exposure to the aforementioned infrastructure shock and the implied changes in transportation costs, and make use of the dimensions of our dataset to account for several potential confounding factors through diverse sets of fixed effects ranging from region-sector to firm-(-region-sector) along with product-destination combinations. Second, we conduct placebo exercises and additionally use the *Inca road network*, the vast pre-Columbian transportation network that was built by the Inca Empire before 1530, as an instrument for the new transport infrastructure to further address the natural endogeneity concerns. To preview our main findings, estimation results indicate that domestic road infrastructure positively affected firms' exports and this expansion in foreign markets induced firms to hire more employees.

In policy circles, domestic transport infrastructure is considered a key determinant of exports, which, in turn, are assumed to lead to more jobs. Statements in official documents introducing public export development programs of several countries are illustrative in this regard. The report presenting the United States National Export Initiative 2011 is a clear example. According to this report, "*American businesses cannot participate in the global economy if they cannot get their products out the door Deficiencies throughout America's transportation system severely impact the ability of businesses to transport their goods to global markets. Now more than ever, America's ability to support additional jobs here at home depends on the ability to export goods and services to the world.*" This argumentative line is not exclusive of developed countries. For instance, in Peru, the Strategic National Export Plan 2003–2013 states "*The exporting sector is one of the most affected by the infrastructure deficit, generally in transportation. [This sector] plays a fundamental role as a growth engine, in generating employment, and in fostering the development of nations.*"

Evidence based on aggregate data indicates that such a link may exist between transport infrastructure, exports, and employment.[4] Raw figures from Peru itself also point to the same direction. Exports from municipalities whose road connections to their main ports improved grew on average more than 150% over the period 2003–2010, while employment did it by 30%.[5] Although suggestive, this kind of evidence is not informative of causality because there are potential endogeneity problems affecting both the relationship between internal infrastructure and exporting as well as that between exporting and employment. Thus, while road improvements might foster exports from regions targeted by infrastructure projects, it is equally possible that increasing foreign sales result in investments in these regions to reduce transport costs.[6] In addition, there might potentially be unobserved factors correlated with road building that can also influence exports. For instance, topography can shape both the within-country spatial distribution of road infrastructure and economic activity and thereby that of exports (see, e.g., Ramcharan, 2009). Similarly, firms may hire more workers in response to additional demand from abroad or they may increase their number of employees to reach a scale that will make them later easier to deepen their penetration into foreign markets. Unfortunately, available evidence on to what extent infrastructure matters for exports is limited. In the same vein, whether these exports make a difference in terms of employment is far from clear.

We focus on Peru to fill this gap in the literature for several reasons. First, as mentioned above, road expansion in Peru was remarkable during the period under analysis. Specifically, more than 5000 kilometers of new roads were constructed in the country between 2003 and 2010, which roughly amounted to a more than 10% net expansion in the country's main road network (see Cornejo Ramirez, 2010 and MTC, 2012).[7] As shown in Fig. 1, to finance this expansion of the road network, public resources allocated to road infrastructure increased 610% (in nominal US dollars) to reach 1.3% of the country's GDP in 2010 from its initial level of 0.5% in 2003 (see MEF, 2013).[8] Second,

[4] There is a large number of studies showing that international transport costs have a significant negative impact on trade (see, e.g., Hummels, 2001; Limão and Venables, 2001; Clark et al. 2004; Blonigen and Wilson, 2008; Mesquita Moreira et al., 2008). See Behar and Venables (2010) for a useful survey of this literature.

[5] See the Section A.1.1 in the online Appendix for cross-country correlations and case-based evidence illustrating the relationship between roads, exports and employment that are often used by practitioners to justify investment in infrastructure.

[6] From a political economy point of view, this would be more likely the case when exporting firms are relatively large as it could be in our case (see Section 2) and would therefore tend to have more bargaining power. As shown in Burgess et al. (2013), other political economy factors could also play a role (e.g., ethnicity).

[7] It should be stressed that, according to the statistical information provided by the Peruvian Ministry of Transport and Communications (MTC), this expansion does not consist of mere bituminization of existing roads but net additions to the network of national and departmental roads. Besides these roads, there are local roads that are mostly non-paved and generally in bad shape (see MTC, 2005). As a consequence, they are not commonly used for international trade shipments. For further information see Volpe Martincus et al. (2013).

[8] According to official documents, the infrastructure plan pursued multiple simultaneous goals including decentralization, sustainable development, internal and external integration, and social inclusion (e.g., improve access to public services such as health and education particularly for poorer individuals living in more remote areas) (see MTC,

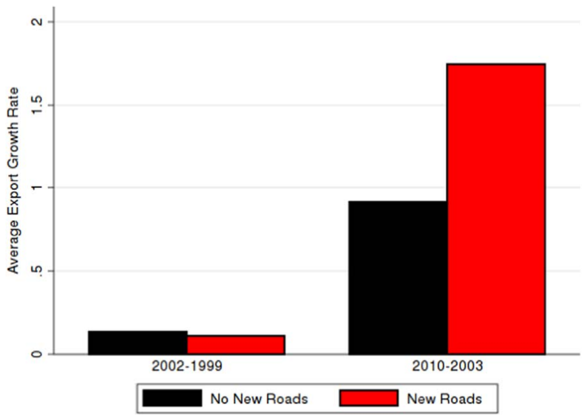

Fig. 2. Average Annual Export Growth Municipalities with Reduced Distances to Ports vs. Municipalities with Unchanged Distances to Ports 1999–2002 and 2003–2010. *Source*: Authors' calculations based on data from SUNAT, MTC, and ArcGIS. The figure shows the average log annual export growth of municipalities with reduced distances to ports and that of their counterparts with unchanged distances to ports both over the period 2003–2010 (i.e., the period during which the new roads were built and distances declined) and over the period 1999–2002 (i.e., a period during which no roads were built and distances remained the same). A mean *t*-test cannot reject the null hypothesis that the average annual export growth rate was the same for both groups of municipalities over the period 1999–2002. In particular, the *t*-statistics is 0.103 and the respective *p*-value is 0.748. In contrast, such test rejects this equality of average annual export growth rate across groups of municipalities between 2010 and 2003. In this case, the *t*-statistics is 6.590 and the respective *p*-value is 0.010.

new roads were asymmetrically distributed across regions in Peru. As a consequence, depending on the initial route(s) from the plants to ports, airports or borders used in exiting the country, available transport infrastructure increased and distance traveled and internal transport costs incurred diminished for some origins while those for others remained the same. Hence, by contrasting exports in both groups while controlling for potential confounding factors, we can, in principle, estimate the impact of this new infrastructure on firms' exports. Fig. 2 provides a visualization of the most basic version of this differences-in-differences strategy at the municipal level. This figure shows that municipalities whose distance to the respective relevant ports shrank thanks to the new roads, experienced larger export growth (as measured by the non-conditional average log annual rate of change) than their counterparts whose distance to the reference ports remained constant over the period in which transport infrastructure expanded (2003–2010). Interestingly, both groups' exports followed parallel trends before this period (1999–2002).[9]

Admittedly, a broad range of factors other than road infrastructure could have driven these developments. In our baseline estimations, we take advantage of our highly disaggregated geo-referenced export data to condition on an extensive set of fixed effects that account for differences over time across regions (i.e., departments) and sectors (i.e., 2-digit ISIC). In robustness checks, we control for differences across even more narrowly defined geographical units (i.e., provinces and municipalities), so that identification comes from the variation *within* these geographical units and activities.[10] Results from these alternative estimations do not differ from the baseline. Another concern is that firms may have self-selected into locations over time and, as a consequence, firms located near the roads may be different from those in the rest of the country. Estimates from specifications that include firm(-region-sector) fixed effects to control for this potential firm heterogeneity also confirm our main findings.

In addition, we conduct a number of placebo exercises using georeferenced information on roads that were planned but had not been built by the end of our sample period and the timing and phase-in of transport infrastructure investments. We thereby accomplish our first and main task, namely, to obtain a consistent estimate of the effects of domestic transport infrastructure on exports while controlling for potential sources of endogeneity. Both ordinary least squares and instrumental variables estimates consistently suggest that new domestic roads have favored increased firms' exports by primarily facilitating larger shipments.

Finally, available historical information for Peru allows us to combine our baseline difference-in-differences strategy with an instrumental variables approach as a complementary way to deal with endogeneity issues. In particular, we use the *Inca road network* as a conditionally exogenous source of variation in transport infrastructure. More specifically, we instrument the change in road infrastructure between 2003 and 2010 with two instruments: (i) the *distance from the geographical origin of the exports to the nearest road that was part of the Inca network*, and (ii) the *distance between this origin and current port that could have been traveled along roads in this network*. True, whereas this pre-Columbian network was clearly built up for reasons entirely disconnected with current foreign trade and—as we shall see below—it is a good predictor of current road infrastructure changes, it may be argued that these instruments might not completely fulfill the exclusion restriction. For example, the Inca roads may have been built in locations that were and are still important from an economic point of view or may have favored settlements that became urban centers that traded more in later centuries (see, e.g., Maloney and Valencia Caicedo, 2012). This would imply a correlation between these historical roads and current economic activity and trade performance across regions. We therefore also condition on the same alternative sets of fixed effects considered in the ordinary least squares estimations. While this helps reduce the risk that the Inca road network affects today's exports through channels other than its correlation with the spatial allocation of new roads, it should be admitted that this strategy is not perfect because it cannot entirely preclude the possibility of such a violation of the exclusion restriction.

In order to achieve our secondary goal of assessing whether and how exports associated with infrastructure improvements influence employment, we use the predicted values from the estimated export equation as an instrument for the actual change in exports in an equation in which changes in employment are explained by changes in exports after conditioning by relevant covariates. Following this strategy, we find that the positive impact of domestic road infrastructure on firms' exports has actually translated into employment generation.

Our analysis contributes to at least two different literatures. First, we add to the literature on the impact of infrastructure on trade. Within this literature, our paper is closer to the study by Volpe Martincus and Blyde (2013) that estimates the effects of domestic transport infrastructure on firms' exports exploiting the earthquake that took place in Chile in February of 2010. We extend their analysis in several

(*footnote continued*)
2007). While it is not possible to establish whether specific roads were conceived to serve specific purposes, the fact that different road layers generally have different primary objectives can be used to focus on non- or less-trade related roads and thereby to assess whether the probable driving force of their construction matters. In particular, in a robustness check exercise in the empirical analysis below we remove from the treatment group (and the estimating sample) all new roads that correspond to the national road network, which are more likely to help connect Peruvian regions with foreign markets, and keep only those belonging to the departmental road network, which is essentially intended to link Peruvian regions with each other. As we shall see below, results remain the same regardless of whether we utilize all new roads or only those additions to the departmental network.

[9] The *t*-test of differences in means indicate that average annual export growth of these two groups of municipalities are not significantly different from each other over the period 1999–2002 but became so over the period 2003–2010. (see notes in Fig. 2).

[10] Peru is administratively organized in 25 departments. These departments are, in turn, subdivided into provinces (195 in total) comprising several municipalities (1841 in total). Municipalities are the smallest political-administrative division and are required to have a minimum of 3500 inhabitants. Lima is the capital city of the country and is located on the coast.

dimensions. First, due to data limitations, their estimated impacts are strictly short run whereas we look beyond an immediate response by considering a longer period.[11] Second, their identification is based on a specific natural experiment, which provides credible quasi-random variation in infrastructure but makes it difficult to generalize and specifically check the external validity (see Redding and Turner, 2014). In contrast, we examine a more policy relevant case, namely, the expansion of a developing country's road network, and address endogeneity by means of a different combination of identification strategies.

