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Trade and Infrastructure Integration in Africa

Lionel Fontagné
Mathilde Lebrand
Siobhan Murray
Michele Ruta
Gianluca Santoni

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Abstract

Economic integration of the African continent rests on two pillars: the ratification of an ambitious trade agreement and massive investment in transportation infrastructure. Leveraging a newly created city-level database on African exporters' transport times, transport route optimization and general equilibrium modeling of international trade, the paper quantifies the impact of greater trade and transport integration in Africa. A pan-African agreement, such as the African Continental Free Trade Area, would increase African countries' exports by an average of 3.4 percent and increase gross domestic product by 0.6 percent. Complementing trade integration by reducing transportation time on roads, ports and border posts would increase exports by 11.5 percent and increase gross domestic product by 2 percent. Major transport investments are necessary to reap the full benefits of the African Continental Free Trade Area.

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Trade and Infrastructure Integration in Africa*

Lionel Fontagné (Bank of France, CEPII and PSE)† Mathilde Lebrand (World Bank)‡
Siobhan Murray (World Bank)§ Michele Ruta (IMF)¶ Gianluca Santoni (CEPII)‖

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†lionel.fontagne@banque-france.fr.
‡Email: mlebrand@worldbank.org.
§Email: smurray@worldbank.org.
¶Email: mruta@imf.org.
‖Email: gianluca.santoni@cepii.fr

Introduction

Economic integration of the African continent rests on two pillars: large investments in transportation infrastructure and the ratification of an ambitious pan-African trade agreement. Both aim at reducing barriers to trade, but in different ways. Better transport infrastructure reduce transport costs between African countries and between them and the rest of the world, and trade facilitation programs reduce queuing times at borders. Preferential trade agreements (PTA) reduce frictions directly between trading partners by reducing tariffs and harmonizing policies on e-commerce, investment, and intellectual property. Infrastructure improvements and trade reforms are therefore potentially complementary: reducing trade frictions alone may not be sufficient if the contracting parties are poorly connected; similarly, improving infrastructure connectivity alone may not be sufficient in the presence of trade barriers (tariff and non-tariff). The contribution of this paper is to address the question of how the effects of both pillars of integration operate in combination using granular data on transport infrastructure, information on the depth of regional trade agreements and general equilibrium trade modeling.

To quantify the joint impact of trade reforms and infrastructure investment in Africa, we first build a new city-level database of travel times using a geographic information system (GIS). We map the current infrastructure and border delays for the entire continent (both within Africa and between Africa and the rest of the world). We then add the infrastructure projects as listed in the Program for Infrastructure Development in Africa (PIDA) and assess their impacts on reducing transportation times. For trade policy, we rely on data from the World Bank's Deep Trade Agreements database (Mattoo, Rocha & Ruta 2020); which contains detailed information on the content of trade agreements on a range of topics, including competition policy, investment, capital movements, and intellectual property rights protection. We follow the cluster analysis on the distribution of provisions done by Fontagné, Rocha, Ruta & Santoni (2023) to sort the agreements according to their ambition into Shallow, Medium, and Deep treaties. We use both datasets to quantify the combined trade and welfare impacts of the infrastructure investments as planned in the PIDA and an ambitious (i.e., Deep) trade agreement for the African continent.

We quantify the impacts in four steps. First, we estimate a structural gravity model (Anderson & van Wincoop 2003) in which we include the level of ambition in trade agreements to explain bilateral trade flows. We include both domestic and international trade flows, as well as the trade deflection effect due to border crossings (an inverse measure of deepening globalization).

Second, we give a functional form to the unobserved bilateral component that depends on transportation time, contiguity, language proximity, past colonial relations, and other unobservable country characteristics for the year 2018. This strategy allows us to determine the elasticity of domestic and international sales to transportation time.

Third, after verifying that the elasticity resulting from our data is consistent with estimates widely used in the literature (Hummels 2007, Hummels & Schaur 2013), we quantify the effect of planned infrastructure investments on transportation.

As a fourth and final step, we construct counterfactuals for trade policy and the transportation network. For infrastructure, we construct two alternative transportation networks based on the projected investments for roads alone and for the combination of roads, ports and land borders. For each of these networks we obtain a new matrix of transport times between African countries and with the rest of the world. On trade policy, we consolidate the various existing trade agreements in Africa into a new "ambitious" trade agreement, such as the African Continental Free Trade Area (AfCFTA). Then we simulate the single and combined impact of these reforms on trade and gross domestic product of African economies. We show that an ambitious trade agreement would increase African countries' exports by an average of 3.6 percent and their GDP by 0.6 percent. Complementing trade integration by reducing transportation time on roads, ports and border posts would increase exports by 11.5 percent and GDP by 2 percent. These results suggest that infrastructure improvements are essential to reap the full benefits of the AfCFTA.

Our paper draws on several strands of research. First, there is a growing body of literature that examines the impact of transportation infrastructure projects on transportation costs, including Donaldson & Hornbeck (2016), Donaldson (2018), Fajgelbaum & Redding (2022), Allen & Arkolakis (2022), and Fan, Lu & Luo (2023). While most of this research focuses on one country and one transportation network, our work covers most African countries (and the rest of the world) and considers roads, ports and land borders simultaneously. A related stream of research examines the impact of transportation costs on exports as mediated by infrastructure, (Limao & Venables 2001, Martincus, Carballo & Cusolito 2017).[1]

A second strand of literature aims to quantify the income gains from new transportation infrastructure using general equilibrium models of trade (Coşar & Fajgelbaum 2016, Fajgelbaum & Schaal 2020). We use on a general equilibrium model of an endowment economy to uncover the trade and income effects of a fall in the cost of trade that induces a reshaping of the geography of trade flows. This fall in the trade cost is the result of a combination of regulatory change (a regional trade agreement) and infrastructure investment.

Third, trade models have been used extensively to quantify the effects of trade agreements (see Limão 2016 for a survey), including recent Structural Gravity General Equilibrium models (Anderson & Yotov 2016, Fontagné & Santoni 2021, Fontagné et al. 2023), New Quantitative Trade Models (Costinot & Rodríguez-Clare 2014, Caliendo & Parro 2015) and Computable General Equilibrium models.[2] While most papers examine the impact of infrastructure investment and trade reforms in isolation, we quantify their combined impact for Africa.

Finally, by combining GIS analysis and trade modeling, our work relates to a final stream of research that uses granular geographic data to shed light on the consequences of major infrastructure projects. The analysis of China's Belt and Road Initiative is a recent and striking example of this (de Soyres, Mulabdic & Ruta 2020, Baniya, Rocha & Ruta 2020, Bird, Lebrand & Venables 2020, Lall & Lebrand 2020). We depart from the latter works in three ways: (i) we extend the transportation network developed by de Soyres, Mulabdic, Murray, Rocha & Ruta (2019) to the entire African continent for both regional and international transportation; this provides us with an ideal setup for quantifying the effect of a change in relative trade costs. (ii) We expand the types of transportation projects analyzed. (iii) We use a structural gravity general equilibrium approach

[1] A related but distinct line of research studies the impact of infrastructure development on allocative efficiency in developing economies. Asturias, García-Santana & Ramos (2019) use plant-level data and focus on domestic sales in India, while we use multi-country aggregate data and consider domestic and international sales.

[2] Examples of recent applications of New Quantitative Trade Model (NQTM) and Computable General Equilibrium models (CGE) to the Africa region are presented in the following studies Abrego, Amado, Gursoy, Nicholls & Perez-Saiz (2019) (for NQTM) and Bengoa, Mathur, Narayanan & Norberg (2021), World Bank (2020), African Development Bank (2019) (for CGE).

to study the effects of "deep" integration through preferential trade agreements combined with infrastructure investment. More generally, our work is also related to the findings of Goldberg & Reed (2022) on the role of demand constraints in national development and, in particular, on how these constraints can be alleviated through international market integration.

The remainder of the paper is organized as follows. Section 1 describes the data used in the analysis. Section 2 presents the ex-post quantification of the trade effects of trade and transport reforms in Africa. Section 3 quantifies the impact of planned infrastructure investments on transport time. Section 4 presents a general equilibrium counterfactual analysis. Concluding remarks follow.

1 Data overview

Analyzing trade and infrastructure in a general equilibrium structural gravity framework requires specific data. The focus of this section is the development and validation of an original dataset on transport times of African exporters. Built using Geographic Information System tools and network analysis, it provides a detailed, fine-scale perspective on transport times. Given the critical role that transport times play in shaping trade patterns, the production of such data is a contribution in its own right. We also discuss the sources of trade and production data and how we combined them to get an accurate picture of domestic and international trade flows.

1.1 Transportation Time

Transportation times become prohibitive not only when roads are in poor condition, but also when there are delays at borders or operations at ports are inefficient. To get a complete picture of transportation costs for African exporters, we take all these aspects into account and construct a new database of transportation times at the city level. We first map the current infrastructure network to obtain our baseline transport time matrix. We then use the list of investments from the Infrastructure Development Program for Africa (PIDA) in its long-term vision (2012-2040) to create our counterfactual.

We start by mapping the current transportation network to calculate transportation times between large cities in African countries and the rest of the world. The nodes in the global network, which serve as export destinations in the analysis, are all cities (worldwide) with a population over 500,000 and the two most populous cities, data permitting, in each African country. This gives a total of 1,037 cities connected to the transportation network and 32 cities with a population of less than 50,000. The subset for Africa includes 165 connected cities that serve not only as destinations but also as export origins. The final network is solved for each origin-destination pair, and routing is determined by the shortest path, adjusting for a maritime preference parameter.

The construction of the transportation network at the city level proceeds as follows.[3] We first build a transportation network for Africa and the rest of the world that includes land and maritime connections. For Africa, we rely primarily on major roads from Open-Street Map, including different classes of roads for which we assume different speeds (see Table A1 in the Appendix). For the rest of the world, we use the land and maritime

[3] To be compatible with trade data, the city-level network is then aggregated to the country level using a theoretically consistent approach. The aggregation procedure, following Hinz (2017), is described in detail below.

networks and speed assumptions from de Soyres et al. (2019). In doing so, we limit the analysis to road and maritime routes for shipments within Africa, while considering rail and maritime connections for shipments to the rest of the world.[4] Two main reasons justify this approach. First, road is by far the main transport mode for trade within Africa, while most international trade in the rest of the world travels by sea and by rail.[5] Maritime shipping accounts for 80% in volume and 70% in value of global trade and rail is the second transportation mode used (International Transport Forum 2017). Second, most transport reforms in Africa included in the PIDA, as discussed in detail in section 3, consist of road and maritime infrastructure investments. This approach allows us to incorporate most of PIDA's proposed interventions.

We then integrate the land transport network by including delays at (land and sea) borders and cargo loading and unloading times at seaports. For this purpose, we first use the World Bank's Doing Business indicators, which provide country-level information on the ease of crossing land or sea borders by measuring the number of documents required to trade, days to cross the border, and costs associated with exporting and importing.[6] We limit our analysis to waiting times to import and export for the latest year available in the dataset. If a country has a maritime gateway, we consider both delays at the land border and delays at the maritime border.

For each country, we define both land and sea border delays if the country is coastal and only land border delays if the country is landlocked. Because data are reported only for the most used gateway per country, which for coastal countries is generally a port, we assume that unobserved land-border times are a fraction of reported sea-border times.[7] In addition to delays at the maritime border, ships may experience additional delays for loading and unloading, which we calibrate using the median number of days container ships stay in ports, derived from UNCTAD data.[8]

Finally, to combine data on land borders and port delays, we rely on the following assumptions. (i) Trucks crossing a border must pass through customs in the country of departure and the country of arrival (total crossing times are equal to the sum of times at the border of departure and the border of arrival). (ii) Export and import procedures at sea borders add up to logistics delays at ports (total times at sea borders are the sum of the country's sea clearance time plus delays at ports).

In order to reduce border delays, several countries have implemented One-Stop-Border Posts (OSBP) to enable goods, people, and vehicles to stop in a single facility in which they undergo necessary controls to exit one state and enter the adjoining state. We include such facilities using maps and status information from the PIDA dashboard which includes up-to-date implementation status and various sources (World Bank reports

[4] Air transport is likely to be the preferred option for perishable goods, especially flowers (HS06) or vegetables (HS07). These goods represent less than 0.04 percent of an African country's total exports in 2018. If all chapters from HS01 to HS08 are considered as perishable goods, the share is still less than 0.09 per cent.

[5] The prevalence of roads as a mode of transportation is also reflected in the PIDA action plan, where most of the priority transportation projects concern the road network (or a combination of roads and borders). Railways, on the other hand, are typically associated with port hub development, except for the Djibouti-Addis corridor and the Kinshasa-Brazzaville road-rail bridge project. We also prioritize road transport because the rail network in Africa is composed of several disconnected components with heterogeneous market sizes, making them difficult to compare.

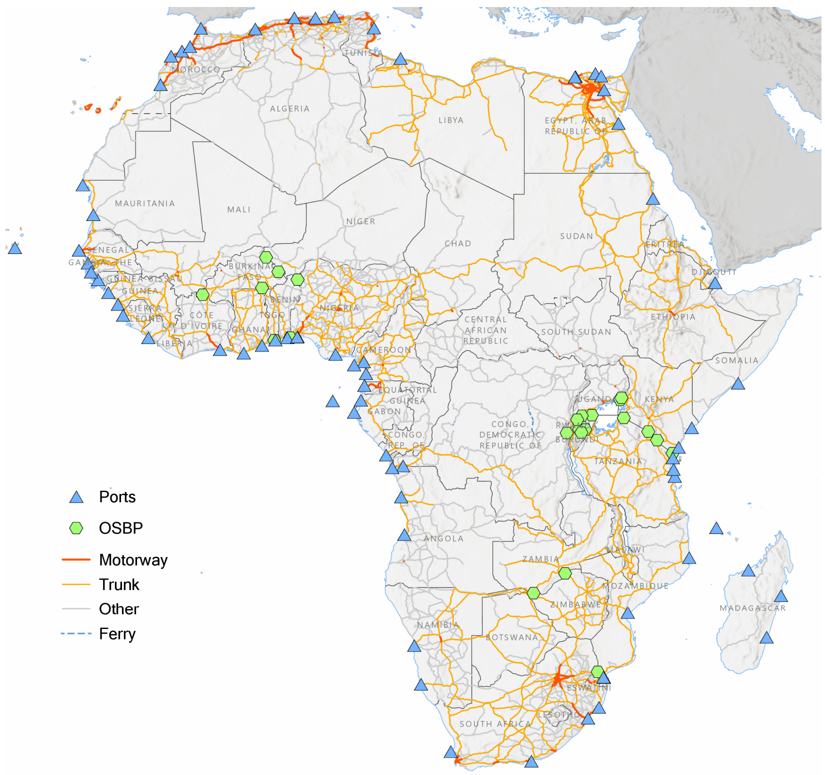
[6] Note that we use border compliance time and do not include export documentation compliance (which is a one-time cost). Whether the country of entry is the final destination of the shipment or just a transit point, the border compliance time is the same. There may be a risk of overestimating border compliance time for transit shipments. However, in a non-free trade zone, it is not obvious that transit trucks would have less wait time than trucks arriving at their final destination. In the context of a broad study of Africa, using a single border wait time seems a safe simplifying assumption.

[7] Details can be found in Table A2 in the Appendix A.

[8] UNCATD reports ship dwell time at ports, this information is constructed from Maritime Traffic data and can be accessed here: `https://unctadstat.unctad.org/wds/TableViewer/tableView.aspx`

and the 2016 One-Stop Border Post Sourcebook from NEPAD/ADB/ICA/JICA) on current, in construction, and planned One-Stop-Border Posts for Africa. We assume that land border delays are reduced by half when a functioning One-Stop-Border Post allows trucks to stop at only one facility instead of two. Figure 1 shows the different road types included in the major road network in Africa, the location of ports and currently active One-Stop Border Posts.[9]

Figure 1: Existing transportation with roads, ports and border posts.



Note: Authors' network based on OSM road networks and locations of ports and OSBP (i.e. One-Stop-Border Posts) according to available information detailed in Appendix.

The choice of transport mode is difficult to model and is subject to different trade-offs specific to each sector. As expected, given the very low speed of maritime connections, most routes with a land-based alternative do not use maritime segments. Similar to de Soyres et al. (2019), to account for the very high share of maritime transport in international trade, we run the baseline twice: without any constraints and then with a preference for maritime routes. Within the optimal path algorithm, this preference is implemented as follows: for each city pair with access to both a maritime and a rail link, the algorithm selects the maritime option whenever the shipping time is less than four times the shipping time using the rail link.[10] The final network is then processed through an optimal routing algorithm, which isolates the shortest path for each city pair.[11]

[9] The rest of the transport network for locations outside of Africa is detailed in de Soyres et al. (2019)

[10] Although this criterion can be seen as a simplification of modal trade-offs, imposing this preference for maritime connections allows us to more accurately represent the observed trade-offs.

[11] As an example, for a transport from Sousse (Tunisia) to Pretoria (South Africa), there are two optimal paths depending on the degree of maritime preference. In the absence of maritime preference, the optimal path is entirely by land (12,400 km of roads, i.e. 19.5 days including delays at the land borders); in the presence of maritime preference, the optimal path is by sea for a total of 30 days (including delays in ports).

From the previous analysis we derived the (shortest) transport time between each pair of cities. As our trade and production data are at the country level, a consistent aggregation approach is required. We address this by considering three essential parameters: location-specific friction, trade elasticity, and trade elasticity with respect to transport time. We aggregate transport time between cities at the country pair level using a theoretically robust iterative method that integrates population weights and a calibrated friction elasticity, as illustrated in Hinz (2017).

The theoretically consistent aggregation for the frictions at the level of the city pairs is as follows:

$$\#days_{ij} = \left(\sum_{k \in i} \sum_{l \in j} \frac{s_k}{s_i} \frac{m_l}{m_j} \#days_{kl}^{\delta\theta} \right)^{1/\delta\theta}$$

When aggregating at the level of a pair of countries ij, with exporter country i and destination country j, we take into account both the relative population of cities k in i and l in j, as well as the transport time elasticity, denoted as $\delta\theta$.[12] The transport time elasticity is calibrated using a simple iterative procedure as follows. We start with an arbitrary initial value of the elasticity (i.e. $\delta\theta = -1$). Then, we estimate the elasticity in a cross-section gravity equation for the year 2018 with origin and destination fixed effects and controlling for PTAs, language proximity, and shared colonial history (border dummies are not included because border crossing time is already included in transport time).[13] We retrieve the transportation time coefficient and then use it as a parameter in the aggregation equation ($\delta\theta = \beta^{transportation}$). In the next iteration, this new aggregation parameter is used.[14]

Using a network analysis to quantify shipping times and the impact of new and improved transportation infrastructure has advantages and disadvantages. On the plus side, a network analysis can be a useful tool to support modeling of international trade flows. It can enhance the understanding of the impact of changes in infrastructure or other factors on an interconnected system allowing to extract information from spatial data. Specifically, a network analysis enables the measurement of the time it takes to go from one location to another taking into account the overall quality and quantity of infrastructure, physical obstacles (e.g. rough terrain) or other barriers (e.g. border delays), and relative performance measures (e.g. processing time at ports or when crossing a border). As with any modeling exercise, it should be acknowledged that our network is a simplified version of reality and results are affected by the quality of inputs. For example, due to limited data availability, we cannot include some elements that might influence the definition of optimal routes, such as freight service quality, service frequency, conflicts or adverse weather events.

1.1.1 Transportation Time Validation

Before using it as an input in the general equilibrium counterfactual analysis of trade and infrastructure reforms, we validate the transportation time in our dataset using evidence from Hummels & Schaur (2013) and Hummels

[12] The elasticity is a combination of trade elasticity θ and location specific friction elasticity δ.

[13] To retrieve the aggregation parameter we rely on a PPML estimator.

[14] We repeat this process until the estimated coefficient remains unchanged in its 5th digit. We do this separately for transport times with and without the sea route preference assumption. The procedure converges in 7 iterations in both cases. Without sea preference, the estimated $\delta\theta$ is -0.852, with sea preference, the estimated parameter is -0.780.

(2007). Table 1 reports the results of the two-step validation exercise.

First we aim at identifying the tariff equivalent of one additional day of shipment for African exporters with the rest of the world by regressing the log of trade in 2018 on the number of days ($days^{\#}_{ij}$) needed to reach any of the destination markets in the sample.[15] The estimated equation reads:

$$\ln X_{ij} = \beta_{days} days^{\#}_{ij} + \gamma \mathbf{D_{ij}} + \epsilon_{ij} \tag{1}$$

where i is the exporter country, j the importer country, D_{ij} a vector of bilateral trade frictions (excluding distance), with i being restricted to African exporter countries while j being any destination in the sample.

Results are shown in column 1 and 2 of Table 1. In column 1 we focus on the shortest path in the transportation matrix without restrictions while in column 2 we add, whenever possible, a maritime preference to the algorithm searching for the shortest path. The estimated coefficients are then translated into tariff equivalent using an elasticity of substitution of $\sigma = 6$, according to the following formula:
Tariff Equivalent $= (exp[(\beta^{days}/-\sigma) - 1]) * 100$.[16]

In our preferred specification, column 1, an additional day of transport is equivalent to a 2.4 percent tariffs *for African exporters*, a plausible value considering that Hummels & Schaur (2013) estimate *for the United States* a tariff equivalent in the range of 0.6 to 2.1 percent. With a preference for maritime routes in the calculation of the optimal transport time, we obtain a tariff equivalent of 1.8 percent (in column 2).

In the second step, that is, in column 4 of Table 1, we regress the number of days against distance (without maritime preferences) and then use the equivalent tariff estimates from column 1 to infer the elasticity of trade costs (which we do not observe) to distance as in Hummels (2007), using $exp[(\beta^{days}/-\sigma) - 1]) * \beta_{dist}$. The results in column 6 replicate the analysis on data with maritime preferences, using the equivalent tariffs derived from column 2. The estimated equation reads:

$$days^{\#}_{ij} = \beta_{dist} dist_{ij} + \omega \mathbf{D_{ij}} + \epsilon_{ij} \tag{2}$$

Column 3 and 5 show the estimation using the log number of days as a dependent variable by sake of comparison. In both columns 3 and 5, the estimated elasticity is around one: the number of days is proportional to the distance, as expected.

The regression results on the number of days indicate an elasticity of trade costs to distance of 0.180 when transportation time is calculated without the maritime preference (column 4) and 0.178 when more weight is given to the maritime route (column 6). The implied elasticity for African exporters is therefore slightly higher than 0.151, the one estimated for the United States in Hummels (2007). The evidence presented here suggests that transport time data can be used with some confidence to quantify the economic impact of trade reforms and infrastructure investments in Africa.[17]

[15] Note that the trade data used for the transport time validation also include domestic sales. The construction of the trade data is detailed in Section 1.2.

[16] The average of elasticities of substitution significant at the 1 percent level is 6.3 in Fontagné, Guimbard & Orefice (2022).

[17] Note that the estimates presented to date are for 2018, and repeating the analysis for 2014 produces virtually unchanged results. The corresponding tables are available on request.

Table 1: Transportation time data validation

Dep Var:	$log(X_{ij})$		Days_{ij} log(#)	Days_{ij} #	Days_{ij}^{MAR} log(#)	Days_{ij}^{MAR} #
	(1)	(2)	(3)	(4)	(5)	(6)
# Days_{ij}	-0.143***					
	(0.012)					
# Days_{ij}^{MAR}		-0.105***				
		(0.009)				
$\log(\text{Distance})_{ij}$			1.116***	7.472***	1.203***	10.090***
			(0.062)	(0.408)	(0.066)	(0.535)
Contiguity_{ij}	2.309***	1.983***	0.403**	-0.950	0.174	-4.492***
	(0.415)	(0.453)	(0.165)	(1.037)	(0.182)	(1.624)
Language Proximity_{ij}	0.441***	0.360***	0.016	0.273**	0.001	-0.417**
	(0.062)	(0.062)	(0.013)	(0.126)	(0.013)	(0.175)
Colonial Ties_{ij}	0.718**	0.768**	-0.007	0.192	0.004	0.741
	(0.316)	(0.323)	(0.079)	(0.608)	(0.074)	(0.689)
Observations	2038	2,038	2,038	2,038	2,038	2,038
# Origins	20	20	20	20	20	20
# Destinations	110	110	110	110	110	110
Period	2018	2018	2018	2018	2018	2018
Transportation	no MAR	MAR	no MAR	no MAR	MAR	MAR
Tariff Equivalent	2.4	1.8				
Distance						
Elasticity				0.180		0.178

Note: MAR indicates that the transportation times are estimated considering maritime preferences. Exporter(i) and Importer (j) fixed effects are included in all regressions. Standard errors in parentheses are clustered by country-pair, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. To compute tariff equivalents we assume $\sigma = 6$. $\log(\text{Distance})_{ij}$, Contiguity_{ij} and Colonial Ties_{ij} variables are from Mayer & Zignago (2011); while for Language Proximity_{ij} we the use "lp" variable from Gurevich, Herman, Toubal & Yotov (2021) (to be more precise we use $log(lp + 0.01)$).

1.2 Trade, Production and PTAs

A fully-fledged general equilibrium structural gravity approach relies on a trade matrix that includes both intra-national and inter-national manufacturing and agricultural trade flows. The inclusion of intra-national sales is critical, as the correct benchmark for trade integration is the domestic economy (Head & Mayer 2014, Yotov 2021). The trade database used for the empirical analysis includes both domestic and international sales of agricultural and manufacturing products. Domestic sales are calculated as the difference between the value of production and total exports (both measured in gross terms).[18]

Manufacturing output and trade come from UNIDO INDSTAT2 (2022) and UN-ComTrade, respectively.[19] We follow standard practice for filling gaps in intra-national flows if output is missing or implies negative domestic sales. Specifically, we linearly interpolate production values between non-missing data points and extrapolate the remaining missing values using the ratio of gross output to value added as in Head & Mayer (2021).

Agricultural product flows come from the Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT).[20] The FAOSTAT reports a Detailed Trade Matrix in both quantities (in tons) and values (in thousands of US dollars) from 1986 to 2018 and a disaggregated agricultural production data. As done for the manufacturing sector, after filling in some missing values following the same procedure mentioned earlier, we combined production and trade data into a dataset containing both domestic and international sales.

Finally, we combine manufacturing and agricultural data and aggregate, for each year, the underlying flows by country of origin and destination. The final dataset includes, for each year, only countries with non-missing (or nonnegative) domestic sales. Overall, the estimation dataset covers 137 countries (34 of which in the African continent) on 1-year intervals from 1986 to 2018. The counterfactual exercises are computed for year 2018 and 2014.[21]

Trade and production data are then combined with the list of in force Preferential Trade Agreement (PTAs) as provided in Fontagné et al. (2023). Using various clustering techniques, Fontagné et al. 2023 show that existing PTAs can be classified into three optimal groups based on the distribution of provisions included in each of the 18 policy areas covered by the World Bank Deep Agreement database. In what follows, we use this classification and estimate the elasticity of bilateral trade flows to different types of PTAs.

[18] If the resulting value of domestic sales is negative, it is considered missing. Head & Mayer (2014) discuss an alternative options based on ratios and proposed by Romalis (2007), and Caliendo & Parro (2015) .

[19] Manufacturing data are available at `https://stat.unido.org/` and `https://comtrade.un.org/`

[20] Agricultural data are available at `http://faostat3.fao.org/home/E`.

[21] In year 2018, the dataset covers 112 and (20 of which in the African continent); while in 2014 the total number of countries is 132 (30 of which in the African continent). Importantly, these data do not include informal trade, which can be a significant part of total agricultural trade (Bouet, Pace & Glauber 2018). The likely underestimation of trade flows between African countries may also have an impact on the estimated gains from the reduction of trade barriers between them.

2 Assessing Trade Impacts of PTAs and Infrastructure Investments

In this paper, we employ a four-step strategy to investigate the trade implications of the AfCFTA and of the improvements in transportation infrastructure. The results of the first two stages are outlined in this section: i) estimating a structural gravity model where the ambition of *signed* trade agreements explains bilateral trade intensity; ii) giving a functional form to the *unobserved* bilateral frictions in relations between African countries and trading partners by making them dependent on transport time as measured in our data set. The third stage, which quantifies the impact of planned infrastructure investments on transport time, is presented in the section 3. The final stage, simulating the general equilibrium effects of policy and infrastructure integration in Africa, is discussed in section 4.

2.1 The Effects of Different Types of PTAs on Trade

In this section, we estimate the trade impact of the three clusters of PTAs identified in Fontagné et al. (2023) in a gravity framework in order to recover the partial effect on trade of existing PTAs associated with the different clusters.This estimation is performed on the worldwide sample of countries and the obtained elasticity is used in the trade policy counterfactuals addressing the economic impact of integration among African countries.[22] To this end we estimate the following structural gravity equation with PPML on panel data:

$$X_{ij,t} = exp\left(\sum_{z=1}^{3}\beta_z PTA^z_{ij,t} + \beta \text{Opted Out } PTA_{ij,t} + \sum_{T=1990}^{2010}\beta_T INTL\ BRDR_{ij} * T + \pi_{i,t} + \chi_{j,t} + \mu_{ij}\right) + \epsilon_{ij,t} \tag{3}$$

Where $X_{ij,t}$ includes both intra-national and international manufacturing plus agricultural trade flows on 1-year intervals from 1986 to 2018.[23] Bilateral flows are normalized with total absorption at destination ($X_{.j,t}$), as to mitigate the differences in the penalization of large and small trade flows of the PPML estimator (Eaton, Kortum & Sotelo 2013, Head & Mayer 2014).

Our main variable of interest, $PTA_{ij,t}$, is sliced across clusters: $PTA^z_{ij,t}$. The dummy $INTL\ BRDR_{ij}$ takes the value of one for international trade flows. We interact this dummy with decades indexed by T (leaving the first period as reference). Exporter-time and importer-time fixed effects control for time-varying Multilateral Resistance Terms, whereas bilateral fixed effects control for time invariant unobserved characteristics of the country pairs, that can potentially lead to self-selection into PTAs (Baier & Bergstrand 2007). As an additional control, we also include the variable $Opted\ Out\ PTA_{ij,t}$, to control for agreements that are no longer in force.

The results presented in Table 2 present the elasticity of bilateral trade to the different types of PTAs (as classified by the clustering procedure) in column 1 to 3 for manufacturing and agriculture, manufacturing only, and agriculture only respectively. Two results emerge. First, PTAs of different ambition have a different impact on trade, with PTAs in cluster # 1 having the largest impact and the PTAs in cluster # 3 the lowest respectively.

[22] The estimated elasticity captures the world average effect of trade integration. African countries register only two agreements within the "deep" class: Common Market for Eastern and Southern Africa (COMESA) and Economic Community of West African States (ECOWAS). Estimating a regional specific elasticity would likely be affected by such scanty sample.