Third, we explore the general equilibrium effects that road expansion may have. More precisely, observed impacts could not only reflect new economic activity but also redistribution of this activity across units or agents. Given their different economic implications, which one prevails makes a substantial difference for the assessment of the policy under consideration. In order to disentangle actual changes from a redistribution of exports, we estimate separate equations comparing "treated" and "untreated" observations and "treated" and "residual" observations, as suggested by Redding and Tuner (2014).[12] These estimates reveal that infrastructure projects have had a net positive effect on exports. Finally, to the extent allowed by the data, we go beyond the impact on exports by tracing its subsequent implications for other economic outcomes, namely, firms' employment.

Our second contribution, in this latter sense, is to the number of papers that examine the effects of exporting on firm performance while properly correcting for endogeneity. Within this extensive literature (see, e.g., Clerides et al., 1998; Bernard and Jensen, 1999; Girma et al., 2003; van Biesebroeck, 2005; De Loecker, 2007), our paper is methodologically closer to two recent contributions by Lileeva and Trefler (2010) and especially Park et al. (2010). Lileeva and Trefler (2010) investigate how exporting affected Canadian plants' labor productivity and innovation between 1988 and 1996 by using plant-specific tariff cuts faced in the United States as an instrument for selling abroad. Similarly, Park et al. (2010) analyze the impact of exporting on Chinese firms' productivity, employment, sales and other performance variables over the period 1995–2000. They instrument exporting with firm-specific exchange rate shocks based on the destination of firms' exports before the Asian crisis.[13] Unlike these papers, we examine -to our knowledge for the first time—the employment effects associated with increased exports driven by transport infrastructure improvements.

The remainder of this paper is organized as follows. Section 2 introduces the dataset and presents basic statistics and preliminary evidence. Section 3 discusses the impact of road infrastructure on exports. Section 4 examines the effect of exports on employment and its relationship with the road infrastructure changes, and Section 5 concludes.

2. Dataset and descriptive evidence

Our dataset consists of three main databases. First, we have highly disaggregated export data for 1999, 2002, 2003 and 2005–2010 from the Peruvian customs. Data are reported at the transaction level and cover the entire universe of transactions in those years. Specifically, each record includes the firm's tax ID, the geographical origin of the flow (municipality), the product code (HS 6 digit), the port, airport or land border (hereafter generically "ports") through which the good

Table 1

Aggregate export indicators: differentiated products		
Indicators	**2003**	**2010**
Total exports	1461.7	3122.1
Number of exporting firms	3934	5605
Number of destinations	145	150
Number of exported products	2598	2765
Number of shipments	202.1	474.6
Number of ports	11	15
Number of firms with reduced distance to ports		793
Average exporter of differentiated products		
Total exports	733.7	1813.4
Number of destinations	2.2	2.3
Number of exported products	8.9	9.7
Number of shipments	60.9	93.9
Employment	111.9	81.8

Differences between observations with and without changes in infrastructure, 2003	
Export value	0.214
	(0.397)
Export weight	0.627
	(0.467)
Number of shipments	0.013
	(0.171)
Distance to Callao	−0.569
	(0.703)
Firm's Number of employees	0.106
	(0.217)
Firms' age	0.011
	(0.053)
Municipality's height	0.015
	(0.079)
Municipality's population	0.099
	(0.068)
Municipality's population density	0.038
	(0.089)
Municipality's share of urban population	0.000
	(0.003)
Department-2 digit ISIC sector fixed effect	Yes
Observations	5415

Source: Authors' calculations based on data from SUNAT and MTC. The first two panels of the table characterize both aggregate exports of differentiated goods (upper panel) and the average exporter of differentiated goods (lower panel). Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). Total aggregate exports are expressed in millions of US dollars. Average firm total exports are expressed in thousands of US dollars. The bottom panel of the table presents estimates of an equation in which the dependent variables are the natural logarithm of the export value, the natural logarithm of the export weight, the natural logarithm of the number of shipments, the natural logarithm of the distance to Callao (Peru's main port and airport), the natural logarithm of the firms' number of employees, the natural logarithm of the firms' age, the natural logarithm of the municipality's height, the natural logarithm of the municipality's population, the natural logarithm of the municipality's population density, and the municipality's share of urban population at the level of the data used in the main estimation (i.e., firm-product-destination) in 2003 and the main explanatory variable is a binary indicator that takes the value of one if the distance to the main port declined for the observation in question between 2003 and 2010 and zero otherwise. Department-2 digit ISIC sector fixed effects included (not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. *Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level.

[11] Strictly speaking, given the length of our sample period, estimates are likely to capture medium term effects. Some of the papers investigating the relationship between roads and other economic outcomes are able to consider longer time periods and thereby provide estimates that would be more representative of long term effects (see, e.g., Baum-Snow, 2007 and Michaels, 2008).

[12] We followed Redding and Turner (2014) by defining "untreated" observations as those observations that are physically and economically close to their counterparts "treated" with increased infrastructure and thus potentially exposed to externalities; and "residual" observations as the remaining ones.

[13] Brambilla et al. (2012) use the exogenous changes in exports and export destinations associated with the 1999 Brazilian devaluation to identify the causal effect of exporting and of exporting to high-income countries on skill utilization by Argentinean manufacturing firms.

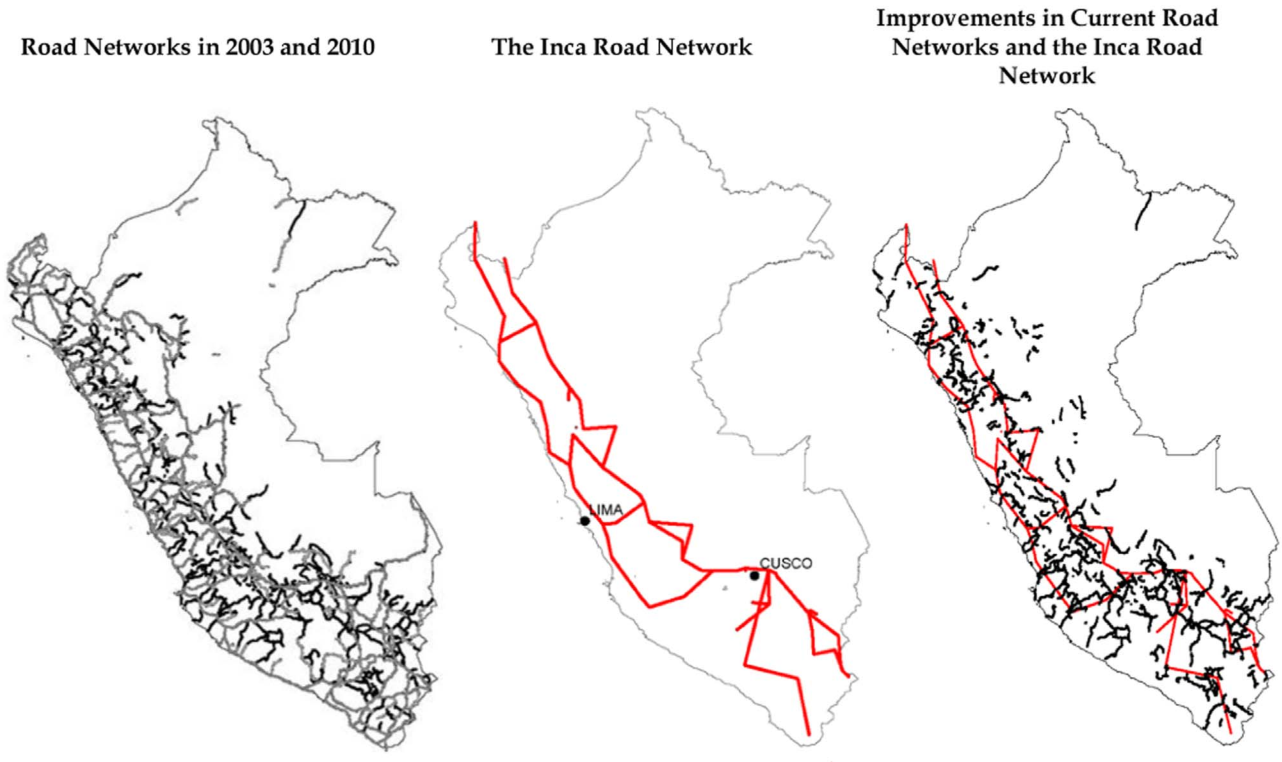

Fig. 3. Road Networks in 2003 and 2010. The Inca Road Network. Improvements in Current Road Networks and the Inca Road Network. *Source*: Authors' calculations based on data from MTC, ArcGIS, and Regal (1936). Left Panel: The 2003 (national and departmental) road network is colored in grey, whereas the additions to this network between 2003 and 2010 are colored in black. Middle Panel: The Inca Road Network appears in red. Right Panel: The additions to the (national and departmental) road network between 2003 and 2010 are colored in black. The Inca Road Network appears in red (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper).

exits Peru, the destination country, the export value in US dollars, and the quantity (weight) in kilograms. Hence, for each firm, we know the geographical origin of their exports, the export value, the quantity shipped, the number of shipments, and the exiting port for each of its product-destinations. We should mention herein that the sum of these firms' exports virtually adds up to the total merchandise exports as reported by the Central Bank of Peru, with the annual difference being always less than 1%. In the analysis below we focus on exports of differentiated products as defined according to the classification proposed by Rauch (1999).[14] The reason is that these products are mainly transported by road. In contrast, transport modes other than roads account for a non-negligible and even relatively important share of natural resources—specifically minerals and metals- and primary products' total cargos (see MTC, 2005).[15] Second, we have firm-level data on employment, sector of activity, and starting date from Peru's National Tax Agency, SUNAT.[16]

The first panel of Table 1 presents a snapshot of Peruvian total exports of differentiated goods in 2003 and 2010—which will be the initial and final sample years in our econometric analysis—along with key export extensive margin indicators. Exports of differentiated goods grew more than 120% between these years to reach 3.1 billion US dollars in 2010. These foreign sales expanded along the firm, destination, and product extensive margins. Thus, the number of firms, destination countries, and exported products increased by 42.5%, 3.4%, and 6.5% from 2003 to 2010, respectively. Yet, most of the expansion is accounted for by a larger intensive margin on the product-country dimension, i.e., larger average exports by product and country. This was the result of both larger average shipments and a larger number of shipments, which rose nearly 135%. These shipments exited the country through 15 ports. The second panel of Table 1 characterizes the average Peruvian exporter of differentiated products in these years. On average, in 2010 exporting firms had 82 employees and sold 9.7

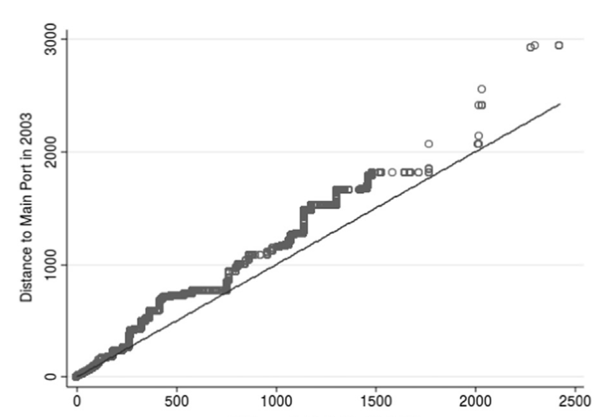

Fig. 4. Distribution of Distances to Main Ports, 2003 and 2010. *Source*: Authors' calculations based on data from SUNAT, MTC, and ArcGIS. The figure is a quantile-quantile graph that plots the quantiles of the distances traveled (in kilometers) from the plants to the exiting ports at the beginning and at the end of the sample period for exports that are positive in both periods.