[23] Although results are robust to the use of longer intervals, e.g. 4-year intervals as in Anderson & Yotov (2016), we privilege a specification on sequential data as suggested by Egger, Larch & Yotov (2022).

Second, the trade impact of the most ambitious PTAs in cluster # 1 is magnified for agricultural products, a sector where ensuring compatibility of norms and controls is an important challenge.

Table 2: Partial equilibrium impacts of different types of PTAs, PPML estimates

Dep Var: X_{ijt}/X_{jt}	Manufacturing and Agriculture (1)	Manufacturing only (2)	Agriculture only (3)
$\text{PTA}_{ij,t}^{z\#1}$	0.519***	0.447***	0.981***
	(0.065)	(0.066)	(0.112)
$\text{PTA}_{ij,t}^{z\#2}$	0.268***	0.262***	0.174***
	(0.032)	(0.034)	(0.060)
$\text{PTA}_{ij,t}^{z\#3}$	0.107***	0.011	0.121*
	(0.035)	(0.036)	(0.072)
Opted Out $\text{PTA}_{ij,t}$	0.157***	0.108**	-0.086
	(0.043)	(0.045)	(0.107)
INTL BRDR∗1990	0.274***	0.233***	0.155**
	(0.032)	(0.034)	(0.063)
INTL BRDR∗2000	0.761***	0.616***	0.825***
	(0.043)	(0.048)	(0.079)
INTL BRDR∗2010	1.130***	0.963***	1.269***
	(0.050)	(0.056)	(0.097)
Observations	486,623	413,265	388,594
R-squared	0.984	0.974	0.997
Period	1986-2018	1986-2018	1986-2018
Interval	1-year	1-year	1-year
FEs	it jt ij	it jt ij	it jt ij

Notes: Exporter-time (it), Importer-time (jt) and Exporter-Importer (ij) fixed effects. Standard errors in parentheses are clustered by country-pair, *** p < 0.01, ** p < 0.05, * p < 0.1. The excluded category for the international border dummy is the period 1986-1989.

As in Fontagné & Santoni (2021), we derive a matrix of bilateral frictions on the basis of the estimates from column 1 of Table 2:

$$\widehat{\tau_{ij,t}^{1-\sigma}} = exp(\widehat{\mu_{ij}} + \widehat{\beta_T} INTL\ BRDR_{ij} * T + \widehat{\beta_0} Opted\ Out\ PTA_{ij,t} + \sum_z \widehat{\beta_z} RTA_{ij,t}^z) \times (\frac{X_{ij,t}}{\widehat{X_{ij,t}}}) \quad if\ X_{ij,t} > 0$$

$$\widehat{\tau_{ij,t}^{1-\sigma}} = exp(\widehat{\mu_{ij}} + \widehat{\beta_T} INTL\ BRDR_{ij} * T + \widehat{\beta_0} Opted\ Out\ PTA_{ij,t} + \sum_z \widehat{\beta_z} RTA_{ij,t}^z) \quad if\ X_{ij,t} = 0$$

where $(X_{ij,t}/\widehat{X_{ij,t}})$ is the ratio of observed to predicted trade from Equation 3. The "estibrated" $\widehat{\tau_{ij,t}^{1-\sigma}}$ as well as the estimated inward and outward multilateral resistance terms represent the key elements for the baseline and the counterfactual exercise that follows. Note that given $\sigma = 6$, the estimated term $\widehat{\tau_{ij,t}^{1-\sigma}}$ should be interpreted as the reciprocal of the bilateral trade friction, denoted by $\tau_{ij,t}$. Consequently, this term serves as a measure of the ease with which trade occurs between countries i and j at time t. [24]

2.2 The Role of Transportation in Shaping Bilateral Trade Frictions

In this section we want to quantify to what extent transportation – as revealed by the network analysis above – is a source of bilateral frictions in trade relations between African countries and their trading partners. To proceed, we start from $\widehat{\tau_{ij,t}^{1-\sigma}}$, the estimated trade friction matrix from the previous step and regress them on transportation time. In the regression, we include the existing PTAs (i.e. the baseline) and additional controls that capture geography and historical bilateral determinants of trade (i.e. language proximity, contiguity and colonial ties) and control for unobserved exporter and importer characteristics using fixed effects. The estimation is performed in cross section for the year 2018 because we do not have time variation in our analysis of transport networks.[25]

Having identified the functional form for bilateral frictions, we will be able in the next section to build counterfactuals using the estimated elasticity of $\widehat{\tau_{ij,t}^{1-\sigma}}$ to changes in transportation time to model our counterfactual scenarios. Table 3 presents the results of these estimates across specifications. Column 1 shows the average impact of transportation time. Column 2, on the other hand, distinguishes between domestic trade (namely $i = j$) and cross-border trade, and shows that the elasticity of cross-border trade frictions with respect to transport time is significantly larger than that of domestic trade. In column 3 we introduce a maritime preference in the choice of the optimal route, which has a limited impact on the measured elasticity, as shown by the standard errors. Our preferred estimates are reported in columns 2 and 3. These coefficients are used in the next section to translate changes in transport time into changes in bilateral trade frictions.

In our preferred specifications, we include the PTA variable as a control variable. This ensures that the elasticity of trade frictions with respect to transport time is orthogonal to the trade agreement in question. Omitting PTAs from the equation would have a limited effect on the estimate of the cross-border elasticity, while the effect on the estimate of the domestic elasticity would be slightly reduced. [26] However, it could be argued that there is an interdependence between PTAs and transportation time. Columns 4 and 5 examine this relationship by introducing an interaction between these two variables. The resulting interaction term is negative and statistically significant. For example, in column 4, the elasticity of cross-border trade frictions increases slightly when the interaction with PTAs is taken into account ($-1.836 - 0.581 = -2.417$). Interestingly, the elasticity of domestic trade frictions also increases when the interaction term is included (-1.024). These results suggest that the expected benefits associated with improved connectivity and synchronized trade policies

[24] All other things being equal, an increase in one of the determinants of trade frictions, such as distance or transportation time, implies a decrease in the ease of trade. The underlying values of $\widehat{\beta}$ and $\widehat{\mu_{ij}}$ are calculated over the entire period and are therefore time-invariant, although both the baseline and the counterfactual are calculated in a cross-section (either 2018 or 2014, depending on data availability). Since 0.6% of the estimated $\widehat{\mu_{ij}}$ are unidentified, we replace missing trade costs with standard gravity regression predictions using log distance, common border, colonial ties, and language proximity as explanatory variables.

[25] When we use year 2014, although the regional coverage increases to 30 African countries, the estimated elasticity of $\widehat{\tau_{ij,t}^{1-\sigma}}$ to transportation time hardly changes. In 2014, without maritime preferences (corresponding to column 4 of Table 3) the coefficient for log(Transportation Time)$_{i \neq j}$ is -2.369 (se 0.119); whereas the estimated coefficient for log(Transportation Time)$_{i=j}$ is -0.606 (se 0.157). With maritime preferences (corresponding to column 5 of Table 3) the estimated coefficient for log(Transportation Time)$_{i \neq j}$ is -2.029 (se 0.101); whereas the estimated coefficient for log(Transportation Time)$_{i=j}$ is -0.651 (se 0.157).

[26] Our preferred specification in column 2 of Table 3 without the PTA variable reports an estimated coefficient of -2.454 (se 0.130) for cross-border trade and -0.408 (se 0.169) for domestic trade. The corresponding general equilibrium tables are available upon request.

may be larger when this relationship is incorporated into the general equilibrium analysis. As a result, using the estimates in columns 2 and 3 leads to more conservative effects.

Table 3: Elasticity of bilateral frictions to transportation time

Dep Var:			$\widehat{\tau_{ij,t}^{1-\sigma}}$		
	(1)	(2)	(3)	(4)	(5)
log(Transportation Time)$_{ij}$	-1.572***				
	(0.105)				
log(Transportation Time)$_{i\neq j}$		-2.252***	-1.867***	-1.836***	-1.515***
		(0.135)	(0.115)	(0.236)	(0.228)
log(Transportation Time)$_{i=j}$		-0.678***	-0.734***	-1.024***	-1.043***
		(0.181)	(0.189)	(0.252)	(0.266)
Language Proximity$_{ij}$	0.206***	0.171***	0.151**	0.164***	0.151**
	(0.059)	(0.058)	(0.060)	(0.058)	(0.060)
Colonial Ties$_{ij}$	0.795**	0.735**	0.737**	0.690**	0.692**
	(0.329)	(0.334)	(0.343)	(0.339)	(0.349)
PTA$_{ij}$	1.085***	0.777***	0.870***	2.500***	2.447***
	(0.163)	(0.168)	(0.170)	(0.723)	(0.824)
PTA$_{ij}$ × log(Transportation Time)$_{i\neq j}$				-0.581**	-0.495*
				(0.242)	(0.256)
Observations	2,220	2,220	2,220	2,220	2,220
# Origins	20	20	20	20	20
# Destinations	110	110	110	110	110
Period	2018	2018	2018	2018	2018
Transportation	no MAR	no MAR	MAR	no MAR	MAR
Estimator	OLS	OLS	OLS	OLS	OLS

Note: MAR indicates that transportation time is estimated considering maritime preferences. Exporter(i) and Importer (j) fixed effects are included in all regressions. Standard errors in parentheses are clustered by country-pair, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Colonial Ties$_{ij}$ variable is from Mayer & Zignago (2011); while for Language Proximity$_{ij}$ we the use "lp" variable from Gurevich et al. (2021) (to be more precise we use $log(lp + 0.01)$). The dependent variable $\widehat{\tau_{ij,t}^{1-\sigma}}$ is the unexponentiated reciprocal of bilateral trade friction $\tau_{ij,t}$ and indicates trade ease between countries i and j: increasing transport time implies decreasing bilateral trade easiness.

3 The Effects of New Infrastructures on Transportation Times

Before moving to the general equilibrium exercise, we need to assess how new transport infrastructure would impact transportation times in Africa. We draw upon the list of infrastructure investments from the Program for Infrastructure Development in Africa (PIDA) for our simulations.[27] PIDA has compiled a list of 232 priority projects for roads, ports, borders, airports, and rails, aiming to enhance regional integration and stimulate economic development by 2040. The list of active and future One-Stop-Border Posts is updated using the OSBP Sourcebook 2nd Edition May 2016.[28] From this list, we retain projects related to roads, ports, and border posts that can be geo-referenced and supplement it with 48 additional border posts from the OSBP Sourcebook for Africa. This results in 208 geo-referenced projects (roads, ports, and border posts).[29] Figure 2 displays the newly selected investments in roads, ports, and border posts. By comparing pre- and post-PIDA scenarios, we can quantify the changes in shipping times induced by the new and improved transport infrastructure projects.

The implementation of PIDA projects would significantly increase the number of road and port connections and enhance the speed and processing times along numerous road segments, borders, and ports, thereby reducing shipping times for many African cities. We begin by constructing a new counterfactual transport network that includes the new road classes and investments along the land borders and ports.[30] First, we incorporate road improvements into the new scenario by increasing the speed from the current road type to the average speed of the region's freeways, based on regional road speeds that are an average of country-level speeds used in Weiss et al. 2020.

Second, we reduce queuing time for border points in the new list of one-stop border posts by half, resulting in a reduction of average land border delays between African countries from 3.5 days to 2.9 days. Figure 3 reveals the large heterogeneity of delays across countries, displaying the average border delay per country. Eritrea, Saudi Arabia, Democratic Republic of the Congo, and Central African Republic have the longest current border delays, while Morocco has the shortest border delay. The countries that will benefit from the largest reductions in land border times are Democratic Republic of Congo, Congo-Brazzaville, South Sudan, Burundi, Cameroon, Malawi, and South Africa.[31]

Third, when a project involves building a new port or upgrading an old port, we assume that the associated processing time decreases according to the following rule: The improved port delay equals the second-best performance in the region or the second-best performance in the continent if the port is already among the best in its region. Overall, new border and port improvements at maritime gateways will reduce the average sea border delays from and to Sub-Saharan African coastal countries by 16 percent on average, with larger gains in ports with currently the highest delays. The countries that will benefit from significant reductions in sea border times are Cameroon, Côte d'Ivoire, Congo-Brazzaville, Democratic Republic of Congo, Kenya, Togo,

[27] Access the PIDA projects dashboard online at `https://www.au-pida.org/pida-projects/`.

[28] Further details available at `https://www.tralac.org/documents/resources/african-union/1682-osbp-sourcebook-2nd-edition-may-2016/file.html`

[29] All projects included in the analysis are listed in the Appendix in Table B2 for the road projects, in Table B3 for the border improvements, and in Table B4 for the port projects.

[30] A detailed description of the assumptions used to create our counterfactuals can be found in Appendix B.

[31] Figure 3 is an average at the country level, with some border points that benefit from a reduction in queuing time, others not.

and Tanzania (Figure 4).

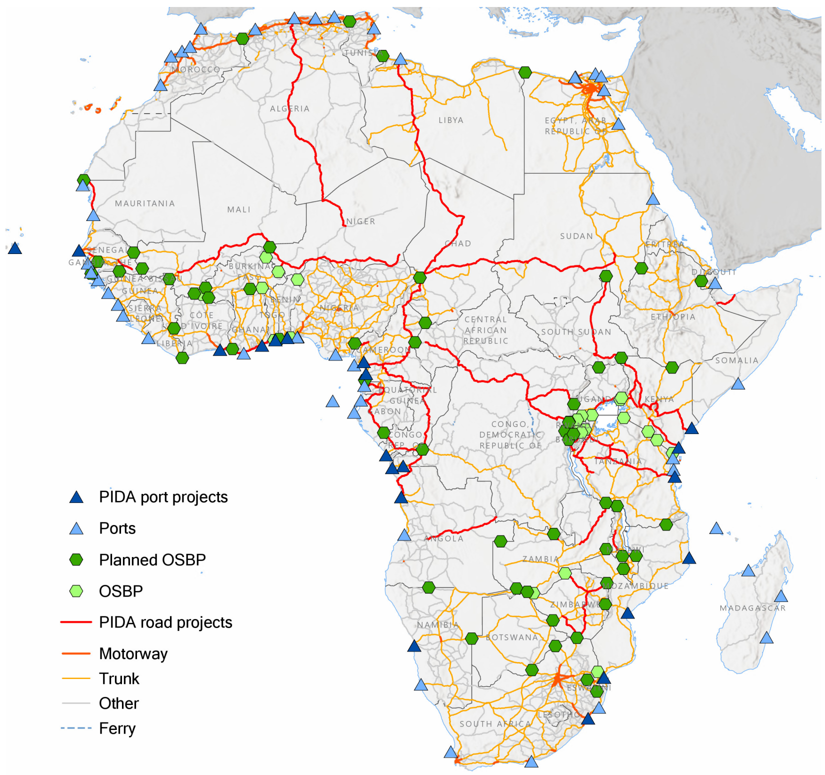
Table 4 presents the average transportation time (*Baseline*) and the expected change with the implementation of all major transportation infrastructure projects, including road, port, and border improvements (with and without the preference for sea routes) for the countries in the estimation sample.[32] Changes in the average shipping time before and after the implementation of the PIDA projects vary across destination countries. Considering all possible investments, countries in the Middle-East and North African region benefit the most from the investments reducing border and port delays, mostly when shipping to other countries in the regions. Without imposing a preference for maritime routes, the proportional reduction in shipping time in the Africa region ranges from 2.57 percent with countries in East Asia to 19 percent within the Africa region. In general, when assuming a preference for maritime routes, changes in transportation times are more pronounced. The country-level results (shown in Appendix Table B6) exhibit significant heterogeneity, demonstrating why it is crucial to use a network approach to include interconnections between different projects and countries. For each country, transport time varies as much with the infrastructure projects that affect it as with those of neighboring countries traversed by its optimal routes.

The optimal mix of sea and land routes also changes between scenarios. In the baseline, on average, 86% of the total trip length is at sea if maritime routes are preferred, and 51% if no preference is assumed. After all infrastructure investments are made, the shares drop to 84% and 45%, respectively. For certain pairs of countries, there are significant mode shifts. For example, simulated trips between Gabon and Senegal are mostly by sea in the baseline, but switch to land corridors when transport and border investments occur (in the scenario without maritime preference). In fact, the reduction in border waiting times favors land routes, and trips that took place by sea in the baseline then switch to land. On the other hand, trips between Burkina Faso and Algeria are mostly made by land in the baseline, but switch to maritime routes when border times are reduced (in the scenario with maritime preference). Indeed, the reduction of border times between Burkina Faso and its coastal neighbors makes the maritime route more accessible.

In the next section, we present the results of three counterfactual scenarios that examine the combined effects of policy and infrastructure reforms in Africa. These scenarios explore various combinations of the implementation of the African Continental Free Trade Area (AfCFTA) and the Program for Infrastructure Development in Africa (PIDA), and their impact on the continent's economic development.

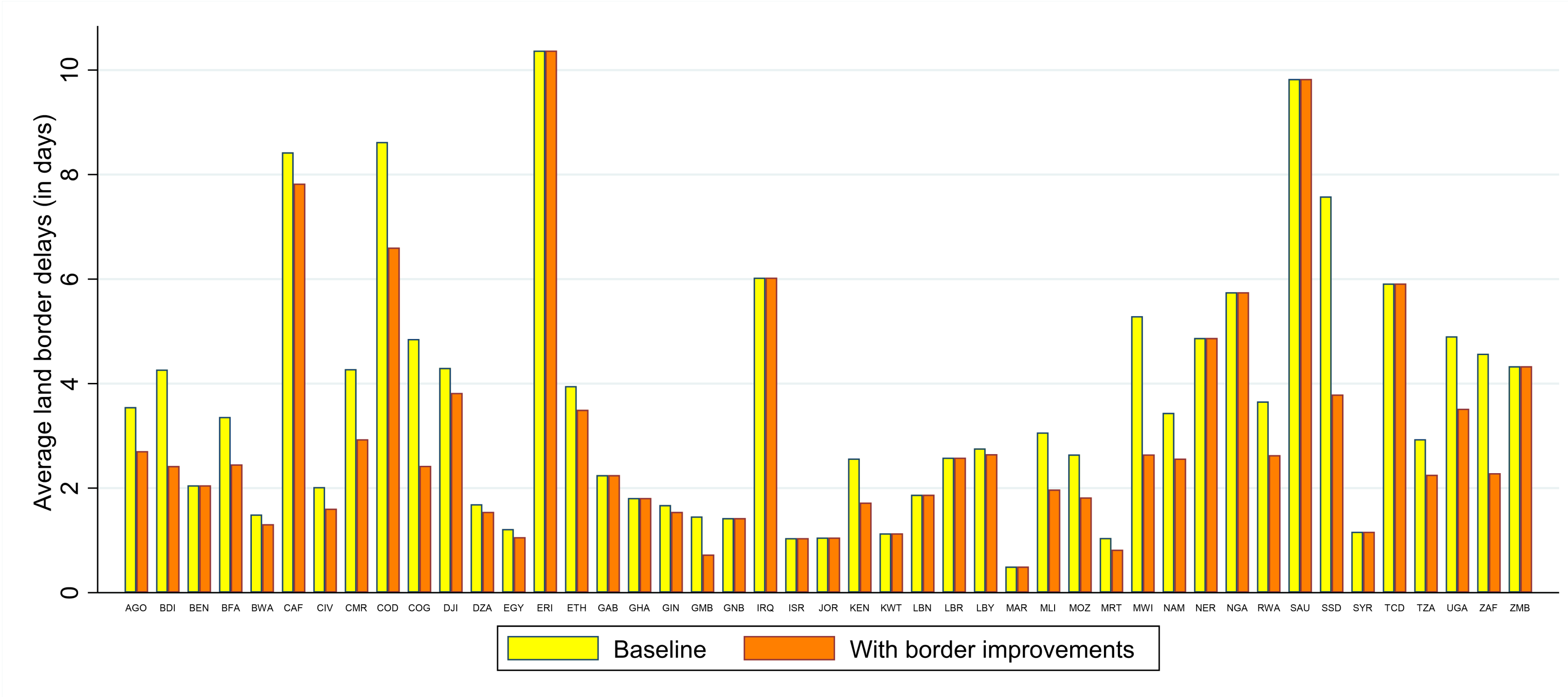
[32] Appendix Table B7 details the incoming and outgoing transport shocks for each country in the estimation sample. Appendix Table B5 provides regional transport statistics for all African economies.

Figure 2: Existing transportation network and new investments in roads, ports and border posts



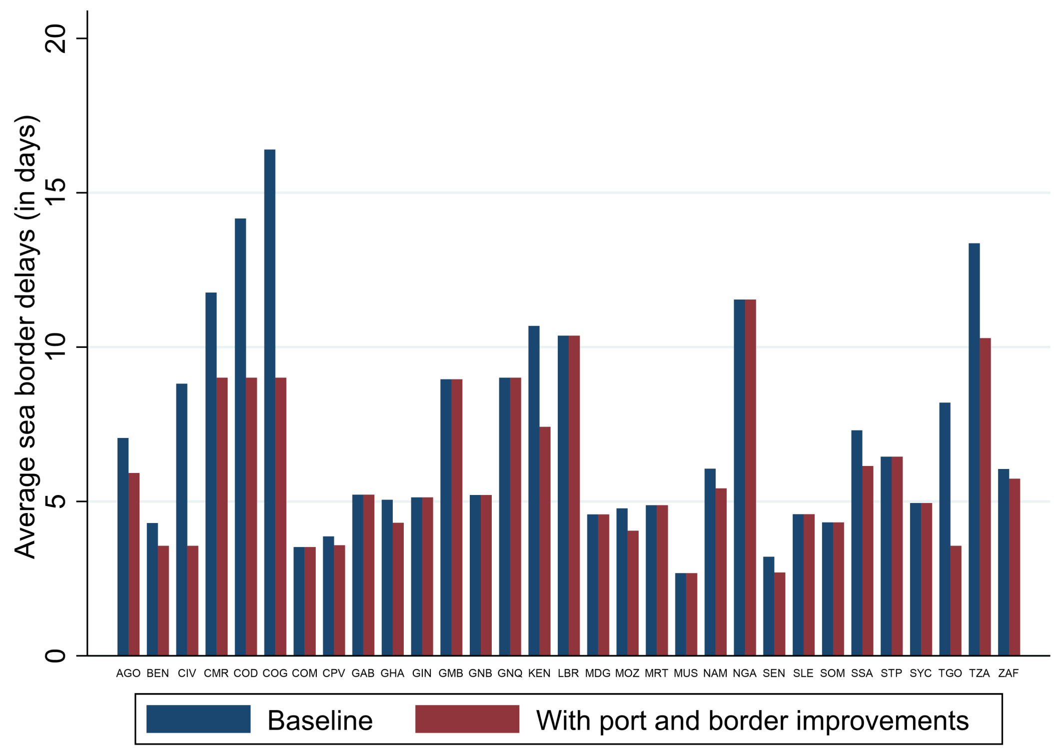
Note: Authors' transport network based on the PIDA list of projects available online as documented in the Appendix.

Figure 3: Average land border time (baseline and counterfactual) per country



Note: Authors' construction based on World Bank Doing Business Indicators. The graph shows the average land border delays per country before, in the baseline scenario, and after, in the counterfactual scenario, for each African country. Border improvements come from the reduction in border delays due to new OSBPs as shown on Figure 2. Border delays are calculated using border delays from the World Bank's Trade Across Border database using border delays for each country. More details can be found in the Appendix.

Figure 4: Total sea border time (baseline and counterfactual) per country



Note: Authors' construction based on World Bank Doing Business Indicators and UNCTAD data on port calls. The graph shows the average sea border delays per country before, in the baseline scenario, and after, in the counterfactual scenario, for each coastal African country. Border improvements come from the reduction in border delays assumed from new investments in port infrastructure as shown on Figure 2. Border delays are calculated using border delays at maritime gateways from the World Bank's Trade Across Border database and UNCTAD data for port calls. More details can be found in the Appendix.

Table 4: Proportional decrease in transportation time, aggregated by regions

Origin	Destination	Baseline	Improvements in Roads land borders and ports
		# Days	% Change
Without Maritime Pref.			
	Africa	17	-19.06
	East Asia & Pacific	33	-2.57
	Europe & Central Asia	23	-5.89
Africa	Latin America & Caribbean	30	-4.77
	Middle East	24	-6.30
	North America	29	-6.69
	South Asia	29	-4.35
With Maritime Pref.			
	Africa	27	-22.77
	East Asia & Pacific	38	-7.39
	Europe & Central Asia	28	-10.74
Africa	Latin America & Caribbean	34	-9.44
	Middle East	30	-11.65
	North America	33	-9.34
	South Asia	33	-8.81

Note: city level transport time are aggregate at the country-pair level using a theory consistent population-weighted average.

4 Quantification Strategy and Counterfactual Results

To assess the impact of policy and infrastructure reforms, we use a general equilibrium structural gravity model of an endowment economy. In this model, bilateral trade responds to simulated reforms through: (i) a direct effect driven by the estimated parameters β^z, with z = $(1, \ldots, 3)$ in Equation 3; (ii) an indirect effect induced by third-country adjustments, such as the effect of simulated East African Community deepening on EU-Kenya trade. The usual trade diversion effect appears, corresponding to the "general equilibrium effects" of an endowment economy (Head & Mayer 2014). The Multilateral Resistance Terms (MRT) "*à la* Anderson & Van Wincoop" 2003 serve as general equilibrium trade cost indices. They transmit local shocks to the overall trade friction matrix. The inward MRTs transmit the impact of the policy shock to consumers, while the outward MRTs transmit it to producers in the exporting country. We analyze three different scenarios to explore the impact of different policy and infrastructure reforms:

Scenario #1: Deepening trade integration in the African region

This scenario examines the AfCFTA's enactment without additional resources for enhancing Africa's transport infrastructure. We assume that the existing transport network remains unchanged, focusing on the trade integration effects facilitated by the AfCFTA. The results provide insights into trade liberalization's potential benefits, excluding improvements to transportation infrastructure.[33]

Scenario #2: Improving connectivity in the African region

The second scenario evaluates the isolated impacts of PIDA's anticipated infrastructure investments, including enhancements to roads, ports, and borders, without the successful completion of the AfCFTA. The primary objective is to assess the potential economic benefits arising from upgraded transport infrastructure across the continent, disregarding the AfCFTA's trade integration effects.[34]

Scenario #3: Combining trade and infrastructure integration

The final scenario combines both trade integration through the AfCFTA and transport infrastructure investment under PIDA. We differentiate between two alternative assumptions regarding the transport network: with and without a preference for maritime transport. Comparing these sub-scenarios' outcomes, we aim to understand better how transport mode selection influences the overall consequences of combined reforms on Africa's economic development.

4.1 Scenario # 1: Deepening Trade Integration in the Africa Region

We now proceed to the general equilibrium analysis of the trade impact of deepening trade integration in Africa with the AfCFTA consolidating and extending all existing trade agreements between African countries, *absent the improvement of transport infrastructure.*

Results for the first scenario, deepening regional trade integration in Africa at the extensive and intensive

[33] We consolidate the existing trade agreements in Africa – and add the missing ones – into a high ambition pan-African trade agreement, the AfCFTA. We impose that non-positive entries in PTA_z are switched to 1, with depth class z = 1 (the most ambitious type). We also deepen the existing agreements signed between African countries. Under this simulation, positive entries in either $\text{PTA}_{z=3}$ or $\text{PTA}_{z=2}$ are switched to zero while the corresponding entries in $\text{PTA}_{z=1}$ are set to 1 at the intensive margin, conditional on i and j being African countries.

[34] Operationally, to derive a counterfactual trade cost matrix, we combine the percentage change in transport time with the estimated elasticity from column 4 of table 3.

margins described above, are shown in Table 5. In column 1, we report the baseline share of intra-African export for each African country, followed by the changes in intra-African exports in column 2 and African exports with the rest of the world in column 3. Column 4 shows the change in total trade, and column 5 the change in GDP. All changes are expressed as percentage deviation from the baseline.

On average, our trade integration scenario increases intra-African trade by 34.7 percent, while reducing trade with the rest of the world by 1.3 percent (diversion effects). This translates into an overall increase in GDP by 0.6 percent. These values may be viewed as modest, but one must recall that intra-African trade is hampered by trade frictions (e.g. roads). In the next sections, we gradually add the simulated impacts of the infrastructure investments.

Table 5: General-Equilibrium effects of deeper trade integration in the African region, no improvement of transport infrastructure

Country	Baseline	Regional Trade (%)	ΔX_i Regional	ΔX_i RoW	ΔX_i	ΔGDP_i
		(1)	(2)	(3)	(4)	(5)
Algeria	2018	5.32	47.94	-0.82	1.77	0.28
Botswana	2018	15.70	33.98	-4.76	1.33	7.34
Burkina Faso	2014	27.44	35.02	3.29	11.99	0.67
Burundi	2018	16.75	40.77	8.94	14.27	0.28
Cabo Verde	2014	8.85	61.55	-1.28	4.26	0.26
Cameroon	2014	3.62	32.31	0.77	1.91	0.23
Congo, Rep.	2014	17.02	50.76	-5.98	3.67	2.70
Côte d'Ivoire	2018	7.25	26.33	-0.05	1.87	0.32
Egypt, Arab Rep.	2018	11.84	34.34	-1.65	2.61	0.32
Ethiopia	2014	3.79	19.70	0.51	1.24	0.06
Ghana	2018	8.89	44.65	-1.68	2.44	0.38
Kenya	2018	27.16	33.97	0.18	9.36	0.44
Lesotho	2018	39.69	32.70	-9.94	6.99	9.45
Madagascar	2014	7.69	43.69	0.28	3.62	0.46
Malawi	2014	31.40	28.68	2.21	10.53	0.88
Mauritius	2018	15.70	33.79	-1.90	3.70	1.13
Morocco	2018	4.08	42.72	-0.57	1.19	0.34
Mozambique	2018	14.18	44.02	-0.43	5.88	2.54
Namibia	2018	28.60	25.72	-6.32	2.84	7.42
Niger	2018	14.74	8.59	2.59	3.47	0.22
Nigeria	2018	11.27	34.59	-2.02	2.10	0.18
Rwanda	2018	14.23	59.26	11.56	18.34	0.85
Senegal	2018	17.50	38.32	-0.29	6.46	0.56
South Africa	2018	21.76	24.90	-1.33	4.38	0.68
Eswatini	2018	86.81	17.09	-18.96	12.33	9.96
Tunisia	2018	6.79	47.97	-1.58	1.78	0.78
Uganda	2018	44.72	38.64	-3.40	15.40	1.39
Tanzania	2018	40.24	30.45	-3.41	10.21	0.85
Zambia	2014	17.07	35.83	0.98	6.93	2.34
Zimbabwe	2014	67.28	17.23	-17.22	5.96	9.92
Overall			34.68	-1.34	3.41	0.64

Note: "Regional" stands for intra African exchanges. In column 1 the Regional trade percentages are computed at the baseline levels. In column 2 to column 5 percent changes with respect to the baseline in total exports and GDP of participating countries. We assume $\sigma = 6$. The reference country for the normalization is New Zealand.