[14] The classification proposed by Rauch (1999) distinguishes among homogeneous goods, which are internationally traded in organized exchanges; reference-priced goods, which are not traded in these organized exchanges but have reference prices quoted in specialized publications; and differentiated goods, which are neither traded in organized exchanges nor have reference prices, i.e., prices do not convey all the relevant information for international trade on these goods. In particular, we use the conservative version of this classification.

[15] Moreover, from the point of view of our instrumental variables estimates, by restricting the sample this way, we are excluding commodities that are more likely to have existed and could have been domestically shipped in the past (e.g., in the colonial era or even before).

[16] We consider the ISIC 2-digit Revision 3 sector classification. In this classification there are 61 sectors, out of which 31 are production (non-service) sectors and 23 correspond to manufacturing.

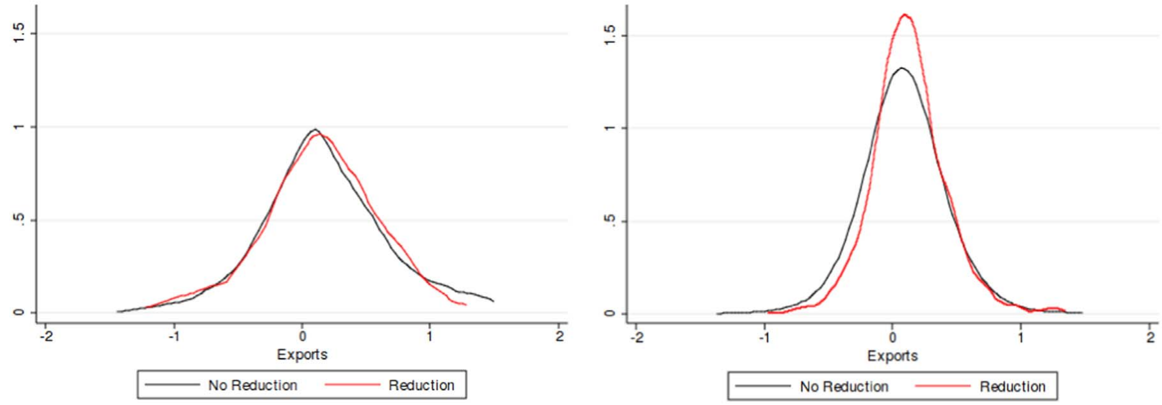

Fig. 5. Distribution of Average Annual Growth Rates of Exports with and without Reduced Distances to Ports 1999–2002. 2003–2010. *Source*: Authors' calculations based on data from SUNAT, MTC, and ArcGIS. The figure presents kernel density estimates of the average annual growth rate of firm-product-country exports whose distances to the respective main ports decreased as a consequence of the new roads built between 2003 and 2010 and their counterparts whose distances to the respective ports remained the same over this period, both for 1999–2002 (left) and 2003–2010 (right). The Kolmogorov-Smirnov test shows that the distribution of the average annual export growth rates is similar for firms with and without reduced distance to their main port over the period 1999–2002. The combined Kolmogorov-Smirnov test statistic is equal to 0.053 and the respective *p*-value is 0.723. In contrast, such test rejects the equality between the distributions of the average annual export growth rates across groups over the period 2003–2010. The combined Kolmogorov-Smirnov statistic is 0.071 and the respective *p*-value is 0.004. Furthermore, the Kolmogorov-Smirnov one-sided test reveals that the distribution of average annual export growth rates for firms with no reductions in their distance to the respective main port is stochastically dominated by the corresponding distribution for firms that did experience a decline in their distance to their respective main port In particular, the Kolmogorov-Smirnov statistic for the null hypothesis that the distribution corresponding to no reduction is dominated by the distribution corresponding to reduction is −0.037 and the *p*-value is 0.983. In contrast, the Kolmogorov-Smirnov statistic for the null hypothesis that distribution corresponding to reduction is dominated by the distribution corresponding to no reduction is 0.071 and the *p*-value is 0.002.

products to 2.3 countries for approximately 1.8 million US dollars. In selling abroad, each of these firms made 94 annual shipments.

Third, the Peruvian Ministry of Transport and Communications (MTC) kindly provided us with geo-referenced versions of the maps of the Peruvian road (national and departmental) networks in 2003 and 2010 (see the left panel of Fig. 3). Assuming that profit-maximizing firms minimize the distance traveled between any two observed shipping locations, we are able to determine both the domestic route(s) that each firm originally used from the production facilities to the exiting ports in shipping each of their products to each of their destination countries and the routes utilized after new roads were built. We identified these routes following a method that makes use of spatially geo-referenced data on the road network (see, e.g., Combes and Lafourcade, 2005).[17]

The average exporter was located 252.9 km away from its main port in 2003. With road infrastructure improvements in place, the average distance to the main ports declined around 10% from 2003 to 2010.[18] Note that this is an average across all exporters, i.e., taking into account both those with changed and unchanged shipping distances. If we instead consider only those roughly 800 firms that could actually use shorter-distance routes thanks to the new roads (see Table 1), this reduction more than doubles to reach 22.1%. Fig. 4 shows the entire distribution of distances traveled between production plants and exit nodes at the beginning and the end of the sample period. This figure reveals that innovations to the road infrastructure caused an important shift in the distribution of distances and, predictably, a reduction in domestic transport costs.

In Fig. 5, we compare non-parametrically the unconditional average annual growth rates of exports whose distances to the respective main port decreased with that of their counterparts whose distances remained the same both for 1999–2002 (i.e., the period before roads were built) and 2003–2010 (i.e., the period during which roads were built). This figure suggests that, while the former experienced average larger expansions than the latter over the period 2003–2010, they do not seem to differ from each other over the period 1999–2002. More specifically, according to the procedure proposed by Delgado et al. (2002), the distribution of the annual growth rates of exports with declining distances stochastically dominates that of the exports with invariant distances in the second period, but does not significantly differ from the latter in the first period.[19]

The third panel of Table 1 compares observations that correspond to cases of improvements in road infrastructure over the period 2003–2010 and observations that correspond to cases of no infrastructure changes over this period in terms of a number of relevant geographical and economic characteristics. This is done conditioning on department-sector fixed effects, which we later include in our baseline estimating equation. Estimates reveal that, once department and sector differences are accounted for, both groups do not seem to have been initially different from each other.

As discussed above, we also resort to instrumental variables estimation. In this sense, we have obtained digital images of maps of the different portions of the Inca road network (see Regal, 1936) and have converted these images into a digital map with the same format and projection as the maps of the 2003 and 2010 road networks (see the middle panel of Fig. 3). Based on this map, we construct the two variables that will be used as instruments in our estimations: the distance from each municipal capital to the Inca road network and the distance that could have been traveled on this network between any given two locations in Peru.

[17] More precisely, we apply a method based on a Geographic Information System (GIS). This system consists of a digitalized real transport network that connects the country's municipalities with each other, including those where ports are located. The network is composed of several arcs that correspond to the different types of roads belonging to the road system (i.e., highways, primary roads, and secondary roads). The Arc View program is used to identify the least-distance itinerary between each municipality of origin and each port, whereby this distance is calculated by adding up the different arcs that connect the respective intermediate end-nodes (see Volpe Martincus and Blyde, 2013).

[18] The distribution of the share of each Peruvian department in the total number of exporters whose connection with their respective main port improved as consequence of the new roads and that of their share in the total number of peers not experiencing any change in this regard across Peruvian departments resemble each other. In fact, according to the Kolmogorov–Smirnov test, these distributions are not significantly different from each other. More specifically, combined test statistic is 0.294 and the corresponding *p*-value is 0.454.

[19] See notes in Fig. 5.

3. Domestic road infrastructure and exports

3.1. Estimation approach

We aim at estimating the effects of domestic road infrastructure on exports. Clearly, as mentioned above, there are factors other than this infrastructure that may affect firms' foreign sales. Thus, these sales may be larger because of higher firm productivity or other public policies. Failure to properly account for these other factors would result in biased impact estimates. Our baseline empirical model of exports therefore includes appropriate sets of fixed effects to control for such factors. We specifically postulate the following export equation:

$$\ln X_{frspc}(t) = \alpha D_{frspc}(t) + \lambda_{frspc} + \theta_{rs}(t) + \varepsilon_{frspc}(t) \quad (1)$$

where f denotes firm, r stands for region (Department), s indicates sector (2-digit ISIC), p corresponds to product, c refers to destination country, and t indexes year. The main variables are X and D. The former represents export value. The latter, D, is a binary indicator that takes the value of 1 if firm located in region r and belonging to sector s uses a shorter distance route to ship product p to the respective main port through which it exports to destination country c and 0 if it uses a same-distance route. In other words, our main explanatory variable captures whether distance to the port declined and accordingly access to it improved for the firm over time. Thus, the coefficient on the indicator variable D, α, is our parameter of interest. If $\alpha > 0$ ($\alpha = 0$), then reduced distance—and hence transport costs—due to new roads had a positive (no) impact on exports.

Two considerations are worth making in this regard. First, we use a binary indicator in our benchmark specification because it imposes less parametric structure than a linear relationship between distance to ports and exports.

In this sense, note that topography can create important non-linearities. This holds particularly true for Peru, which is the third roughest country in the world, only surpassed by China and Nepal (see Ramcharan, 2009).[20] Second, distance to the main port is utilized since most firms just use one port in shipping a given product to a given destination. In fact, while firms can and do use different ports depending on the specific product-destination combinations, the average (median) number of ports per firm-product-country is 1.02 (1).

The remaining terms of Eq. (1) correspond to control variables. Thus, λ_{frspc} is a set of firm-region-sector-product-country fixed effects that captures, for instance, the firm's knowledge of the market for a given product in a given country; $\theta_{rs}(t)$ is a set of region-sector-year fixed effects that absorb the influence of sector-region shocks such as, for example, changes in other public policies aimed at promoting exports in specific regions or sectors (see, e.g., Volpe Martincus, 2010) as well as changes in foreign demand for goods produced by firms in particular sectors that are primarily concentrated in certain regions; and $\varepsilon_{frspc}(t)$ is the error term.

In estimating Eq. (1), we use differencing to eliminate the firm-product-country fixed effects.[21] Further, by aggregating time series information into two periods 2003 and 2010, we address the serial correlation problem to which equations such as ours are typically subject (see Bertrand et al., 2004). In particular, we estimate the following baseline equation:

$$\Delta \ln X'_{frspc} = \alpha D_{frspc} + \theta'_{rs} + \varepsilon'_{frspc} \quad (2)$$

where $\Delta \ln X'_{frspc} \equiv [\ln X_{frspc}(2010) - \ln X_{frspc}(2003)]/7$ is the average annual log change in exports; we already have taken into account that $\Delta D_{frspc} = D_{frspc}(2010)$ because no infrastructure improvements took place in the initial period (i.e., $D_{frspc}(2003) = 0 \; \forall \; frspc$); $\theta'_{rs} = \theta_{rs}(2010) - \theta_{rs}(2003)$ accounts for all region-sector shocks; and $\varepsilon'_{frspc} = \varepsilon_{frspc}(2010) - \varepsilon_{frspc}(2003)$.

Eq. (2) essentially corresponds to a differences-in-differences estimation, whereby the before and after change in exports whose routes' length did not change is used as an estimate of the counter-factual for those exports whose routes' length declined as a result of the increased availability of road infrastructure. By comparing these changes, the difference-in-differences estimator permits controlling for observed and unobserved firm(-region-sector)-product-destination time-invariant factors as well as time-varying ones common to both treated and comparison groups that might be correlated with being exposed to the positive infrastructure shock and exports (see, e.g., Galiani et al., 2008). Eq. (2) additionally includes fixed effects that account for systematic differences across region-sectors pairs, so that effects are ultimately identified from deviation from regional-sectoral changes over time. This reduces the risk of omitted variable biases and particularly of heterogeneity in regional-sectoral export dynamics.

Table 2

The impact of new roads on firms' exports, 2003–2010

OLS estimates	Binary indicator	Continuous distance	Bins
D	0.037***		
	(0.01)		
D Continuous		0.216***	
		(0.052)	
D Bin 1			0.004
			(0.014)
D Bin 2			0.048***
			(0.011)
D Bin 3			0.116***
			(0.039)
Department-2 digit sector fixed effects	Yes	Yes	Yes
Adjusted R2	0.042	0.042	0.043
Observations	5415	5415	5415

Source: Authors' calculations based on data from SUNAT and MTC. The table reports OLS estimates of Eq. (2). The dependent variable is the change in the natural logarithm of export value at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). Column 1: The main explanatory variable (D) is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. Column 2: The main explanatory variable (D Continuous) is the absolute change in the natural logarithm of the distance over which a firm shipped their products to their main port when exporting to a given country as a consequence of the new roads built between 2003 and 2010. Columns 3: The main explanatory variables are three binary indicators that take the value of one if the absolute reduction in the distance over which a firm shipped their products to their main port when exporting to a given country as a consequence of the new roads built between 2003 and 2010 is up to the 25th percentile (D Bin 1), between the 25th and the 75th percentile (D Bin 2), and above the 75th percentile (D Bin 3) of the respective distribution and zero otherwise. Department-2 digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported in parentheses immediately below the estimated coefficients. *Significant at the 10% level; **Significant at the 5% level; *** Significant at the 1% level.

[20] Notwithstanding, we also estimate our model under a linear relationship between distance to ports and exports as a robustness check (see Table 2). Similarly and in the same vein, we also consider a specification based on distance reduction bins (see Table 2) to relax our binary specification.

[21] When the number of periods is equal to two, first-differencing and fixed effect estimation produce identical estimates and inference (see Wooldridge, 2002).

3.2. Baseline results

Column 1 of Table 2 presents ordinary least squares estimates of Eq. (2). The coefficient of interest is positive and statistically different from zero. In particular, according to the point estimate, the average annual rate of growth of those exports whose routes to the main port experienced a reduction in their length due to the construction of new roads has been 3.8% higher than that of their counterparts whose route length remained the same over the period 2003–2010.[22] In assessing the significance of the effects, we consider standard errors clustered by department to account for potential correlation of exports stemming from the same region.[23]

Given that the average (logarithmic) distance traveled to the exit point would have decreased by 22.1% for trade flows with shorter distances and that the estimated ordinary least squares coefficient on the long differences (2003–2010) is 0.259, the distance elasticity of exports would be roughly 1.2. This is similar to the estimate reported in Volpe Martincus and Blyde (2013), but it is larger than that estimated by Duranton et al. (2014). Note, however, that the latter estimate corresponds to domestic trade and are obtained from data at a higher aggregation level (i.e., region-pair level instead of firm-product-country level). Moreover, unlike the former study, our estimated elasticity informs the effect of new roads as opposed to existing roads (or their disappearance) in a country with much more limited transport infrastructure.[24]

A simple back-of-the-envelope calculation based on the estimated impact of infrastructure on the 2003–2010 export growth reveals that, in the absence of changes in domestic road infrastructure, total exports of differentiated goods would have been roughly 5.6% smaller in 2010. Taking into account that annual average public investment in road infrastructure over the period 2003–2010 was approximately USD895 million, this implies that additional exports of differentiated goods alone would have amounted to more than 17% of such average investment in just one year.[25]

In our basic specification increased road infrastructure is captured by a binary indicator. Thus, the estimated coefficient on this variable gives the effect associated with the infrastructure treatment status. Assuming that the intensity of this treatment can be proxied with the change in raw distances to the main port between 2003 and 2010 as computed according to the method referred to above, we can re-estimate Eq. (2) using this plain distance change as the main explanatory variable. Alternatively, we can assume a more flexible functional form whereby reduced distances to ports are allowed to have different effects on exports depending on their size but in discrete intervals. In particular, we can also estimate a variant of Eq. (2) using as main explanatory variables three binary indicators that correspond to three distance reduction bins: up to the 25th percentile, between the 25th and 75th percentile, and above the 75th percentile. Estimates of these modified equations are presented in the second and third columns of Table 2, respectively. Both estimates point to the same direction and indicate that the impact is stronger the larger is the reduction in the distance to ports made it possible by the new roads.[26] Noteworthy, the direct estimated distance elasticity is comparable to that implied by our baseline estimation results.[27] We next go through several robustness checks.

3.3. Robustness checks

3.3.1. Stricter fixed effects

While our baseline specification includes region-sector fixed effects and thus isolate the influence of regional-sectoral level confounders, there may be other factors that can also potentially play a role in explaining exports which differ within region-sector pairs. This is for instance the case with geography, level of development, and sectoral structure in terms of economic activities. Hence, we also estimate variants of Eq. (2) including fixed effects that control for differences across lower level geographical units such as provinces and municipalities in combination with sectors of activity.[28] In this regard, notice that the median Peruvian municipality is relatively small (208 squared kilometers or 81 squared miles), so that systematic differences in terms of geography or level of development relevant for exporting are less likely to prevail within these jurisdictions. Further, if local differences existed in terms of natural endowments (e.g., land quality) and expressed themselves in diverging economic structures across areas within these districts, the municipality-sector fixed effects included in one of the specifications can contribute to isolate them. Ordinary least squares estimates of these alternative export equations, which are obtained by strictly exploiting the variation within province-sector and municipality-sector, are presented in Columns 1 and 2 of Table 3 and confirm the baselines.

While this battery of fixed effects goes a long way in controlling for potentially relevant unobserved factors, identification problems related to such kind of factors cannot be considered ruled out. Thus, for instance, while Peruvian municipalities are not large, they can still be big enough to host areas with geographical and economic characteristics that differ in such a way that municipality-sector fixed effects are not able to account for differences between sub-locations with improved road access to ports and their counterparts without changes in road infrastructure. More generally, other so far omitted, even more granular factors may have played a role in explaining the expansion of firms' foreign sales. Further, as referred to before, firms may self-select in locations and those close to main roads may be different from their counterparts located elsewhere along relevant dimensions.[29] Thus,

[22] We have estimated variants of Eq. (1) that include location-sector linear trends using data for 1999, 2003, and 2010. Estimates from these equations confirm our baseline results (see Table A.2.1 in the online Appendix).

[23] This result remain robust to clustering standard errors by province and municipality (see Table A.3.1 in the online Appendix). Even though there are relatively few of them, we prefer to be conservative and cluster standard errors by department instead of the alternatives because exports are likely to be correlated across provinces and municipalities given their relatively small size and similar specialization.

[24] As shown in the left panel of Fig. 3, almost no roads were built in the Selva (tropical rain forest) region (see Volpe Martincus et al., 2013). In an alternative estimation we have accordingly excluded observations that correspond to firms shipping goods from departments belonging to this region. Estimates are robust to removing these observations. Results from these estimations are included in Table A.4.1 in the online Appendix.

[25] This figure should be seen as a lower bound as only a portion of the aforementioned resources was actually invested in the construction of new roads. Part of these resources was allocated to maintenance, repairing, and rehabilitation of roads.

[26] This is also confirmed by results from a semi-parametric estimation (see Figure A.5 in the online Appendix).

[27] Admittedly, besides the construction of new roads that allowed for such a decline in plain distances, existing roads may have been improved over the sample period, which could also lead to a reduction in the effective distances to the main ports (see Volpe Martincus et al., 2013). Unfortunately, we do not have information on road quality for both initial and final sample years to compute effective distance changes. In contrast, we do have data on topographic conditions. The results do not change when these conditions are taken into account (see Table A.6.1 in the online Appendix).

[28] These effects account—at least partially—for potential mechanisms other than reduction in physical distance and transportation costs by which road infrastructure can affect exports such as diffusion of ideas and labor mobility.

[29] We do not observe relocation of firms during our sample period. Nevertheless, firms could have endogenously chosen their location based on predictions of new roads. This could be more likely the case and to make more economic sense when the time gap between their establishment and the actual construction of roads is relatively short. Hence, a natural way to assess whether endogenous location affects our results is to re-estimate Eq. (2) on a sample of firms that were created several years prior the building of the new roads. Thus, in so doing, we specifically remove from the sample all exports originated from firms that started to operate less than two, four, six, eight, or ten years before the beginning of the period we focus on. Estimates based on these alternative samples are in line with those shown here and are presented in Table A.7.1 in the online Appendix. It should be acknowledged though that older firms are likely to be larger and have accordingly more bargaining power to get new roads. We specifically address this potential remaining source of endogeneity below where we report estimates based on specifications including firm fixed effects.

Table 3

The impact of new roads on firms' exports, 2003–2010
Robustness check
Alternative specifications—OLS estimates

	(1)	(2)	(3)	(4)	(5)	(6)
D	0.033***	0.040***	0.045***	0.044***	0.034**	0.042***
	(0.008)	(0.009)	(0.015)	(0.014)	(0.014)	(0.016)
D Continuous	0.208***	0.245***	0.224**	0.219***	0.174**	0.152***
	(0.049)	(0.063)	(0.09)	(0.076)	(0.086)	(0.014)
D Bin 1	−0.006	0.022*	0.016	0.013	−0.009	0.023
	(0.007)	(0.012)	(0.026)	(0.024)	(0.018)	(0.015)
D Bin 2	0.047***	0.040**	0.047***	0.047***	0.039**	0.044**
	(0.011)	(0.015)	(0.014)	(0.015)	(0.015)	(0.019)
D Bin 3	0.113**	0.117**	0.151***	0.156***	0.130***	0.100**
	(0.041)	(0.054)	(0.032)	(0.026)	(0.029)	(0.039)
Province-2 digit sector fixed effects	Yes	No	No	No	No	No
Municipality-2 digit sector fixed effects	No	Yes	No	No	No	No
Firm fixed effects	No	No	Yes	Yes	Yes	Yes
HS 2 digit product fixed effects	No	No	No	Yes	Yes	No
Destination fixed effects	No	No	No	No	Yes	No
HS 2 digit product-destination fixed effects	No	No	No	No	No	Yes
Adjusted R^2 : D	0.048	0.123	0.243	0.241	0.242	0.241
Adjusted R^2 : D Continuous	0.049	0.123	0.244	0.241	0.242	0.241
Adjusted R^2 : D Bins	0.048	0.123	0.243	0.241	0.242	0.241
Observations	5415	5415	5415	5415	5415	5415

Source: Authors' calculations based on data from SUNAT and MTC. The table reports OLS estimates of Eq. (2). The dependent variable is the change in the natural logarithm of export value at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). Rows 1–2: The main explanatory variable (D) is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. Rows 3–4: The main explanatory variable (D Continuous) is the absolute change in the natural logarithm of the distance over which a firm shipped their products to their main port when exporting to a given country as a consequence of the new roads built between 2003 and 2010. Rows 5–10: The main explanatory variables are three binary indicators that take the value of one if the absolute reduction in the distance over which a firm shipped their products to their main port when exporting to a given country as a consequence of the new roads built between 2003 and 2010 is up to the 25th percentile (D Bin 1), between the 25th and the 75 th percentile (D Bin 2), and above the 75th percentile (D Bin 3) of the respective distribution and zero otherwise. Alternative sets of fixed effects (i.e., Province-2 digit ISIC sector; Municipality-2 digit ISIC sector; Firm; Firm and HS 2 digit product; Firm, HS 2 digit product, and destination; Firm and HS 2 digit product-destination) included (but not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

exports from the former may have grown because of increased firm productivity or because of larger demand for particular goods from particular importing countries associated with a decline in the respective transport costs or tariffs applied thereon (see, e.g., Volpe Martincus and Blyde, 2013). Moreover, firms exposed to infrastructure improvements may have also received support from Peru's national export promotion organization -PROMPERU- to participate in trade missions and international marketing events leading to foreign sales, in which case we would be overestimating the effect of interest (see, e.g., Volpe Martincus and Carballo, 2008).