4.2 Scenario # 2: Improving Connectivity in the Africa Region

In this section, we investigate the outcomes of a counterfactual scenario that focuses on improving connectivity in Africa *without creating an extensive and ambitious free trade area.* Table 6 presents the results for this scenario, showcasing the impacts of improved roads, ports, and border delays by country (without mode preference) in columns (1) and (2), and the results assuming a preference for sea routes in columns (3) and (4).

Overall, improving infrastructure connectivity in Africa would increase trade by 7.56 percent and GDP by 1.15 percent, relative to the baseline scenario. This could reach up to 1.46 percent if maritime transport is prioritized. The gains are not evenly distributed across the three levers considered: roads, ports, and land borders. Although the implementation of one-stop border posts accounts for a substantial share of the estimated gains in the simulated scenario,[35] the impact of other levers is not trivial. Improvements in road infrastructure alone increase GDP by 0.11 percent on average. This increase in GDP rises to 0.33 percent when road infrastructure improvements are combined with reductions in port delays. Related infrastructure projects are particularly attractive from a cost-benefit perspective. According to the PIDA Priority Action Plan, the estimated investment in transportation infrastructure \$25.4 billion.[36] Based on the GDP impacts estimated above, road infrastructure development could yield a cumulative rate of return of 4.1 percent for the African continent, calculated as the sum of the GDP gains for the countries in our sample. The rate of return for the continent rises to 12.6 percent if road development is complemented by port improvement projects.[37]

At the country level, the results exhibit significant heterogeneity. When border delays are high, road network development primarily boosts internal connectivity. However, when combined with additional reductions in border and port delays, intra-continental and intercontinental connectivity significantly improves, generating substantial benefits. Major increases in trade flows are observed in Burkina Faso, Burundi, Cameroon, Côte d'Ivoire, the Arab Republic of Egypt, Kenya, Malawi, Senegal, Uganda, Zambia, and Zimbabwe. Uganda, Zambia, and Zimbabwe, being landlocked countries, indirectly benefit from port investments in transit countries such as Tanzania or Mozambique.

Differences in outcomes without and with maritime preferences stem from variations in the assumptions used to construct the transport network and its counterfactuals. For instance, Egypt experiences a significant decrease in transport costs when a maritime preference is assumed. In this case, flows transition from longer maritime routes in the baseline scenario to shorter land routes when land border delays are substantially reduced between Egypt and its neighbors. This explains why the average impacts are considerably larger with the maritime preference than without.

GDP effects arise from the interplay of complex general equilibrium effects, relying on a country's characteristics and position in the global trade network. The countries that gain the most include Botswana, Cameroon, Namibia, Niger, and Zambia. Egypt and Tunisia also observe substantial GDP gains when assuming a mar-

[35] In line with previous studies, customs delays have been shown to be a significant barrier to trade. For example, Volpe Martincus, Carballo & Graziano (2015) find that if all exports in Uruguay had been subject to physical inspection, and if such inspections had lasted two days, then total exports in 2011 would have been 16.4 percent lower than they actually were. Using transaction-level data from El Salvador, Carballo, Graziano, Schaur & Martincus (2022) show that upgrading transit systems to streamline border processing in developing countries can be a high-return investment (with a back-of-the-envelope estimated return of US\$3 to 1).

[36] Link to PIDA Priority Action Plan

[37] Considering that the general equilibrium analysis is done in comparative statics we do not apply a discount factor to compute the return.

itime preference. Some of these countries directly benefit from infrastructure investments in their territories, while others gain from spillovers originating from investments in neighboring countries. Although some of these countries experience significant increases in their trade flows, others do not, highlighting the importance of employing a general-equilibrium model that considers the complex trade interactions among African countries and the rest of the world.

Table 6: General Equilibrium Effects, improving connectivity of the African Region

Country	Baseline	Roads, land borders and ports			
		Without Maritime Pref.		With Maritime Pref.	
		ΔX_i	ΔGDP_i	ΔX_i	ΔGDP_i
		(1)	(2)	(3)	(4)
Algeria	2018	6.63	0.93	11.10	1.76
Botswana	2018	2.98	11.81	2.86	10.36
Burkina Faso	2014	38.37	2.01	38.38	1.99
Burundi	2018	37.07	1.35	43.22	1.45
Cabo Verde	2014	0.12	0.01	2.55	0.17
Cameroon	2014	17.46	2.70	9.47	1.89
Congo, Rep	2014	5.24	4.60	8.43	6.24
Côte d'Ivoire	2018	9.39	1.41	15.01	2.17
Egypt, Arab Rep.	2018	8.43	0.99	7.36	1.01
Ethiopia	2014	14.39	0.59	8.92	0.36
Ghana	2018	5.88	0.99	5.12	0.90
Kenya	2018	12.74	0.94	24.83	1.70
Lesotho	2018	0.60	-0.25	-0.16	-0.51
Madagascar	2014	0.12	0.01	0.74	0.09
Malawi	2014	25.22	1.99	17.07	1.36
Mauritius	2018	0.00	-0.03	-0.03	-0.02
Morocco	2018	2.20	0.59	2.09	0.61
Mozambique	2018	2.90	0.67	2.20	0.55
Namibia	2018	3.22	7.62	3.43	7.10
Niger	2018	4.28	4.15	1.59	4.51
Nigeria	2018	7.50	0.58	13.59	1.38
Rwanda	2018	34.36	1.60	36.46	1.50
Senegal	2018	9.84	1.05	13.98	1.48
South Africa	2018	4.77	0.58	3.89	0.57
Eswatini	2018	1.78	0.37	2.94	1.24
Tunisia	2018	2.90	1.19	3.05	1.36
Uganda	2018	8.97	1.06	14.49	1.72
Tanzania	2018	12.79	1.68	20.83	2.78
Zambia	2014	19.74	6.63	14.14	4.86
Zimbabwe	2014	11.81	18.85	10.02	15.76
Overall		7.56	1.15	9.61	1.46

Note: percent change compared to the baseline in total exports and GDP of participating countries. We assume $\sigma = 6$. The reference country for the normalization is New Zealand.

4.3 Scenario # 3: Combining Trade and Infrastructure Integration

In the third scenario, we explore the potential outcomes of concurrently implementing both trade integration through the AfCFTA and transport infrastructure investment as per PIDA's projections. By considering the combined effects of these two initiatives, we aim to provide a comprehensive understanding of the potential synergies that may arise from simultaneous policy and infrastructure development.

Two sub-scenarios are considered: the first without a maritime preference (columns 1 and 2), and the second with a maritime preference (columns 3 and 4) in Table 7. The results indicate that reducing both types of trade frictions simultaneously offers cumulative benefits that exceed the sum of the individual policy effects. On average, when no maritime preference is considered, exports increase by 11.49 percent and GDP by 2 percent. When a maritime preference is assumed, the expected gains are slightly higher, with total exports and GDP increasing by 14.80 percent and 2.27 percent, respectively.

Table 7: General Equilibrium Effects, improving connectivity and deepen integration of the African Region

		Deep PTAs plus roads, borders and ports improvements			
		Without Maritime Pref.		With Maritime Pref.	
Country	Baseline	ΔX_i	ΔGDP_i	ΔX_i	ΔGDP_i
		(1)	(2)	(3)	(4)
Algeria	2018	9.12	1.40	14.42	2.22
Botswana	2018	4.79	21.45	4.70	19.56
Burkina Faso	2014	56.63	3.09	56.00	3.02
Burundi	2018	59.20	1.83	66.42	1.89
Cabo Verde	2014	4.23	0.28	6.86	0.46
Cameroon	2014	19.96	3.01	11.63	2.14
Congo, Rep.	2014	9.57	8.28	12.91	10.12
Côte d'Ivoire	2018	11.57	1.85	18.74	2.58
Egypt, Arab Rep.	2018	12.00	1.50	13.30	1.67
Ethiopia	2014	16.51	0.67	10.64	0.43
Ghana	2018	8.15	1.39	7.90	1.27
Kenya	2018	22.93	1.43	38.71	2.21
Lesotho	2018	7.50	9.10	7.09	8.75
Madagascar	2014	3.75	0.47	4.60	0.57
Malawi	2014	41.00	3.43	31.95	2.68
Mauritius	2018	3.67	1.07	3.70	1.07
Morocco	2018	3.97	1.13	3.97	1.15
Mozambique	2018	8.47	3.20	8.01	3.03
Namibia	2018	6.24	16.86	6.55	15.96
Niger	2018	9.15	4.45	9.51	4.73
Nigeria	2018	9.55	0.81	17.65	1.49
Rwanda	2018	60.82	2.88	61.22	2.73
Senegal	2018	18.08	1.78	24.73	2.26
South Africa	2018	9.34	1.36	9.37	1.35
Eswatini	2018	13.77	10.30	15.15	11.01
Tunisia	2018	5.59	2.47	5.91	2.66
Uganda	2018	25.47	2.65	32.16	3.29
Tanzania	2018	23.83	2.77	33.30	3.65
Zambia	2014	27.90	10.53	22.33	8.43
Zimbabwe	2014	17.83	32.58	16.08	28.97
Overall		11.49	2.00	14.80	2.27

Note: percent change compared to the baseline in total exports and GDP of participating countries. We assume $\sigma = 6$. The reference country for the normalization is New Zealand.

5 Conclusions

Major trade reforms and infrastructure investments are essential levers of economic integration for Africa. Quantifying their contribution can be challenging because of the lack of data and the presence of general equilibrium effects. In this paper, we start by constructing a new granular dataset of transport times faced by African exporters to quantify the reduction in times from the implementation of the Program for Infrastructure Development in Africa, an ambitious list of transport investments for the next decade. We then use data from the World Bank's Deep Trade Agreements project to assess the response of trade to different degrees of agreement ambition using a structural gravity model. We recover the elasticity of domestic and international sales to transportation time for African countries, with a functional form for unobserved bilateral frictions, making them depend on transport time and other unobservable characteristics of the origin and destination countries. Finally, we build on our calibrated model to simulate the trade and economic impacts of our investment scenarios in roads, ports, and land borders, and the consolidation of various trade agreements signed in Africa into the African Continental Free Trade Area.

Our results show that trade reforms and infrastructure improvements complement each other. The combination of tariff reduction and trade facilitation, which improves border delays and behind-the-border frictions, can substantially reduce trade costs and increase exports by 11.5 percent and GDP by 2 percent for countries in the continent.

Bibliography

Abrego, M. L., Amado, M. A., Gursoy, T., Nicholls, G. P. & Perez-Saiz, H. (2019), *The African Continental Free Trade Agreement: welfare gains estimates from a general equilibrium model*, International Monetary Fund working paper 19/124.

African Development Bank (2019), *Integration for Africa's Economic Prosperity, African Economic Outlook, Ch.3*, African Development Bank Group.

Allen, T. & Arkolakis, C. (2022), 'The Welfare Effects of Transportation Infrastructure Improvements', *The Review of Economic Studies* **89**(6), 2911–2957.

Anderson, J. E. & van Wincoop, E. (2003), 'Gravity with gravitas: A solution to the border puzzle', *American Economic Review* **93**(1), 170–192.

Anderson, J. E. & Yotov, Y. V. (2016), 'Terms of trade and global efficiency effects of free trade agreements, 1990–2002', *Journal of International Economics* **99**, 279–298.

Asturias, J., García-Santana, M. & Ramos, R. (2019), 'Competition and the welfare gains from transportation infrastructure: Evidence from the golden quadrilateral of india', *Journal of the European Economic Association* **17**(6), 1881–1940.

Baier, S. L. & Bergstrand, J. H. (2007), 'Do free trade agreements actually increase members' international trade?', *Journal of international Economics* **71**(1), 72–95.

Baniya, S., Rocha, N. & Ruta, M. (2020), 'Trade effects of the new silk road: A gravity analysis', *Journal of Development Economics* **146**, 102467.

Bengoa, M., Mathur, S., Narayanan, B. & Norberg, H. C. (2021), 'Environmental effects of the african continental free trade agreement: a computable general equilibrium model approach', *Journal of African Trade* **8**(2), 36–48.

Bird, J., Lebrand, M. & Venables, A. J. (2020), 'The belt and road initiative: Reshaping economic geography in central asia', *Journal of Development Economics* **144**, 102441.

Bouet, A., Pace, K. & Glauber, J. W. (2018), Informal cross-border trade in Africa: How much? Why? And what impact?, IFPRI discussion papers 1783, International Food Policy Research Institute (IFPRI).

Caliendo, L. & Parro, F. (2015), 'Estimates of the trade and welfare effects of NAFTA', *The Review of Economic Studies* **82**(1), 1–44.

Carballo, J., Graziano, A. G., Schaur, G. & Martincus, C. V. (2022), 'The Effects of Transit Systems on International Trade', *The Review of Economics and Statistics* pp. 1–41.

Costinot, A. & Rodríguez-Clare, A. (2014), Chapter 4 - trade theory with numbers: Quantifying the consequences of globalization, *in* G. Gopinath, E. Helpman & K. Rogoff, eds, 'Handbook of International Economics', Vol. 4 of *Handbook of International Economics*, Elsevier, pp. 197–261.

Coşar, A. K. & Fajgelbaum, P. D. (2016), 'Internal geography, international trade, and regional specialization', *American Economic Journal: Microeconomics* **8**(1), 24–56.

de Soyres, F., Mulabdic, A., Murray, S., Rocha, N. & Ruta, M. (2019), 'How much will the belt and road initiative reduce trade costs?', *International Economics* **159**, 151–164.

de Soyres, F., Mulabdic, A. & Ruta, M. (2020), 'Common transport infrastructure: A quantitative model and estimates from the belt and road initiative', *Journal of Development Economics* **143**, 102415.

Donaldson, D. (2018), 'Railroads of the raj: Estimating the impact of transportation infrastructure', *American Economic Review* **108**(4-5), 899–934.

Donaldson, D. & Hornbeck, R. (2016), ' Railroads and American Economic Growth: A "Market Access" Approach', *The Quarterly Journal of Economics* **131**(2), 799–858.

Eaton, J., Kortum, S. & Sotelo, S. (2013), *International Trade: Linking Micro and Macro*, Vol. 2 of *Econometric Society Monographs*, Cambridge University Press, p. 329–370.

Egger, P. H., Larch, M. & Yotov, Y. (2022), 'Gravity estimations with interval data: Revisiting the impact of free trade agreements', *Economica* **89**(353), 44–61.

Fajgelbaum, P. D. & Schaal, E. (2020), 'Optimal transport networks in spatial equilibrium', *Econometrica* **88**(4), 1411–1452.

Fajgelbaum, P. & Redding, S. J. (2022), 'Trade, structural transformation, and development: Evidence from Argentina 1869–1914', *Journal of Political Economy* **130**(5), 1249–1318.

Fan, J., Lu, Y. & Luo, W. (2023), 'Valuing Domestic Transport Infrastructure: A View from the Route Choice of Exporters', *The Review of Economics and Statistics* pp. 1–18.

Fontagné, L., Guimbard, H. & Orefice, G. (2022), 'Tariff-based product-level trade elasticities', *Journal of International Economics* **137**, 103593.

Fontagné, L. & Santoni, G. (2021), 'GVCs and the endogenous geography of RTAs', *European Economic Review* **132**, 103656.