In order to control for these additional potential confounding forces and hence check the robustness of our previous estimation results, we include sets of fixed effects along the respective dimensions in the equation estimated on the disaggregated export data. More precisely, we also estimate alternative specifications in which we include firm fixed effects, destination and product fixed effects, and product-destination fixed effects.[30] In the most demanding variant, we incorporate firm and (HS 2 digit) product-destination fixed effects, so that effects are identified based on the variation *within firms* in given locations across (HS 2 digit) product-destination combinations and *within* (*HS 2 digit*) *product-destination combinations* across firms.[31] Ordinary least squares estimates of these augmented export equations are reported in Columns 3–6 of Table 3. Reassuringly, these estimates essentially corroborate our initial findings based on the baseline specification.[32]

3.3.2. Placebo exercises and heterogeneities

In this subsection we assess the robustness of our results by performing four checks that consist of three placebo tests and an assessment based on heterogeneities. First, if our identification strategy is correct, we should not see differences in exports in absence of changes in road infrastructure. Using export data for 1999 and 2002 we carry out a falsification exercise in which we assume that the new roads

[30] Product-destination fixed effects might also likely account for potential positive export information spillovers from firms with improved road connections with their main ports to peers without changes in these connections, thus mitigating the risk of underestimating the effect of interest.

[31] In our data a firm fixed effect is equivalent to a firm-region-sector (i.e., firm-department-2 digit ISIC) fixed effect.

[32] There might have occurred shocks to input provision that might have differential effects on production across goods or changes in firms' competencies across them. Unfortunately, we cannot estimate the specification including firm-product and product-destination fixed effects because this model is overparametrized. Nevertheless, we believe that the estimation results shown in Table 3 provide sufficiently convincing evidence that road infrastructure improvements have positively affected exports.

Table 4

The impact of new roads on firms' exports, 2003–2010
Robustness check
Placebos

Placebos 1 and 2: timing of infrastructure investments and non-built roads—OLS estimates

	Placebo 1		Placebo 2
	Pre- vs. post-road construction periods		Non-built roads
	1999–2002	2003–2010	
D	−0.053 (0.053)	0.064*** (0.012)	−0.061 (0.052)
Department-2 digit sector fixed effects	Yes	Yes	Yes
Adjusted R^2	0.092	0.099	0.042
Observations	1258	1258	4585

Placebo 3: Phase-in of infrastructure investments—OLS estimates

	2003–2006	2006–2010	2003–2010
D	0.012 (0.027)	0.048*** (0.018)	0.037*** (0.010)
Department-2 digit sector fixed effects	Yes	Yes	Yes
Observations	4256	4265	5415

Source: Authors' calculations based on data from SUNAT and MTC. Placebo 1: Column 1 of the first panel of the table presents OLS estimates of Eq. (2) over the period 1999–2002 assuming new roads constructed between 2003 and 2010 were built in that period. Column 2 of the table presents OLS estimates of Eq. (2) over the period 2003–2010 when the estimating sample is restricted to those firm-product-country triples that also existed in 1999–2002. Placebo 2: Column 3 of the first panel of the table reports OLS estimates of Eq. (2) when estimated on the sample of firm-product-destination exports whose routes did not actually change between 2003 and 2010 and projected, not yet built national and departmental roads are assumed to have been constructed over this period. Placebo 3: The table reports OLS of Eq. (2) for different sample periods: 2003–2006, 2006–2010, and 2003–2010. In all cases, the dependent variable is the average annual change in the natural logarithm of export value at the firm-product-country over the respective period. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). The main explanatory variable (D) is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. Department-2-digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

were constructed between 1999 and 2002 instead of between 2003 and 2010.[33] This amounts to test whether exports shipped along shorter routes and exports whose routes did not change in more recent years followed parallel trends before the new roads were constructed. Estimation results are shown in the upper panel of Table 4. Notice that, for comparison purposes, we include estimates for the period

Table 5

The impact of new roads on firms' exports, 2003–2010
Robustness Check
Heavy goods vs. and light goods—OLS estimates

	Heavy goods	Light goods
D	0.065*** (0.013)	0.038*** (0.013)
Department-2 digit sector fixed effects	Yes	Yes
Adjusted R^2	0.096	0.043
Observations	1719	3536

Source: Authors' calculations based on data from SUNAT and MTC. Columns 1 and 2 of the table report OLS estimates of Eq. (2) for heavy goods and light goods, respectively. Goods are classified in heavy and light using worldwide data on weight-to-value ratios from COMTRADE. In particular, goods whose weight-to-value ratios are above the median are considered heavy, while those whose weight-to-value ratios are at or below the median are considered light. In so doing, we exclude the upper and lower 0.5 percentiles of the distribution of weight-to-value ratios, which are clearly outliers. The dependent variable is the average annual change in the natural logarithm of export value at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). The main explanatory variable is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. Department-2 digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported below the estimated coefficients. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

2003–2010 when we restrict the sample to those firm-product-destination triples that are also present in the former sample and, in both cases we use average annual growth rates which accounts for the different length of the sample periods. According to these results, no pre-policy differences in trajectories appear to have prevailed.[34]

Second, available information on transport infrastructure plans and the associated changes in distances to ports that would result from implementing these plans can be used to conduct an alternative falsification exercise that provides additional validation for our findings. More specifically, a recent road inventory in Peru indicates that there were more than 2000 kilometers of projected, not yet built national roads (i.e., roughly 10% of the total length of the national road network) which could be considered comparable to those roads those built between 2003 and 2010 in terms of quality and spatial distribution (see MTC, 2011). We exploit these geo-referenced data to perform a placebo test whereby we assume that these and other departmental projected roads were built between 2003 and 2010 and accordingly create an artificial treatment group within our original control group.[35] Estimates of Eq. (2) on these data are presented in the third column of the upper panel of Table 4 and show no evidence of spurious effects.[36]

Third, while raw data indicate that there were some few changes in the road network from 2003 to 2006, most construction work took place sequentially starting in 2006. Thus, no impact would be expected over the period 2003–2006. We can therefore exploit the phase-in of

[33] We cannot consider a longer pre-treatment period because unfortunately geo-referenced export data are not available before 1999 and we do not have access to other data that could have been used as proxies.

[34] It might be argued that the non-divergence pre-2003 and the divergence post-2003 are primarily driven by macroeconomic factors (i.e., no vs. high growth in general and in exports in particular). Note, however, that results from ordinary least squares estimations pooling both periods and including a department-sector-period fixed effect to account for the economic conjuncture are aligned with those presented in Table 4 (see Table A.8.1 in the online Appendix).

[35] Thus, the estimating sample excludes those exports whose distance to the respective ports actually declined.

[36] In identifying the impact of India's railroad network on a series of economic outcomes, Donalson (2016) also carries out placebo exercises using approved construction plans that were never actually built. Jedwab and Moradi (2013) also do so in their study on Ghana.

road investments as an alternative assessment of our identification approach.[37] This is precisely what we do in the lower panel of Table 4, where we utilize export data for intermediary years to estimate Eq. (2) over two different time windows, 2003–2006 and 2006–2010. As with the previous exercise, the dependent variables are then the respective average export annual growth rates. In addition to the baseline case, estimates are only significant when the later years of our sample period are included, i.e., 2006–2010. This provides further evidence in favor of a causal interpretation of our estimated effects.

Heterogeneities can also inform identification because they can provide evidence on the specific mechanisms by which a variable affects an outcome (see Rajan and Zingales, 1998). In our case, a natural dimension to look for these heterogeneous effects is product categories. In particular, transport infrastructure is likely to favor foreign sales of heavy products more than those of their light counterparts. Table 5 presents estimates of Eq. (2) for these different types of products. Consistent with the priors, estimates indicate that effects were stronger for heavier goods (i.e., goods whose initial weight to value ratio were above the median) than for lighter goods (i.e., goods whose initial weight to value ratio were at or below the median).[38]

3.3.3. The Inca roads as instruments

As discussed in the Introduction, the obvious challenge we face in identifying the effect of road infrastructure on exports is that the former can be endogenous to the latter either because of missing variables that may drive both spatial allocation of new routes and exports or because new roads may have been constructed based on expected future trade. In the analysis below we apply an instrumental variables approach on top of the difference-in-differences strategy as an alternative means to address endogeneity concerns.

Specifically, we use instrumental variables to estimate our export equation on firm(-region-sector)—product-destination data expressed in differences -which allows us to primarily account for time-invariant factors at this level—and that additionally includes region-sector fixed effects. In so doing, we exploit the Inca road system, a network of several thousand kilometers of routes whose origins can be primarily traced back to the mid-fifteen century (see Section A.1.2 in the online Appendix for detailed information on the characteristics of this road system). More precisely, we instrument the change in available road infrastructure (i.e., new road construction leading to reduced distance traveled) with two variables that measure the accessibility to and the coverage of the Inca road network, namely, the *distance from the geographical origin of the export flow to the nearest road that was part of the Inca network and the distance that could have been traveled along these roads between the origin and the current port through which this flow leaves the country*, respectively.[39] More formally, we estimate the following first-stage equation[40]:

$$D_{frspc} = \delta \ln(Dist.\ to\ Inca\ Roads)_{frspc} + \rho \ln(Dist.\ on\ Inca\ Roads)_{frspc} + \gamma_{rs} + \varepsilon_{frspc} \tag{3}$$

These variables are valid as instruments as long as they predict recent road infrastructure improvements, but are otherwise uncorrelated with exports. This involves two conditions. First, these variables must be partially correlated with infrastructure innovations once the other relevant variables have been netted out. As suggested in Fig. 3 (right panel), our both instruments are very likely to predict the evolution over time of the modern road network. The direction of the relationship, however, can *a priori* go in either way. On the one hand, similar to the United States exploration routes, the Inca roads resulted from a search for an easy way to get from one place to another place on foot or animal-back. Since a good route for a man or an animal can be assumed to be also good for a car, the Inca roads will often be good routes for contemporary highways (see Duranton et al., 2014). In such a case, we would expect a negative correlation between infrastructure improvements and distance to the Inca road network and a positive correlation between infrastructure improvements and the distance that could have been traveled on this network between two locations. On the other hand, it may also be perfectly possible that, while first, older roads were already constructed following the trace of and thus overlapped with the Inca road network, newer, more recent roads may be built in regions that are less developed in terms of infrastructure and farther away from where the Inca road network was. Here, a positive correlation between infrastructure improvements and distance to the Inca roads would prevail.

Second, the variables chosen as instruments must be uncorrelated with the error term, i.e., they must be exogenous, which requires to properly accounting for factors that influence exports and are correlated with both the access to and the extension of available Inca roads. In this sense, the construction of the Inca roads had no association with past overseas trade, which was virtually nonexistent. Several researchers coincide in that the closed and family character of the Incas' economic organization did not even create room for markets and domestic trade.[41] In particular, within this organization each family produced what was needed for subsistence and, if any, domestic trade was extremely restricted to specific products (see Romero, 1949; D'Altroy, 1992 and Murra, 2002).[42] This system sharply contrasts with that prevailing in other Latin American pre-Columbian Civilizations such as the Aztecas where domestic trade played a much more preponderant role. Among other things, this scheme was possible due to the notorious local ecological diversity of the area that currently corresponds to Peru, which allowed inhabitants of specific regions to have access to a broad variety of natural products without the need to resort to cross-regional exchanges (see Arciniegas, 1990 and Contreras, 2010).[43]

[37] Regrettably we do not have infrastructure data for intervening years but only for the period's end points, 2003 and 2010.

[38] It might also be the case the firms with more access to external or internal finance are in better position to take advantage of the reduction in transportation costs to expand exports. Unfortunately, we cannot test the potential conditioning influence of access to external financing because we lack data on standard proxies such as proximity to banks or specificity of the collateral the firms use. As for access to internal financing, in absence of information on variables such as cash or *de facto* debt, we use firms' age as a proxy. In particular, we allow for different estimated export effects of road infrastructure depending on whether firms' age is above or below the median in the year the infrastructure investments started to pick up, 2006 (8 years). Estimated impacts do not significantly differ between the different age groups. Keeping in mind the limitations of age as a proxy, this would suggest that internal financing did not play an important role as a source of heterogeneous export responses (see Table A.9.1 in the online Appendix).

[39] For firms off the Inca road network, distances on this network are computed from the point that would have been closest to the municipalities from which their export flows are shipped.

[40] Even though the treatment variable is binary, a linear model is used to estimate the first-stage equation. The reason is that linear 2SLS estimates have a robust causal interpretation that is insensitive to the possible nonlinearity of the first-stage conditional

(*footnote continued*)
expectation function (see Angrist, 2001, 2006).

[41] There was no currency in the Inca Empire (see Rodríguez, 1977; and Arciniegas, 1990). One of the most often cited and highly regarded sources of information about the Inca civilization are the memoirs of Polo de Ondegardo, a Spanish Kingdom representative, who arrived to the Andean region in 1540 and was in charge of supervising Incas' activities. In his records there is no single mention to the existence of markets or merchants (see Romero, 1949).

[42] According to Murra (2002), the Incas implemented a system whereby each family group simultaneously had parcels located in different areas, which allowed them to have access to diverse crops. Kinship as well as military and religious ties guaranteed production sharing.

[43] While Hartmann (1968) argues that some domestic trade took place in the North of the Empire, later revisions by Oberem (1978) and Salomon (1978) challenge this view and unambiguously conclude that, if present at all, trade was very limited and developed at a very late stage. The thesis that postulates the existence of markets and trade was also questioned by Noejovich (1993). The most relevant reference to internal trade corresponds to the exchange of a shell called the *mullu*, which was considered a holy object able to attract the rain (see Rostworowski, 1970). The *mullu* was collected in the South coast of Peru and the artisans who sculpted the mollusks periodically traveled to Cuzco,

Table 6

The impact of new roads on firms' exports, 2003–2010
Robustness check
IV estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
D	0.046*	0.079***	0.064***	0.056***	0.054***	0.101**	0.165***	0.171**	0.176***
	(0.025)	(0.036)	(0.019)	(0.013)	(0.015)	(0.044)	(0.064)	(0.070)	(0.057)
Department-2 digit sector fixed effects	Yes	Yes	Yes	No	No	No	No	No	No
Province-2 digit sector fixed effects	No	No	No	Yes	No	No	No	No	No
Municipality-2 digit sector fixed effects	No	No	No	No	Yes	No	No	No	No
Firm fixed effects	No	No	No	No	No	Yes	Yes	Yes	Yes
HS 2 digit product fixed effects	No	No	No	No	No	No	Yes	Yes	No
Destination fixed effects	No	No	No	No	No	No	No	Yes	No
HS 2 digit product-destination fixed effects	No	No	No	No	No	No	No	No	Yes
	First stage estimates								
Distance to the Inca road	−0.972***		−0.585***	−0.639***	−0.783***	−0.419*	−0.527***	−0.478***	−0.540***
	(0.2332)		(0.129)	(0.124)	(0.189)	(0.215)	(0.164)	(0.166)	(0.139)
Distance on the Inca Road		0.083***	0.075***	0.075***	0.076***	0.064***	0.065***	0.061***	0.043***
		(0.016)	(0.021)	(0.021)	(0.022)	(0.018)	(0.017)	(0.017)	(0.014)
Department-2 digit sector fixed effects	Yes	Yes	Yes	No	No	No	No	No	No
Province-2 digit sector fixed effects	No	No	No	Yes	No	No	No	No	No
Municipality-2 digit sector fixed effects	No	No	No	No	Yes	No	No	No	No
Firm fixed effects	No	No	No	No	No	Yes	Yes	Yes	Yes
HS 2 digit product fixed effects	No	No	No	No	No	No	Yes	Yes	No
Destination fixed effects	No	No	No	No	No	No	No	Yes	No
HS 2 digit product-destination fixed effects	No	No	No	No	No	No	No	No	Yes
F-statistic	21.643	26.3	17.041	24.628	13.024	27.915	29.795	28.635	13.866
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
KP test statistic	23.302	28.311	36.759	53.434	29.808	66.179	82.692	80.954	83.273
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Hansen test statistic			0.482	0.681	0.851	0.921	2.444	1.771	0.007
			[0.488]	[0.409]	[0.356]	[0.337]	[0.118]	[0.183]	[0.936]
Adjusted R^2	0.237	0.413	0.487	0.505	0.542	0.368	0.378	0.33	0.229
Observations	5415	5415	5415	5415	5415	5415	5415	5415	5415

Source: Authors' calculations based on data from SUNAT and MTC. The table reports IV estimates of alternative specifications of Eq. (2) along with estimates of Eq. (3) and the relevant specification test statistics for the latter. The dependent variable is the change in the natural logarithm of export value at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). The main explanatory variable is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. The latter is instrumented with the distance from the geographical origin of the export flow to the nearest Inca road and/or the distance that could have been traveled along the Inca road network from this origin to the port through which the firm exports the product to the destination country. Alternative sets of fixed effects (i.e., Department-2 digit ISIC sector; Province-2 digit ISIC sector; Municipality-2 digit ISIC sector; Firm; Firm and HS 2 digit product; Firm, HS 2 digit product, and destination; Firm and HS 2 digit product-destination) included (but not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. Test statistics and p-values based on these clustered standard errors are presented in the lower panel. The Hausman test cannot reject the null hypothesis that the OLS and the IV estimates are the same. The chi-square statistics is 2.060 and the corresponding p-value is 0.152. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

Furthermore, the Inca road network can hardly be considered to have been designed to facilitate today's exports. The mere length of time and the fundamental political, economic, and social changes occurred since the Inca era speaks in favor of using it for instrumentation purposes. The shifts in economic geography are a testimony to that fact. Thus, while Cuzco was the core of the Inca Empire, with the establishment of the Spanish colony the political and economic center moved to Lima, Peru's current capital city (see the middle panel of Fig. 3). This created an entirely new spatial and transport dynamics as goods started to be shipped from Lima (goods coming from Spain consumed by local authorities and settlers) and to Lima (goods going to Spain, primarily precious metals) (see Contreras, 2010).

Table 6 presents instrumental variables estimates of Eq. (2), estimates of Eq. (3) along with variants thereof whereby only one of the two instruments is considered at a time, and the standard specification tests. In all cases, the F-test statistic is above 10 (see Staiger and Stock, 1997) and 11.52 (see Stock and Yogo, 2005), thus suggesting that the two Inca road network-related variables are indeed correlated with recent innovations in transportation infrastructure.[44] Consistently, according to the Kleibergen–Paap (KP) test statistic, our estimation does not seem to suffer from a weak instruments problem. In addition, the Hansen test formally indicates that, after conditioning by region-sector fixed effects, our overidentifying restrictions cannot be

(*footnote continued*)
although they never actually "sold" them (see, e.g., Murra, 2002).

[44] This critical value corresponds to the bias cutoff method for a 10% maximal bias.

rejected.[45] We have also computed the fractionally resampled Anderson–Rubin test for the significance of endogenous regressors in an instrumental variables regression proposed by Berkowitz et al. (2012). This test makes it possible to conduct reliable inference when instruments are nearly exogenous but not necessarily perfectly exogenous. According to this test, the null hypothesis that the impact of infrastructure on exports is equal to zero is rejected at 5% (with a *p*-value ranging from 0.032 to 0.014 for resampled fractions between 0.20 and 0.25, respectively).[46]

The instrumental variables estimate of the coefficient of interest is positive and significant.[47] This estimated coefficient is larger than the ordinary least squares counterpart. The same results pattern holds in several related studies (see, e.g., Baum-Snow, 2007 and Duranton and Turner, 2012). Notice, however, that, in our case, a Hausman test indicates that ordinary least squares and instrumental variables estimates are not significantly different from each other.[48]

A major concern with these instrumental variable estimates is that the exclusion restriction may not hold. Thus, it might be argued that regions or cities that were large and productive in the Inca times and got a better access to the road network are still today large and productive and, accordingly, tend to export more or that there are geographical factors that may be correlated with both the Inca road network and production and exports (see, e.g., Ramcharan, 2009).[49] In this sense, note, first, that while there seems to be some relationship between relevant municipality-level variables such as population, population density, and the share of urban population and the Inca Roads variables, no association at all is observed in our sample after conditioning by region fixed effects as we do in our baseline estimations.[50] Second, to further mitigate this concern, we re-estimate the alternative specifications of the export equation that include province or municipality fixed effects combined with sector fixed effects or firm(-region-sector) fixed effects with our instrumental variables procedures. Estimation results are presented in Columns 4–9 of Table 6 and corroborate those shown before.[51]

Third, the variables related to the Inca road network might be specifically better at predicting road constructions that are important for exports. Nevertheless, the estimated coefficient of the first-stage equation as estimated on the subsample of exporting municipalities does not significantly differ from the counterpart estimated on the subsample of never exporting municipalities.[52] Finally, the road network in Peru consists of national and departmental roads, which have different purposes. Thus, national roads interconnect the country

Table 7

The impact of new roads on firm exports, 2003–2010 OLS estimates	
Channels	
Log quantity (Kg)	
D	0.028***
	(0.008)
Log unit value (US Dollars per Kg)	
D	0.005
	(0.006)
Log number of shipments	
D	0.006
	(0.005)
Log average exports per shipment (US Dollars)	
D	0.030***
	(0.006)
Log average quantity per shipment (Kg)	
D	0.034***
	(0.008)
Department-2 digit sector fixed effects	Yes
Observations	5415
Firm export extensive margin	
D	0.005
	(0.009)
Department-2 digit sector fixed effects	Yes
Adjusted R^2	0.023
Observations	8750

Source: Authors' calculations based on data from SUNAT and MTC. The upper panel of the table reports OLS of Eq. (2). The dependent variables are the change in the natural logarithm of export value, export quantity (weight), unit value, number of shipments, average exports per shipment, and average quantity (weight) per shipment at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). The main explanatory variable is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. The lower panel of the table reports OLS estimates of a modified version of Eq. (2). The dependent variable is a binary indicator that takes the value of one if a firm exported in 2010 and zero otherwise. The main explanatory variable is a binary indicator that takes the value of one if the distance over which a firm could ship their products to their (potential) main port when exporting declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. Initial and final routes are identified based on the ports used by exporting firms that belong to the same sector and are located in the same province. The estimating sample consists of all active firms belonging to tradable sectors that did no export in 2003. Department-2 digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. *Significant at the 10% level; **Significant at the 5% level;
*** Significant at the 1% level.