Fontagné, L., Rocha, N., Ruta, M. & Santoni, G. (2023), 'The Economic Impact of Deepening Trade Agreements', *The World Bank Economic Review* . lhad005.

Goldberg, P. K. & Reed, T. (2022), Demand-Side Constraints in Development: The Role of Market Size, Trade, and (In)Equality, Technical report, Working Paper.

Gurevich, T., Herman, P. R., Toubal, F. & Yotov, Y. V. (2021), One Nation, One Language? Domestic Language Diversity, Trade and Welfare, CESifo Working Paper Series 8860, CESifo.

Head, K. & Mayer, T. (2014), *Gravity Equations: Workhorse, Toolkit, and Cookbook*, Vol. 4 of *Handbook of International Economics*, Elsevier, chapter 3, pp. 131–195.

Head, K. & Mayer, T. (2021), 'The United States of Europe: A gravity model evaluation of the four freedoms', *Journal of Economic Perspectives* **35**(2), 23–48.

Hinz, J. (2017), The view from space: Theory-based time-varying distances in the gravity model, Annual conference 2017 (Vienna): Alternative structures for money and banking, Verein für Socialpolitik / German Economic Association.

Hummels, D. (2007), 'Transportation costs and international trade in the second era of globalization', *Journal of Economic Perspectives* **21**(3), 131–154.

Hummels, D. L. & Schaur, G. (2013), 'Time as a trade barrier', *American Economic Review* **103**(7), 2935–59.

International Transport Forum (2017), *ITF Transport Outlook 2017*.

Lall, S. V. & Lebrand, M. (2020), 'Who wins, who loses? understanding the spatially differentiated effects of the belt and road initiative', *Journal of Development Economics* **146**, 102496.

Limao, N. & Venables, A. J. (2001), 'Infrastructure, geographical disadvantage, transport costs, and trade', *The world bank economic review* **15**(3), 451–479.

Limão, N. (2016), Chapter 6 - preferential trade agreements, Vol. 1 of *Handbook of Commercial Policy*, North-Holland, pp. 279–367.

Martincus, C. V., Carballo, J. & Cusolito, A. (2017), 'Roads, exports and employment: Evidence from a developing country', *Journal of Development Economics* **125**, 21–39.

Mattoo, A., Rocha, N. & Ruta, M. (2020), *Handbook of Deep Trade Agreements*, number 34055 *in* 'World Bank Publications', The World Bank.

Mayer, T. & Zignago, S. (2011), Notes on CEPII's distances measures: The geodist database, Working Papers 2011-25, CEPII.

Romalis, J. (2007), 'NAFTA's and CUSFTA's impact on international trade', *The review of Economics and Statistics* **89**(3), 416–435.

Volpe Martincus, C., Carballo, J. & Graziano, A. (2015), 'Customs', *Journal of International Economics* **96**(1), 119–137.

Weiss, D., Nelson, A., Vargas-Ruiz, C., Gligoric, K., Bavadekar, S., Gabrilovich, E., Bertozzi-Villa, A., Rozier, J., Gibson, H., Shekel, T., Kamath, C., Lieber, A., Schulman, K., Shao, Y., Qarkaxhija, V., Nandi, A., Keddie, S., Rumisha, S., Amratia, P. & Gething, P. (2020), 'Global maps of travel time to healthcare facilities', *Nature Medicine* **26**, 1–4.

World Bank (2020), *The African Continental Free Trade Area : Economic and Distributional Effects*.

Yotov, Y. (2021), The Variation of Gravity within Countries, School of Economics Working Paper Series 2021-12, LeBow College of Business, Drexel University.

A Network analysis - Method and assumptions

As a starting point, we build a network model which accounts for the current transportation network and we use it to compute transportation times between all city-pairs using a shortest-path algorithm. From this reference point, we run multiple improved scenarios that account for the planned infrastructure projects linked to the PIDA and we assess the reduction in shipping times resulting from these projects. We build a transport network for Africa and the rest of the world which includes land and maritime transport links. To simplify the network, we restrict the analysis to road and maritime links for Africa abstracting from rail and air connectivity, and to rail and maritime links in the rest of the world.

The multimodal network used in this analysis was constructed by merging two types of features: maritime and land (roads and rail). These features are largely non-overlapping and separated in space. For Africa, we rely on the road network from Open-Street Map, including most major road types for which we assume different speeds, as well some minor roads and ferries that provide essential connectivity. For the rest of the world, we use the rail and maritime networks from de Soyres et al. (2019) assuming different speeds on maritime and rail links. The rail network comes from Delorme Atlas of the Earth (DAE), 2015 release. Maritime features were generated separately for the Pacific, Atlantic and Indian Oceans, and for the Caribbean Basin and Seas of Indonesia.

To simulate plausible transoceanic shipping routes, great circle arcs were generated from near-port locations along the boundary of Exclusive Economic Zones. More details on the maritime and rail networks can be found in de Soyres et al. (2019). Each type of network element is assigned a cost calculated as the segment length divided by speed, where the speed of distinctive features is presented in Table A1. Segments that cross land borders and port links incur additional costs, as described in sections below.

Table A1: Speed assumptions (km/h) for different types of roads

	Eastern Africa	Middle Africa	Northern Africa	Southern Africa	Western Africa
motorway	90	80	106	110	107
motorway link	40	40	68	60	43
trunk road	81	64	79	95	73
trunk link	71	54	69	85	63
primary road	62	51	62	76	71
primary link	47	30	38	45	50
secondary road	54	58	62	66	51
secondary link	44	48	52	56	41
minor road	30				
rail	50				
ferry	25 + 2 hours				
maritime	25				

Note: Regional road speeds are averaged over country level speeds used in Weiss et al. (2020). Link speeds not reported (trunk link, secondary link) in the Weiss analysis are populated by subtracting 10 from the main type.

Once the network features are assembled, a shortest path algorithm is used to find the least-cost route (in terms of shipping time) between every city-pair in our network, considering all possible ways to link the origin city to the destination city. The output origin-destination (O-D) matrix includes 165 cities in Africa and over 1000 cities globally (inclusive of the African cities). While the network solution minimizes cost in time, we also calculate the total route length in kilometers and length of maritime portion.

The construction of a transport dataset for network analysis requires many assumptions and simplifications. First, the lack of data on traffic and road condition surely limits our ability to properly capture some routing. These limitations may also lead to an underestimation of gains resulting from some road projects, due to the utilization of roads in the baseline that are unsuitable for trucking, may require much lower speeds or even be impassable in rainy season. Nevertheless, comparison of baseline results with other sources (`google.com`, `openstreetmap.org`, `searoutes.com`) demonstrates general agreement with a small number of route comparisons.

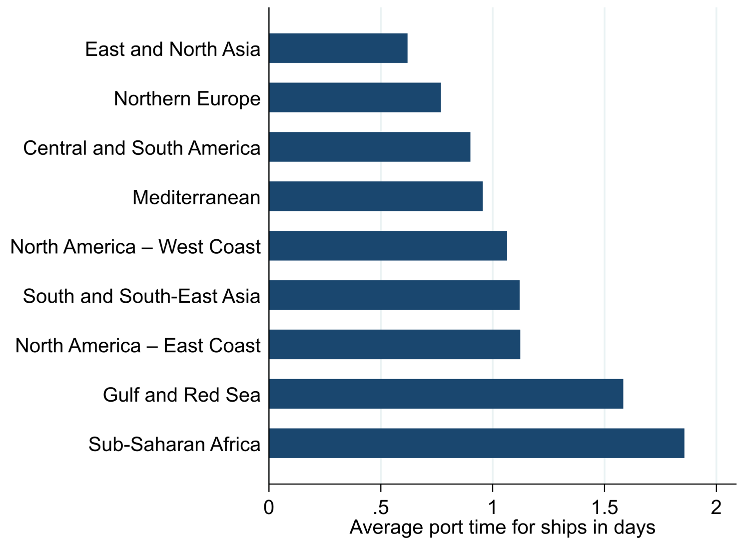
We account for the very high share of maritime shipping in international trade by using a network preference to produce a maritime alternative where land connectivity exists (same as in de Soyres et al. (2019)). Within the optimal path algorithm, this preference is implemented in the following way: for any city pair that has access to both a maritime and a rail link, the algorithm selects the maritime option whenever the shipping time is lower than four times the shipping time incurred using the rail link. While such a criterion can be seen as a strong simplification of the actual trade-offs, the imposition of such a preference for maritime links allows us to have a representation of the world that is very much in line with other data sources in terms of both modal shares and total shipping times.

Assumptions for port delays

On top of the time cost computed along the transport network elements, we account for processing times when a shipment is reaching / leaving ports due to delays in loading and unloading and other inefficiencies creating congestion at ports. We calibrate port congestion using the median number of days for container ships at ports from UNCTAD data on time vessels spend in port. The aggregated figures are derived from the fusion of automatic identification system (AIS) information with port mapping intelligence by MarineTraffic (at `http://marinetraffic.com`), covering ships of 1000 GT. The data used is the median time vessels spent within port limits (in days). Figure A1 shows the average port time based on UNCTAD delays at port for 2019 per maritime area. Ports in Sub-Saharan African countries have on average the longest delays at port, with ships waiting on average 1.8 days at port.

Processing time when crossing an international border is also an important part of overall transportation time for international trade. To account for border delays in our computations, we include importing and exporting time from the "trading across borders" section in the World Bank's Doing Business Database. The data is available for each country considered in our analysis. World Bank Doing Business indicators provide country-level information on the ease of crossing land or sea borders by measuring the number of documents required to trade, the days to cross the border, and the related costs to export and import. We restrict our analysis to time delays for importing and exporting for the latest year available. For each country, we define both land and sea border delays if the country is coastal and only land border delays if the country is landlocked.

Figure A1: Average port time based on UNCTAD delays at port for 2019



Note: Authors' calculations based on UNCTAD data on port calls for the median number of days for container ships at ports. Port data are averaged at the maritime area level.

Because data are reported only for the most used gateway per country, which for costal countries is generally a port, we assume that unobserved land-border times are a fraction of reported sea-border times. When only sea-border delays are available in the data, we assume that land-border delays are equal to a fourth of sea-border delays. We check that this assumption is in line with other cases when both land and sea border delays are available. In addition, we compare the obtained delays with data from external documents to ensure that this coefficient is acceptable.

In order to reduce border delays, several countries have implemented One-Stop-Border Posts (OSBP) to enable goods, people, and vehicles to stop in a single facility in which they undergo necessary controls to exit one state and enter the adjoining state. For border posts in Africa, we include such facilities using maps and status information from the Program for Infrastructure Development in Africa (PIDA) and various sources (World Bank reports and the 2016 One-Stop Border Post Sourcebook from NEPAD/ADB/ICA/JICA) on current, in construction, and planned One-Stop-Border Posts for Africa. We assume that land border delays are reduced by half when a functioning One-Stop-Border Post allows trucks to stop at only one facility. Table A2 summarizes the construction of the land border delays depending on the information available from the World Bank Doing Business indicators and on whether a country-pair border has an OSBP or not.

Finally, we combine these data to calculate delays for country-pair land borders and for each port. To get bilateral values for land border delays for each country-pair, we compute the total border delay as the sum of time for each border. Whenever a border is crossed along the optimal route, the "border penalty" is incurred.

Figure B2 shows the average border time per type of borders. The average land border delays in Africa are 90 hours for the borders without OSBPs and 50 hours for the borders with OSBPs. Figure B3 shows the distribution of these delays for all land borders with delays below 10 hours to delays above 250 hours. The fastest land-border delays are mostly in Northern Africa and between certain countries such as Botswana and

Table A2: Construction of final land border times without and with OSBP

Final land border time **without OSBP**		Country A	
		Land: time^{A}_{Land}	Sea: $time^{A}_{Sea}$
Country B	Land: time^{B}_{Land}	$\text{time}^{A}_{Land} + \text{time}^{B}_{Land}$	$0.25 \times time^{A}_{Sea} + time^{B}_{Land}$
	Sea: time^{B}_{Sea}	$\text{time}^{A}_{Land} + 0.25 \times time^{B}_{Land}$	$0.25 \times (time^{A}_{Sea} time^{B}_{Land})$

Final land border time **with OSBP**		Country A	
		Land: time^{A}_{Land}	Sea: $time^{A}_{Sea}$
Country B	Land: time^{B}_{Land}	$0.5 \times (time^{A}_{Land} + time^{B}_{Land})$	$0.5 \times (0.25 \times time^{A}_{Sea} + time^{B}_{Land})$
	Sea: time^{B}_{Sea}	$0.5 \times (time^{A}_{Land} + 0.25 \times time^{B}_{Land})$	$0.5 \times (0.25 \times time^{A}_{Sea} + 0.25 \times time^{B}_{Land})$

Namibia, Mozambique and South Africa, Kenya and Tanzania (Table A3). The longest delays are mostly in Central Africa around DRC, Central African Republic, and in Eastern Africa around North Sudan, South Sudan and Eritrea (Table A3). We finally cross-check our assumed border delays with observed delays from diverse external sources to validate our assumptions. To get delays at port, we compute the total delay as the sum of the processing time at the port to load or unload goods as defined previously and of the processing time at the maritime border.

Table A3: Land-border delays in hours (lowest 10 versus highest 10)

Top 10:			hours
BWA_NAM	Botswana	Namibia	10
MOZ_ZAF	Mozambique	South Africa	15
KEN_TZA	Kenya	Tanzania	20
LBY_TUN	Libya	Tunisia	21
DZA_TUN	Algeria	Tunisia	23
AGO_NAM	Angola	Namibia	24
CIV_GHA	Côte d'Ivoire	Ghana	26
BEN_NGA	Benin	Nigeria	26
BWA_ZAF	Botswana	South Africa	26
DZA_MAR	Algeria	Morocco	26
Bottom 10:			
CAF_COG	Central African Republic	Congo	191
COD_ZMB	Congo, Dem. Republic of	Zambia	194
CAF_COD	Central African Republic	Congo, Dem. Republic of	196
ETH_SSD	Ethiopia	South Sudan	197
DJI_ERI	Djibouti	Eritrea	212
COD_SSD	Congo, Dem. Republic of	South Sudan	220
ERI_ETH	Eritrea	Ethiopia	227
CAF_TCD	Central African Republic	Chad	228
CAF_SSD	Central African Republic	South Sudan	268
ERI_SDN	Eritrea	North Sudan	271

Note: Authors' calculations based on World Bank Trade Across Border Indicators. Land-border delays are assumed to be non-directional.

B Impacts of new PIDA projects on transportation times

Description of assessed projects

To build our estimates of shipping time reductions to be associated with the new continental free trade agreement, we need to enrich the current transportation network with planned projects. We use the set of projects described in the Program for Infrastructure Development in Africa to define the improvements. PIDA's long-term strategic planning for Africa's regional infrastructure (2012-40) has been conducted under the coordination of the African Union Commission, United Nations Economic Commission for Africa, African Development Bank and NEPAD Planning and Coordinating Agency, in cooperation with all African stakeholder. It aims at prioritizing the infrastructure necessary for more integrated transport, energy, ICT and transborder water networks to boost trade, spark growth and create jobs. Among the 409 projects, 232 projects focus on transport investments in ports, railways, roads, airports, and borders. As of 2018, among the 232 transport projects, only 37 are in operation, others are either in construction or at conception according to the PIDA dashboard webpage. In addition, we only keep the road, ports, and border projects with sufficient information for mapping.