[45] The tests for overidentifying restrictions is a test of joint-exogeneity and, as such, do not strictly provide information on the validity of the instruments, but on their coherence, i.e., whether they identify the same vector of parameters (see Parente and Santos Silva, 2012).

[46] This is the range of the resampling block sizes for which the test exhibits best size and power properties (see Riquelme et al., 2013). Test statistics are presented in Table A.10.1 in the online Appendix.

[47] Estimation results based on the specification exploiting the change in (the natural logarithm of) the road distance convey exactly the same message. Furthermore, these results are robust to alternative clustering of standard errors. These alternative estimates are reported in Table A.11.1 in the online Appendix.

[48] See notes in Table 6.

[49] Roughness imposes severe challenges to development and maintenance of transport networks. In fact, according to recent estimates, a 1% increase in roughness is associated with about 1% decline in the number of kilometers of roadway (see Ramcharan, 2009).

[50] See Table A.12.1 in the online Appendix.

[51] New roads may have facilitated not only exporting, but also sourcing of inputs used to produce the goods that are sold abroad. Thus, to the extent that this is not fully controlled for by the set of fixed effects, our estimates would be capturing the direct effects of transport infrastructure on exports plus its impact on input sourcing. We therefore restrict the estimating sample to those firms whose increases in import values, import quantities, number of imported products, number of origin countries, and number of entry ports between 2003 and 2010 were below the respective medians. Results from these estimations are shown in Table A.13.1 in the online Appendix. These results do not significantly differ from the baseline.

[52] These estimation results are presented in Table A.14.1 in the online Appendix.

longitudinally and transversely to allow for transport and commercial links with neighboring nations, connect the departments' capitals with each other and the main production and consumption centers, and articulate national and international ports and airports as well as railways. The departmental roads link the departmental capitals with the provincial capitals, each of these capitals with each other, and municipalities in different provinces enabling the circulation of people and goods at the regional level, and articulate regional ports and airports (see MTC, 2005, 2010, 2011 and Zecerrano Mateus, 2011). Clearly, national roads play a more important, direct role for foreign trade. We therefore re-estimate Eq. (2) on a sample that excludes all observations with new national road segments. Also in this case, these estimates are in line with our benchmark ordinary least squares and instrumental variables estimations.[53]

In closing this subsection, we should stress that, even though our instrumental variables estimates appear to be seemingly convincing, they cannot be considered enough to establish causality by themselves because the exclusion restriction could be allegedly potentially violated even after including different sets of fixed effects.[54]

3.4. Channels and the extensive margin

Our data also allow us to explore the channels through which effects arise. In particular, we estimate the impact of new roads on the quantity (weight) shipped, the unit values, the number of shipments, and the average value and quantity per shipment, based on Eq. (2). Estimation results are presented in the upper panel of Table 7. These results reveal that expansion in transport infrastructure, by leading to decreased distances to ports and therewith to lower transport costs, has translated into larger shipments and thereby into increasing quantities shipped, but has not influenced unit values.

Up to this point, we have primarily focused on the export intensive margin (i.e., continuing flows). Increased transport infrastructure might have also helped some firms start exporting. Hence, we also examine the effect of changes in available roads on the firm export extensive margin by estimating a linear probability model paralleling Eq. (2) in which the dependent variable is a binary indicator that takes the value of one if the firm began to export in 2010 and zero otherwise, on the sample of active firms belonging to tradable sectors that did no export in 2003.[55] Estimation results are reported in the lower panel of Table 7. According to these results, road infrastructure innovations do not seem to have had a significant impact on firm entry into foreign markets.[56] This is confirmed when we estimate Eq. (2) on data at the municipality-sector-product-destination level and use as a dependent variable the number of firms exporting a product to a destination in a given municipality-sector pair.[57]

3.5. General equilibrium effects

The positive effects of transport infrastructure on exports revealed by our estimations can originate from increases in firms' foreign sales whose distance to the respective main port declined as a consequence of the roads built during our sample period without other firms' foreign sales being affected. In this case, aggregate exports would have experienced a net expansion. However, such estimated effects could be also observed if these larger exports from firms getting new roads would be at the expense of those from counterparts that are not beneficiaries of the infrastructure projects. In the extreme scenario in which both compensate, a mere redistribution of exports across firms would have taken place and total exports would have not changed. Given their different implications for the economy as a whole, it is crucial for a proper evaluation of infrastructure investments to establish whether and to what extent they cause changes in the level of exports vis-a-vis a simple reallocation across economic units.

Assuming that the aforementioned externalities are restricted to the same municipality or the same province and are specific to foreign sales of given products (e.g., HS 4 digit products to allow potential substitutability across finely defined HS 6 digit goods belonging to a given HS 4 digit category), we do so by estimating our differenced Eq. (2) on alternative subsamples that involve comparisons between (1) exports with shorter routes to ports ("treated") and their counterparts in the same municipality/province without changes in their roads exporting the same HS4 products ("untreated"); (2) "treated" exports and those from other municipalities or provinces without changes in their roads exporting other HS 4 digit products ("residual"); and (3) "untreated" and "residual" exports (see Redding and Turner, 2014). Alternatively, to avoid the arbitrariness implicit in administrative divisions, externalities can be assumed to be similarly localized but in terms of distance ranges (e.g., 100 or 300 km). Keeping in mind that these exercises critically depend on the assumptions regarding the nature of the spillovers and that they should accordingly be taken as indicative, we present the estimates of these equations in Table 8. Estimates point to no significant differences between "untreated" and "residual" both with each other and relative to "treated" export flows. This would suggest that improvements in domestic transport infrastructure seem to have had a net positive effect on country's exports of differentiated products.

Moreover, better roads for some exports might have directly affected the survival of similar exports coming from nearby areas without improved transport infrastructure. In order to investigate whether such full crowding out took place, we estimate a linear probability model on the sample of firm-product-destinations flows existing in 2003 separately for "treated" and "untreated" observations and "treated" and "residual" observations, whereby the dependent variable is a binary indicator taking the value of one if the export flow is present in 2010 and zero otherwise and the explanatory variable is a binary indicator taking the value of one if exports could be shipped to the port along a shorter route thanks to the new roads built from 2003 to 2010 and zero otherwise, and region-sector fixed effects.[58] In addition, survival of "untreated" and "residual" export flows could be compared by estimating a similar linear probability model but on the sample of firm-product-destinations flows existing in 2003 with no change in routes in subsequent years and using as the main explanatory variable a binary indicator that takes the value of one if there is at least an export flow with improved access to port within a given geographical unit or within a certain distance and zero otherwise (or their number). Again, there is no evidence that the infrastructure investment treatment has benefited some export flows at the price of

[53] These estimation results are reported in Table A.15.1 in the online Appendix.

[54] According to Eqs. (2) and (3), we are instrumenting changes in the road network between 2003 and 2010 with the Inca road network. If this latter network is correlated with the initial road network in 2003 due to historical persistence (e.g., Maloney and Valencia Caicedo, 2012; Michaels and Rauch, 2013), then we would be basically instrumenting the change in transport infrastructure with its initial level. In this Arellano–Bond type of estimation, a key identifying assumption is that the factors explaining the initial levels do not explain the future changes conditional on the fixed effects included. This condition may not hold in our case.

[55] The main explanatory variable is, as before, the binary indicator of changes in available transport infrastructure. Initial and final routes of these non-exporting firms are primarily identified based on the main ports used by their exporting counterparts that are located in the same province and belong to the same sector.

[56] In the same vein, it might be thought that increased firms' exports thanks to infrastructure improvements may have favored the creation of other firms through backward linkages. Estimates of a similar equation in which the dependent variable is the change in the natural logarithm of the number of active firms in a municipality-sector pair over the sample period and zero otherwise do not provide support to this hypothesis (see Table A.16.1 in the online Appendix).

[57] Table A.17.1 in the online Appendix reports estimates obtained using data at the municipality-sector-product-destination level.

[58] Estimation results are similar if we instead include firm and product-destination fixed effects. These alternative estimation results are available from the authors upon request.

Table 8

The impact of new roads on firm exports, 2003–2010
General equilibrium effects
OLS estimates

Assumption 1: Externalities are restricted to a given municipality/province and are specific to given product categories

	Treated vs. untreated		Treated vs. residual		Untreated vs. residual	
	Same HS4 and same		Different HS4 and different			
	Municipality	Province	Municipality	Province	Municipality	Province
D	0.074*** (0.018)	0.060*** (0.017)	0.050*** (0.019)	0.054** (0.021)	−0.014 (0.011)	0.010 (0.014)
Department-2 digit sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.094	0.060	0.043	0.058	0.042	0.041
Observations	1701	3209	4421	2913	4722	4725

Assumption 2: Externalities are restricted to a given geographical area and are specific to given product categories

	Treated vs. untreated		Treated vs. residual		Untreated vs. residual	
	Same HS4 and Distance <		Different HS4 and distance =>		Distance	
	100	300	100	300	100	300
D	0.040*** (0.009)	0.038*** (0.009)	0.033*** (0.010)	0.036** (0.013)	0.000 (0.001)	0.003 (0.009)
Department-2 digit sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.070	0.055	0.050	0.056	0.039	0.042
Observations	2811	3197	3331	2945	4078	4037

Source: Authors' calculations based on data from SUNAT and MTC. The table reports OLS estimates of Eq. (2). The dependent variable is the average annual change in the natural logarithm of export value at the firm-product-country level between 2003 and 2010. Exports consist exclusively of differentiated goods. Goods are classified as differentiated using the conservative version of the classification proposed by Rauch (1999). The main explanatory variable is a binary indicator that takes the value of one if the distance over which a firm shipped their products to their main port when exporting to a given country declined between 2003 and 2010 as a consequence of the new roads built in this period and zero otherwise. The different samples are defined to compare "treated" vs. "untreated", "treated" vs. "residual", and "untreated" vs. "residual". In the upper panel of the table, "untreated" are defined as those firm-product-destination exports that did not experience any change in their roads to the respective main port between 2003 and 2010 and stemmed from the same municipality or the same province and consist of the same HS 4 digit products as those of counterparts that did experience a reduction in their distance to the respective main port thanks to new roads built between 2003 and 2010 (Columns 1 and 2, respectively), whereas "residual" are defined as those firm-product-destination exports that did not experience any change in their roads to the respective main port between 2003 and 2010 and stemmed other municipalities or other provinces and consist of HS 4 digit products that are different from those of counterparts that did experience a reduction in their distance to the respective main port thanks to new roads built between 2003 and 2010 (Columns 3 and 4, respectively). In the lower panel, "untreated" are defined as those firm-product-destination exports that did not experience any change in their roads to the respective main port between 2003 and 2010 and stemmed from locations within 100 (300) kilometers around and consist of the same HS 4 digit products as those of counterparts that did experience a reduction in their distance to the respective main port thanks to new roads built between 2003 and 2010 (Columns 1 and 2, respectively), whereas "residual" are defined as those firm-product-destination exports that did not experience any change in their roads to the respective main port between 2003 and 2010 and stemmed from locations at or at more than 100 (300) kilometers and consist of HS 4 digit products that are different from those of counterparts that did experience a reduction in their distance to the respective main port thanks to new roads built between 2003 and 2010 (Columns 3 and 4, respectively). Department-2 digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported below the estimated coefficients. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

pushing others out of international markets.[59] We now turn to the effect of exports on employment.