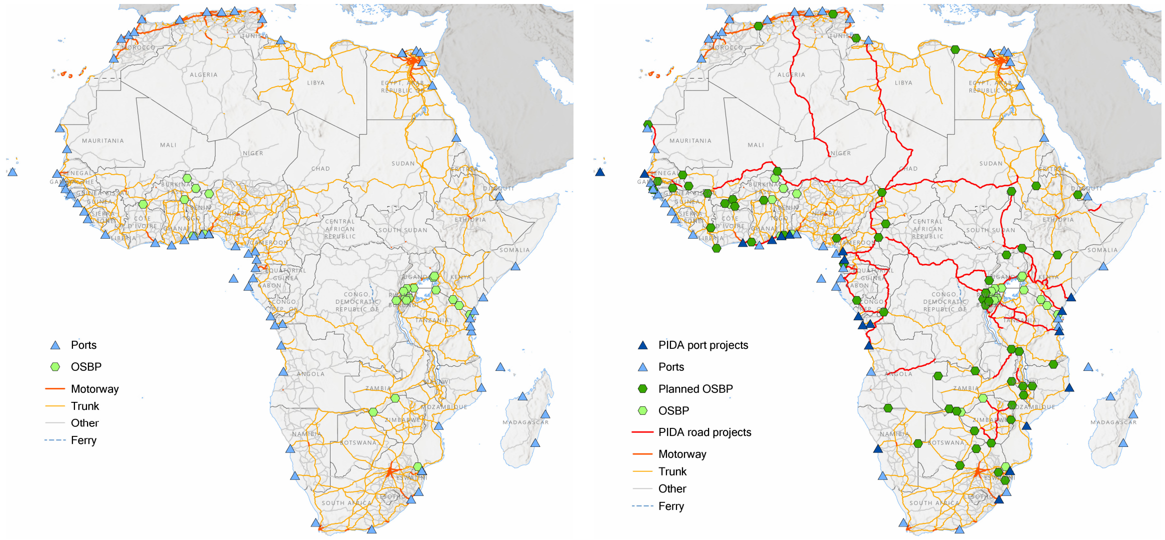
The result is 208 geo-referenced projects (roads, ports and border posts), summarized by country in Table B1. Projects are listed individually for roads, border posts, and for port investments.

Figure B1 shows the location of all PIDA projects included in our counterfactual. Port improvements will happen in the following places: Santa Cruz de Tenerife, Praia, Matadi, Beira, Lome, Maputo, Dar Es Salaam, Douala, Moanda, Mombasa, Nacala, Walvis Bay, Luanda, Kribi, Tema, Cotonou, Abidjan, Durban, Dakar, and Pointe Noir. Road upgrades range from less than 20 km to greater than 2000 km in length for sections of some Trans-African Highways. New border posts investments will reduce delays in all regions of Africa. As shown in the right map in Figure B1, projects can have a synergistic effect, resulting in dramatic reduction in transport time when road improvements, port upgrades and OSBP are implemented along the same route.

Table B1: Infrastructure Improvements by Country

Region	Country	Road (km)	OSBP	Port
Eastern Africa:	Burundi	417	5 (2)	0
	Djibouti	79	1	0
	Eritrea	0	0	0
	Ethiopia	25	3	0
	Kenya	2756	8 (5)	1
	Madagascar	0	0	0
	Malawi	238	5	0
	Mozambique	0	7 (1)	3
	Rwanda	157	9 (3)	0
	Somalia	246	0	0
	South Sudan	1292	3	0
	Tanzania	2512	10 (4)	1
	Uganda	546	7 (2)	0
	Zambia	670	8 (2)	0
	Zimbabwe	1480	6 (2)	0
Middle Africa:	Central African Republic	445	1	0
	Angola	1418	2	1
	Cameroon	2554	5	2
	Chad	2576	2	0
	Congo, Dem. Rep.	3063	7	2
	Equatorial Guinea	256	1	0
	Gabon	929	1	0
	Congo, Rep.	1718	2	1
Northern Africa:	Algeria	2332	2	0
	Egypt, Arab Rep.	0	1	0
	Libya	1240	2	0
	Morocco	0	2	0
	Sudan	1596	2	0
	Tunisia	0	2	0
Southern Africa:	Botswana	0	5	0
	Lesotho	0	0	0
	Namibia	0	3	1
	South Africa	0	6 (1)	1
	Eswatini	0	2	0
Western Africa:	Benin	137	3 (1)	1
	Burkina Faso	0	6 (3)	0
	Cabo Verde	0	0	1
	Côte d'Ivoire	167	6	2
	Gambia, The	0	1	0
	Ghana	544	3	1
	Guinea	0	2	0
	Guinea-Bissau	0	1	0
	Liberia	0	2	0
	Mali	1363	7	0
	Mauritania	481	1	0
	Niger	2291	4 (3)	0
	Nigeria	115	2	0
	Senegal	234	5	1
	Sierra Leone	0	0	0
	Togo	52	3 (1)	1

Figure B1: Existing transportation network and new investments in roads, ports and border posts



Note: Authors' construction based on the PIDA dashboard.

Table B2: List of geo-referenced road projects from PIDA

Program	Project	Location
Abidjan Lagos Coastal Transport Corridor	Abidjan - Grand Bassam Missing Road Links	Côte d'Ivoire
	Abidjan - Lagos Corridor Highway	Benin, Côte d'Ivoire, Ghana, Nigeria, Togo
	Agona Junction - Alubo Road	Ghana
	Godomey - Pahou Road	Benin
Central African Inter-Capital Connectivity	Huambo-Kuito Road	Angola
	Ketta-Djoum Road	Cameroon, Congo, Rep.
	Kinshasa - Luanda Road (Angola section)	Angola
	Kinshasa - Luanda Road (DRC section)	Congo, Dem. Rep.
	Kribi-Campo Bata Road	Cameroon, Equatorial Guinea
	Kuito-Luena Road	Angola
	Libreville-Bata Road	Equatorial Guinea, Gabon
	Libreville-Brazzaville Road (Congo section)	Congo, Rep.
	Libreville-Brazzaville Road (Gabon section)	Gabon
	Luena-Luau-Dilolo Road	Angola
	Ndende - Doussala - Dolisie	Gabon, Congo, Rep.
	Yaounde-Brazzaville Road (Cameroon section)	Cameroon
	Yaounde-Brazzaville Road (Congo section)	Congo, Rep.
Central Multimodal Transport Corridor	Bujumbura - Bugarama Road	Burundi
	Bujumbura - Rumonge (RN3) Road Section	Burundi
	Chaya-Manyoni Road	Tanzania
	Dar es Salaam - Chalinze - Morogoro Road Capacity Upgrade	Tanzania
	DSM-Manyoni-Isaka Road	Tanzania
	Gitega - Karuzi - Muyinga (RN12) Road	Burundi
	Isaka-Lusahunga Road	Tanzania
	Kasulu-Kibondo Nyakanazi Road	Tanzania
	Kayanza - Bugarama Road	Burundi
	Kidahwe-Kanazi-Kasulu Road	Tanzania
	Kidahwe-Uvinza Road	Tanzania
	Kigali - Ngoma Road	Rwanda
	Kigoma-Kidahwe Road	Tanzania
	Kobero - Muyinga Road	Burundi
	Lusahunga-Rusumo Road	Tanzania
	Mpanda - Kanazi Road	Tanzania
	Mpanda-Kasulu-Nyakanazi and Kasulu-Kigoma Roads	Tanzania
	Mpanda-Kasulu-Nyakanazi and Kasulu-Kigoma Roads	Tanzania
	Nyahua-Chaya, Urambo-Kaliua	Tanzania
	Kazirambwa-Chagu and Malagarasi-Uvinza Roads	Tanzania
	Nyakarara - Mwaro - Mweya -Gitega (RN18) Road Upgrade	Burundi
	Nyanza Lac-Mugina (RN3) Road	Burundi
	Nzega-Tabora Road	Tanzania
	Rumonge-Nyanza Lac Road	Burundi
	Tabora-Nyahua Road	Tanzania
	Urambo-Tabora Road	Tanzania
	Uvira - Bukavu Road	Dem. Rep. of Congo
	Dialocoto to Tambacounda on Dakar-Bamako Road	Senegal
	Kaolack to Fatick on Dakar-Bamako Road	Senegal
	Mako - Dialocoto Road	Mali

Table B2: List of geo-referenced road projects from PIDA (continued)

Djibouti-Addis Transport Corridor	Berbera-Hargeisa-Kalabayd-Togowuchale Road	Somalia
	Dobi - Galafi Road	Ethiopia
	Galafi - Yakobi Road	Djibouti
Douala-Bangui Douala-N Djamena Multimodal Corridor	Douala-N'Gaoundéré-N'Djamena Road	Chad
	Douala-N'Gaoundéré-N'Djamena Road Links in Cameroon	Cameroon
	Garoua - Boulai - N'Gaoundéré Road	Cameroon
Lamu Gateway Development	Eldoret - Nadapal Road	Kenya
	Garissa - Isiolo Highway	Kenya
	Isiolo - Lokichar - Lodwar - Nadapal Highway	Kenya
	Juba-Torit-Kapoeta-Nadapal Road	South Sudan
	Lamu - Garissa Highway	Kenya
North-South Multimodal Transport Corridor	Bulawayo - Gwanda Road	Zimbabwe
	Chirundu - Harare Road Link 1 (Chirundu Border Post)	Zimbabwe
	Chirundu - Harare Road Link 2 (Makuti to Karoi)	Zimbabwe
	Chirundu - Harare Road Link 3 (Karoi to Chinhoyi)	Zimbabwe
	Chirundu - Harare Road Link 4 (Chinhoyi to Harare)	Zimbabwe
	Gwanda - Beitbridge Road	Zimbabwe
	Harare - Beitbridge Road Link 1 (Harare to Chivhu)	Zimbabwe
	Harare - Beitbridge Road Link 2 (Chivhu to Masvingo)	Zimbabwe
	Harare - Beitbridge Road Link 3 (Masvingo to Turn Off)	Zimbabwe
	Harare - Beitbridge Road Link 4 (Turn Off to Beitbridge)	Zimbabwe
	Harare - Nyamapanda Road Project	Zimbabwe
	Kamuzu International Airport (KIA)	Malawi
	Kitwe - Chingola Road	Zambia
	Serenje - Nakonde Road Link 1 (Serenje - Mpika)	Zambia
	Serenje - Nakonde Road Link 2 (Mpika - Chinsali)	Zambia
	Serenje - Nakonde Road Link 3 (Chinsali - Nakonde)	Zambia
Northern Multimodal Transport Corridor	Bachuma Gate - Maji ya Chumvi Road	Kenya
	Bungoma - Eldoret Road	Kenya
	Eldoret - Kitale Road	Kenya
	Goma-Kisangani Road (DRC National Road No.2)	Congo, Dem. Rep.
	Juba-Bor-Malakal-Renki-Sudan border Road	South Sudan, Sudan
	Kabale - Kisoro Road (100km)	Uganda
	Kampala - Eldoret Road	Kenya
	Kampala Bombo Expressway Road	Uganda
	Kampala-Jinja Road	Uganda
	Kampala-Kibuye Busega-Mpigi Expressway Road	Uganda
	Katuna - Biumba Road	Uganda
	Masaka - Malaba Road	Uganda
	Mbarara-Ntugamo Road	Uganda
	Molo-Eldoret Road	Kenya
	Mombasa - Voi Road	Kenya
	Mombasa Southern Bypass Road	Kenya
	Mombasa-Nairobi Toll Road	Kenya
	Voi - Athi Road	Kenya
Pointe Noire - N Djamena Multimodal Transport Corridor	Dollisie - Brazzaville Road	Congo, Rep.
	Mambili - Ouesso Road	Congo, Rep.
Trans-African Highway Programme	TAH2: Algiers to Lagos - Missing Road Links in Algeria	Algeria
	TAH2: Algiers to Lagos - Missing Road Links in Niger	Niger
	TAH3: Tripoli to Cape Town - Missing Road Links	Libya, Niger, Nigeria
	TAH6: Ndjamena to Djibouti - Missing Road Links in Chad	Chad
	TAH6: Ndjamena to Djibouti - Missing Road Links in Sudan	Sudan
	TAH8: Lagos to Mombasa - Missing Road Links in Cameroon	Cameroon
	TAH8: Lagos to Mombasa - Missing Road Links in CAF	CAF
	TAH8: Lagos to Mombasa - Missing Road Links in DRC	Congo, Dem. Rep.
Trans-Maghreb Highway	Nouakchott - Nouadhibou Road	Mauritania

Notes: CAF stands for the Central African Republic ; DRC stands for the Democratic Republic of the Congo.

Table B3: List of border post improvements from PIDA and other sources

Program	Project	Location
Abidjan-Lagos	Elubo/ Noe One-Stop Border Post (OSBP)	Côte d'Ivoire, Ghana
Coastal	Hillacondji-Sanveekondji OSBP	Benin, Togo
Transport Corridor	Kraké/ Sémé Badagry OSBP*	Benin, Nigeria
	Noépé OSBP*	Ghana, Togo
	Ouidah/Hillacondji/Sanveekondji OSBP	Togo
Abidjan-Ouagadougou-Bamako	Kaouara-Niangoloko OSBP	Burkina Faso, Côte d'Ivoire
Multimodal Corridor	Pogo-Zegoua OSBP*	Côte d'Ivoire, Mali
Beira-Nacala	Colomue/Dedza OSBP	Malawi, Mozambique
Multimodal Transport	Forbes/Machipanda OSBP	Mozambique, Zimbabwe
Corridors	Nyamapanda/ Cuchimano OSBP	Mozambique, Zimbabwe
Central Multimodal	Gatumba/Kavimvira OSBP	Burundi, Congo, Dem. Rep.
Transport Corridor	Kabanga/Kobero OSBP*	Burundi, Tanzania
	Mutukula OSBP*	Tanzania, Uganda
	Rusumo OSBP*	Rwanda, Tanzania
Dakar-Bamako-Niamey	Kidira/ Diboli OSBP	Mali, Senegal
Multimodal Corridor	Koloko/Heremakono OSBP	Burkina Faso, Mali
Djibouti-Addis Corridor	Galafi OSBP	Djibouti, Ethiopia
Douala-Bangui Douala-N Djamena	Campo OSBP	Cameroon, Equatorial Guinea
Multimodal Transport	Garoua Boulai OSBP	Cameroon, CAF
Corridor	Kousséré OSBP	Cameroon, Chad
	Koutéré OSBP	Cameroon, Chad
Kinshasa-Brazzaville Bridge Road		
and Rail Project & Rail to Ilebo	Brazzaville-Kinshasa OSBP	Congo, Dem. Rep.
		Congo, Rep.
North-South	Beitbridge OSBP	South Africa, Zimbabwe
Multimodal Corridor	Martin's Drift OSBP	Botswana, South Africa
Northern Multimodal Transport Corridor	Katuna/Gatuna OSBP*	Rwanda, Uganda
	Malaba OSBP*	Kenya, Uganda
	Mpondwe OSBP	DRC, Uganda
	Nadapal OSBP	Kenya, South Sudan
	Renk (South Sudan/Sudan) OSBP	South Sudan, Sudan
	Rusizi/Bukavu OSBP	Congo, Dem. Rep. , Rwanda
Trans-African Highway	Zobue/Mwanza OSBP	Malawi, Mozambique
Trans-Maghreb Highway	Dakla/Nouadhibou OSBP	Mauritania, Morocco
	Ghardimaou OSBP	Algeria, Tunisia
	Musaid-Soloum OSBP	Egypt, Arab Rep. , Libya
	Oujda Tlemcen OSBP	Algeria, Morocco
	Ras Adjir OSBP	Libya, Tunisia

Notes: CAF stands for the Central African Republic ; DRC stands for the Democratic Republic of the Congo. * Projects that are considered already open in the baseline.