4. From exports to employment

The previous section has established that improved domestic road infrastructure is associated with increased firms' exports. In this section, we build upon these findings to explore to what extent these increased exports lead to employment growth.[60] There are important challenges to identification of a causal relationship between these variables as several factors can affect firms' employment. Despite these limitations, we believe that this byproduct analysis can provide interesting insights on the broader economic (non-strictly trade) implications of infrastructure investments as typically argued in national export plans.

In carrying out this analysis, we assume the following empirical model of employment:

$$\ln L_{frs}(t) = \beta \ln X_{frs}(t) + \gamma_{frs} + \pi_{rs}(t) + v_{frs}(t) \quad (4)$$

where L corresponds to the firms' number of employees and X to firms' total export value. The remaining terms of Eq. (4) are control variables. Thus, γ_{frs} is primarily a set of firm fixed effects that captures, for instance, firm's productivity and other firm-level factors that are constant over time; $\pi_{rs}(t)$ is a set of region-sector-year fixed effects that controls for potential region-sector time varying factors such as

[59] See Table A.18.1 in the online Appendix.
[60] Unfortunately, we do not have firm-level data on production or sales.

labor market frictions, labor participation rates, wage differential across region-sectors, and public policies (e.g., subsidies to SMEs) aimed at promoting employment in particular sectors in certain departments (see, e.g., (INEI, 2011)); and $v_{frs}(t)$ is the error term.[61]

As before, we first-differentiate Eq. (4) to eliminate the firm-region-sector fixed effects. Thus, we estimate the following baseline employment equation:

$$\Delta \ln L'_{frs} = \beta \Delta \ln X'_{frs} + \pi'_{rs} + v'_{frs} \tag{5}$$

where the dependent variable is the annual average log change in the firms' number of employees: $\Delta \ln L'_{frs} \equiv [\ln L_{frs}(2010) - \ln L_{frs}(2003)]/7$; the main explanatory variable is the annual average log change in exports: $\Delta \ln X'_{frs} \equiv [\ln X_{frs}(2010) - \ln X_{frs}(2003)]/7$; $\pi'_{rs} = \pi_{rs}(2010) - \pi_{rs}(2003)$ absorbs all region-sector shocks; and $v'_{frs} = v_{frs}(2010) - v_{frs}(2003)$.

Clearly, exports can be endogenous to employment. Hence, we alternatively instrument them with the predicted values derived from our previous ordinary least squares or instrumental variables estimations of Eq. (2).[62] Note that, after conditioning on region-sector fixed effects, these predicted values are primarily driven by the change in road infrastructure. Under the assumption that is change in infrastructure is exogenous either directly or once instrumented with the distance to and on the Inca Roads, the implied variation in exports can then be used to identify the impact of infrastructure-related exports on employment at the firm level.

More precisely, we first compute the predicted export values for each firm-product-country from Eq. (2) using the estimated coefficients reported in Tables 2 and 4. These predicted values can be summed over product-destinations to arrive at a prediction for the change in firm-level exports (see, e.g., Frankel and Romer, 1999; and Feyrer, 2009). Formally, we obtain a prediction for the total logarithmic export change for each firm as follows:

$$\widehat{\Delta \ln X_{frs}} = \hat{\pi}'_{rs} + \hat{\alpha} \sum_{f,pc} \frac{x_{frspc}(2003)}{\sum_{f,pc} x_{frspc}(2003)} D_{fpc}(2010) \tag{6}$$

We then use the annual average predicted value as the instrument for actual annual average export change in estimating Eq. (5) by instrumental variables.[63] Because the first-differenced firm-level employment equation includes region-sector fixed effects, the identification comes from the within region-section variation and, hence, is not generated by these effects.[64] A possible concern with our specification is that our instrument does not satisfy the exclusion restriction. In order for this restriction to be fulfilled, we need that, after conditioning on region-sector fixed effects, infrastructure only affects employment through exports instead of directly via alternative mechanisms. An informal way to assess whether this is the case is to include the infrastructure improvement indicator D as an additional separate explanatory variable. It turns out that the change in infrastructure has a non-significant and virtually null effect on employment growth (see Table 9). This suggests that most of the employment effect of the new roads is going specifically through exports as opposed to other channels (e.g., domestic trade, migration, etc.).

Table 9 reports ordinary least squares and instrumental variable estimates of Eq. (5) and variants thereof, also accompanied in this case by the first-stage results and the specification test corresponding to the latter for years 2003–2010. The F-test statistic as well as the under-identification test statistic indicate that our instruments are relevant. The estimated ordinary least squares coefficient indicates that increased exports are indeed associated with employment growth.

Importantly, the instrumental variable estimate reaffirms the conclusion we draw from the OLS estimate. In fact, these estimates are not statistically different from each other. These estimates specifically suggest that a 10% increase in (the rate of growth of) exports—driven by improved transport infrastructure—leads to a 3% increase in the (rate of growth of the) number of employees. This estimated elasticity is remarkably similar to that estimated in Park et al. (2010) on a sample of Chinese firms over the period 1995–2000 using exchange rate shocks as instruments for changes in exports.

As a robustness exercise, we re-estimate Eq. (5) using as an additional instrument the weighted average change in the GDP of exporting firms' destination countries between 2003 and 2010 where the weights are the share of these countries in the firms' total exports in the initial year.[65] Results from this estimation are reported in Columns 4 to 6 of Table 9. These results are in line with those discussed above and, importantly, pass all specification tests.[66] Note, however, that the same concerns regarding the possible violation of the exclusion restriction discussed when presenting the instrumental variables estimated impact of road infrastructure on exports, also apply here. In particular, either the new roads or the Inca roads can conceivably affect current firms' employment through channels other firms' foreign sales.

In closing and having these caveats in mind, we use the previous estimations along with the firm-level data at hand to provide some quantification of the export-related impact of road infrastructure on employment. First, firms-product-destinations that saw their distances to the main ports reduced have registered an average (logarithmic) export growth of 87.1% between 2003 and 2010. Based on the estimates of the export equation in long differences, 25.9% of this growth can be attributed to domestic transport infrastructure improvements. Long differences equivalents to estimates presented in Table 9 then imply that employment would have grown by 6% in the aforementioned companies as a consequence of the increased exports that the construction of the new roads allowed for. Further, given that the (logarithmic) growth of the total number of employees of these companies was 57% and that around 23% of this growth can be traced back to increased foreign sales, this would mean that infrastructure-driven exports accounts for approximately 4% of the (net) new jobs that

[61] Exporting firms are formal. Accordingly, they are registered with the tax agency and pay taxes. Nevertheless, they might have shares of registered employees smaller than one, i.e., some of their workers might be informal. As a consequence, changes in the level of formal employment may originate from actual hiring of new employees as well as from formalization of previously informal workers. Even though the existing empirical evidence points to a complex pattern of co-movement between the degree of formalization and macroeconomic fluctuations, the former may be thought to increase when the economy is growing, such as in Peru over the sample period (see, e.g., Fiess et al., 2010 and Loayza and Rigolini, 2011). Hence, this might potentially explain at least part of the changes observed in the number of employees. Note, however, that as along as changes in formality are region-sector specific, as it is most likely the case, the region-sector fixed effects included in the estimating equation would account for them.

[62] In the instrumental variables variant, the region-sector fixed effects account for employment changes in firms located in specific regions and belonging to specific sectors that might potentially be related to certain regional or sectoral characteristics directly correlated with the distance to or the distance that could have been traveled on the Inca Roads or with determinants of their geographical location.

[63] When using predicted values from an instrumental variables estimation as we do here, it can be ignored that the instrument was estimated in using instrumental variables for inference (see Wooldridge, 2002).

[64] New Economic Geography models predict that reduced transport costs may foster labor migration across regions, which can affect local labor markets (see, e.g., Krugman, 1991). This might create a challenge to our estimation of the employment effects of exports. However, if anything, internal migration in Peru has declined over the sample period, both in relative and absolute terms (see, e.g., INEI, 2009). Further, as mentioned above, the region-sector fixed effects are likely to control for most of the relevant changes in migration across regions.

[65] This instrumenting strategy is similar in spirit to that implemented by Park et al. (2010) who use the change in destination countries' exchange rates weighted by the share of these countries in initial firms' total exports as an instrument for exports when estimating their effects on other firms' performance variables such as employment.

[66] The estimated employment equation and the overidentification test in particular might suggest that new roads have primarily affected employment through their impact on exports rather than through domestic demand. This may be the case if relatively good roads were already available to sell in Peruvian main economic centers such as Lima, but those recently constructed also made it possible to sell more abroad. Unfortunately, data required to establish whether this has been actually the case are not available.

Table 9

The impact of exports on firms' employment, 2003–2010
OLS and IV estimates

	OLS	OLS	IV	IV	IV	IV	IV
χ	0.033***	0.032***	0.030***	0.030***	0.042***	0.038***	0.038***
	(0.003)	(0.002)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)
D		0.0016					
		(0.004)					
Department-2 digit sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.256	0.242					
			First stage estimates				
Predicted exports			0.171***	0.133***		0.179***	0.176***
			(0.015)	(0.013)		(0.016)	(0.049)
GDP destination change 2003–2010					2.711***	2.777***	2.746***
					(0.153)	(0.157)	(0.512)
Department-2 digit sector fixed effects			Yes	Yes	Yes	Yes	Yes
F-Statistic			170.254	11.932	202.369	246.847	20.826
			[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
KP test statistic			150.333	14.076	385.326	638.221	49.152
			[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Hansen test statistic						0.852	0.194
						[0.356]	[0.659]
Adjusted R^2			0.043	0.023	0.041	0.086	0.079
Observations	604	604	604	604	604	604	604

Source: Authors' calculations based on data from SUNAT and MTC. The table reports OLS and IV estimates of Eq. (5) along with the first stage estimates and the relevant specification test statistics for the latter. The dependent variable is the average annual change in the natural logarithm of a firm's number of employees between 2003 and 2010. The main explanatory variable is the average annual change in the natural logarithm of a firm's exports between the same years. In the IV estimations, the latter is instrumented with the predicted value of this change as estimated by OLS and IV based on Eq. (2) (Columns 2 and 3, respectively) and/or the weighted average change in the GDP of firms' destination countries over the period 2003–2010, where the weighting factor is the share of each of these countries in the firms' total exports in 2003 (Columns 4 to 6). Department-2 digit ISIC sector fixed effects are included (but not reported). Standard errors clustered by department are reported in parentheses below the estimated coefficients. *P*-values based on these standard errors are reported below the respective tests statistics. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 5% level.

exports created between 2003 and 2010.

To sum up, our econometric results provide robust evidence that increased road infrastructure, by reducing the distance that shipments must be transported along to the respective main ports and hence the incurred transport costs, translated into larger firms' exports and therewith seem to have actually contributed to job growth in benefited companies.

5. Concluding remarks

Public investments in transportation infrastructure are often justified by arguing that resulting new roads (or improved roads) would help firms expand their exports. Larger foreign sales would then lead to more jobs. However, whether and to what extent this presumption finds support in reality is virtually unknown. In this paper, we address this relevant policy question, thereby filling a notorious gap in the literature. We primarily examine the effects of new roads constructed in Peru between 2003 and 2010 on firms' exports. In addition, we explore the subsequent impact on employment. In so doing, we exploit a rich dataset consisting of the universe of export transactions of differentiated goods in these years and detailed geo-referenced information on the road network. Also important, we address potential endogeneity of new road infrastructure by including extensive sets of fixed effects that control for a myriad of possible unobserved confounders and, in robustness checks, by performing placebo tests and by resorting to an instrumental variables approach that uses the Inca Roads as instruments. Results consistently suggest that new roads have made possible increased firms' exports. Further, this deepened penetration of foreign markets seems to have in fact been associated with higher employment.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jdeveco.2016.10.002.

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