Table B3: List of border post improvements from PIDA and other sources (continued)

Program	Project	Location
added from OSBP Source book	Trans-Gambia Bridge	Senegal, Gambia, The
2nd Edition May 2016	Lebombo/Ressano Garcia*	South Africa, Mozambique
	Mandimba/Chiponde	Mozambique, Malawi
	Victoria Falls*	Zimbabwe, Zambia
	Taveta/Holili*	Kenya, Tanzania
	Moussala	Senegal, Mali
	Lunga Lunga/Horo Horo*	Kenya, Tanzania
	Tabou	Côte d'Ivoire, Liberia
	Wenela/Katima Mulilo	Namibia, Zambia
	Unity Bridge(Mtambaswala/Namoto)	Tanzania, Mozambique
	Lavumisa	Eswatini, South Africa
	Oshoek/Ngwenya	Eswatini, South Africa
	Gaya/Malanville*	Niger, Benin
	Paga/Dakola	Ghana, Burkina Faso
	Danane	Côte d'Ivoire, Liberia
	Nemba/Gasenyi I*	Rwanda, Burundi
	Mamuno/Trans Kalahari	Botswana, Namibia
	Pioneer's Gate/Skilpadeshek	South Africa, Botswana
	Kagitumba/Mirama Hills*	Uganda, Rwanda
	Labézanga	Mali, Niger
	Chirundu*	Zimbabwe, Zambia
	Akanyaru/Kanyaru	Rwanda, Burundi
	Kasumbalesa	Zambia, DRC
	Pételkolé*	Niger, Burkina Faso
	Doussala	Gabon, Congo, Rep.
	Rubavu/Goma	Rwanda, DRC
	Busia/Busia*	Uganda, Kenya
	Mpack	Guinea Bissau, Senegal
	Kantchari/Makalondi*	Niger, Burkina Faso
	Namanga/Namanga*	Kenya, Tanzania
	Isibania/Sirari*	Kenya, Tanzania
	Gisenyi/Goma	Rwanda, DRC
	Kasumulu/Songwe	Tanzania, Malawi
	Nigouni	Côte d'Ivoire, Mali
	Oshikango/Santa Clara	Namibia, Angola
	Ruhwa/Ruhwa*	Rwanda, Burundi
	Tunduma/Nakonde	Tanzania, Zambia
	Moyale	Kenya, Ethiopia
	Bibia/Elegu-Nimule	Uganda, South Sudan
	Gallaba/Metema	Sudan, Ethiopia
	Plumtree/Ramokgwebane	Zimbabwe, Botswana
	Mwami/Mchinji	Zambia, Malawi
	Kazungula	Botswana, Zambia
	Boundou/Fourdou	Guinea, Senegal
	Kouremale	Mali, Guinea
	Mfum	Cameroon, Nigeria
	Cinkansé*	Togo, Burkina Faso
	Chavuma/Caripande	Angola, Zambia

Notes: CAF stands for the Central African Republic ; DRC stands for the Democratic Republic of the Congo. * Projects that are considered already open in the baseline.

Table B4: List of port projects from PIDA

Program	Project	Location
Central Africa Hub Port	Banana Port Upgrade	DRC
and Rail Programme	Douala Port Upgrade	Cameroon
	Kribi Port Upgrade	Cameroon
	Matadi Port Upgrade	DRC
	Pointe Noire Port Upgrading	Congo, Rep.
Central Multimodal	Dar es Salaam New Berths Vijibweni,	
Transport Corridor	Mbwamaji and Kunduchi	Tanzania
	Dar es Salaam New Container Terminal	Tanzania
	Dar es Salaam New SPM Oil Terminal	Tanzania
	Dar es Salaam Port Modernisation	Tanzania
Northern Multimodal Transport Corridor	Mombasa Port New Container Terminal	Kenya
	Mombasa Port New Petroleum Facility	Kenya
Praia-Dakar-Abidjan	Marine transport system for operations	
Multimodal Transport Corridor	from Praia to West African ports (with PPP)	Cabo Verde
Southern Africa Hub Port	Beira New Coal Terminal Development	Mozambique
and Rail Programme	Beira Port Dredging	Mozambique
	Durban Port Expansion	South Africa
	Luanda Port Expansion	Angola
	Maputo Port Expansion	Mozambique
	Nacala Port Container Terminal Expansion	Mozambique
	Nacala Port New Coal Terminal	Mozambique
	Walvis Bay Port New Container Terminal	Namibia
West Africa Hub Port	Abidjan Port Upgrading	Côte d'Ivoire
and Rail Programme	Cotonou Port Upgrading	Benin
	Dakar Port Upgrading	Senegal
	Ile Boulay New Port / Container Terminal	Côte d'Ivoire
	Lome Port Upgrading	Togo
	Tema Port Upgrading	Ghana

Notes: CAF stands for the Central African Republic ; DRC stands for the Democratic Republic of the Congo.

Effects of new projects on transportation times

In this section, we present the results on transportation times from the network analysis before and after the PIDA projects are implemented. We start with an initial network of links connecting all cities considered in our analysis, and we then add additional links and improved speed corresponding to transport infrastructure projects that are linked to the PIDA list of projects.

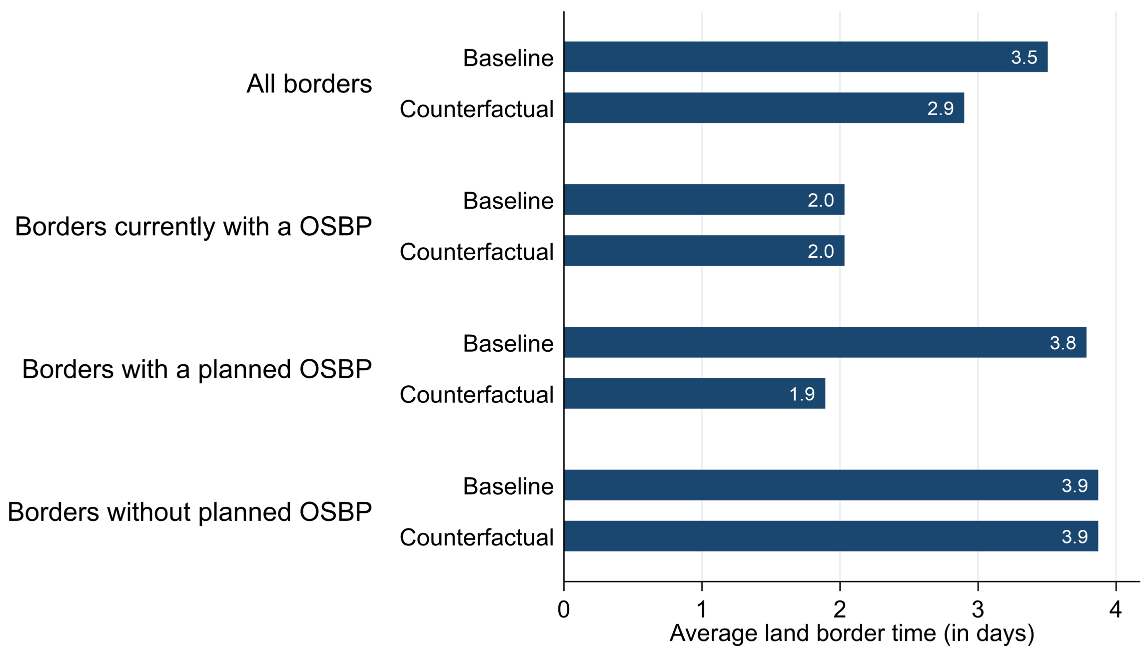
In the improved scenario, road improvements are introduced as an increase in speed from the current road type to average speed of motorway links in the region. We do not add any new road links to the network, which limits the potential gains deriving from road improvements only.

Similarly, when a project involves building a new port or upgrading an old port, we assume that the associated "processing time" decreases according to the following rule. The improved port delay equals the second-best performance in the region or the second-best performance in the continent if the port is already among the best in its region. Dividing Africa into 5 regions (North, West, Central, East, and South), we assume that a port investment will reduce port and border delays to the level of the second-best performer in the same region according to the UNCTAD dataset and World Bank Doing Business Indicators.

Figure A1 in the previous section reports the baseline and new total sea-border time per country which is the sum of the port delays for ships as reported by UNCTAD and the sea-border delays as reported by World Bank Doing Business Indicators. When a project involves a border improvement to create a One Stop Border Post, the border delay is divided by two following the rule described in Table A2.

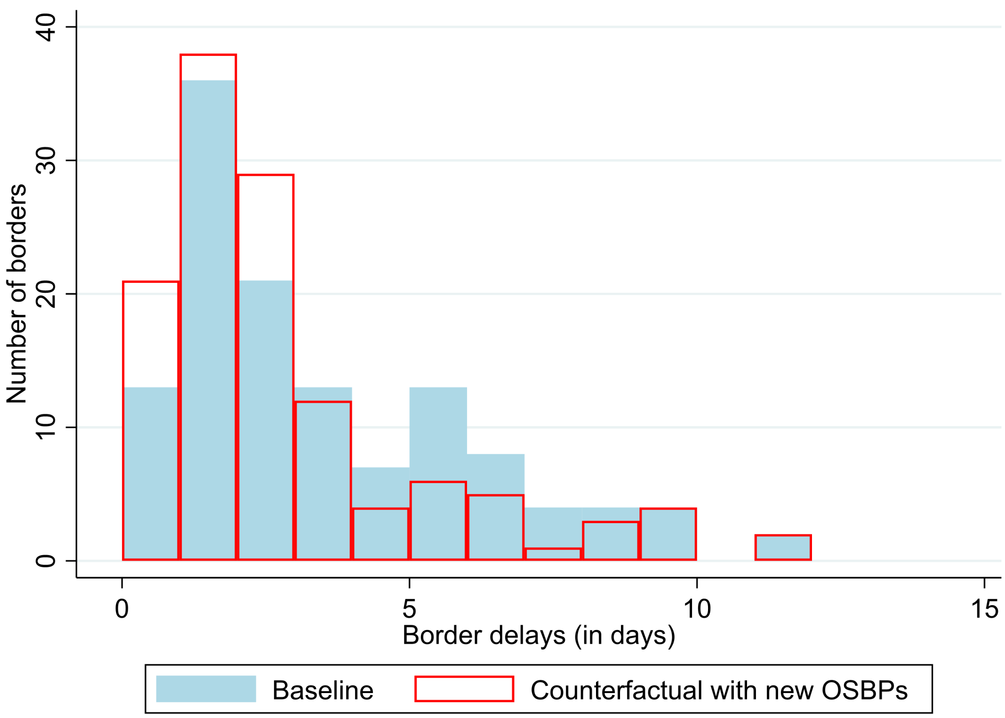
Figure B2 shows the average land border time in the baseline and counterfactual scenarios. For all borders, the average time will decrease form 3.5 days to 2.9 days. For the borders with a planned investment, the average border delays will drop from 3.8 to 1.9 days. Figure B3 shows the new distribution of land border delays when considering new OSBPs. The new distribution clearly moves to the left with fewer borders with delays from 5 to 9 days. The list of PIDA projects does not include investments for the borders with the longest delays, above 9 days.

Figure B2: Average border time per type of border



Note: Authors' construction based on World Bank Doing Business Indicators

Figure B3: Distribution of land border delays in Africa, before and after the new investments



Note: Authors' construction based on World Bank Doing Business Indicators.

Total impacts on transportation times

Based on the method detailed above, we estimate reductions in transportation times between all the pairs of cities considered in our analysis. To aggregate all values at the country-pair level, we take a theory consistent approach based on Hinz (2017) and detailed in the main text.

At a more disaggregated level, the results assuming maritime preference feature significant heterogeneity when looking across country-pairs (Table B6 for the results from each country towards the Middle East and North Africa region, and towards the Sub-Saharan Africa region.). The countries experiencing the largest reduction in shipping times assuming maritime preference to Sub-Saharan African countries when investing in roads, borders and ports are South Sudan, Burundi, Rwanda, the Republic of Congo, Togo, Uganda, Zambia, Kenya, Tanzania and Tunisia. The countries benefiting the least are the Arab Republic of Egypt, Eritrea, Madagascar, Guinea-Bissau, Liberia and Sao-Tome and Principe. These results show why it is important to use a network approach in order to understand the interconnections of all planned infrastructure: the gains in landlocked countries are the results of the infrastructure in the country of interest as well as transit countries to reach a port.

Finally, Table B7 details for each country the average percentage change in transportation time for incoming (In) and outcoming (Out) shipments as projected in the different simulation scenarios. Those shocks are used in the general equilibrium assessment as the counterfactual changes in connectivity for African economies.

Table B5: Proportional decrease in transportation time, aggregated by regions (all African countries)

Origin	Destination	Baseline	Improvements in Roads land borders and ports
		# Days	% Change
Without Maritime Pref.			
	Africa	17	-18.63
	East Asia & Pacific	37	-2.26
	Europe & Central Asia	22	-5.47
Africa	Latin America & Caribbean	29	-4.82
	Middle East	25	-6.75
	North America	28	-6.00
	South Asia	31	-4.46
With Maritime Pref.			
	Africa	26	-19.69
	East Asia & Pacific	41	-5.77
	Europe & Central Asia	27	-8.95
Africa	Latin America & Caribbean	32	-8.40
	Middle East	31	-9.17
	North America	32	-7.79
	South Asia	35	-7.14

Note: city level transport time are aggregate at the country-pair level using a theory consistent population-weighted average.

Table B6: Decrease in transportation time, aggregated by country

	Without Maritime pref		With Maritime pref	
	Baseline	Improvements in: Roads, land borders ports	Baseline	Improvements in: Roads, land borders land borders
	# Days	% Change	# Days	% Change
AGO	25	-3.42	30	-9.99
BDI	28	-12.68	38	-25.63
BEN	23	-4.60	27	-5.50
BFA	25	-7.95	34	-16.00
BWA	25	-4.60	28	-6.89
CAF	29	-11.19	39	-16.10
CIV	24	-7.39	31	-18.64
CMR	31	-12.24	40	-10.82
COD	28	-9.73	37	-15.69
COG	29	-12.04	39	-23.26
COM	25	-1.34	26	-2.74
CPV	24	-1.98	26	-4.02
DJI	22	-7.95	26	-3.24
DZA	20	-6.54	25	-13.48
EGY	20	-6.77	27	-3.69
ERI	23	-2.45	26	-2.69
ETH	23	-10.23	28	-8.30
GAB	26	-5.56	28	-2.61
GHA	25	-6.45	28	-7.97
GIN	23	-6.55	27	-3.31
GMB	23	-7.38	31	-17.89
GNB	23	-4.43	27	-3.09
GNQ	28	-9.26	32	-2.87
KEN	23	-8.69	32	-21.72
LBR	26	-7.14	32	-2.96
LBY	20	-6.22	25	-11.48
LSO	30	-3.16	33	-4.43
MAR	20	-6.24	25	-6.51
MDG	26	-1.21	28	-2.53
MLI	23	-7.05	28	-7.57
MOZ	24	-4.59	27	-5.63
MRT	21	-7.28	27	-4.58
MWI	26	-9.91	29	-6.81
NAM	25	-3.57	29	-6.44
NER	23	-6.53	28	-9.27
NGA	25	-7.35	34	-18.88
RWA	28	-12.25	37	-22.44
SDN	22	-8.74	36	-7.41
SEN	22	-4.97	25	-6.75
SLE	24	-4.74	27	-3.06
SOM	23	-6.13	26	-2.72
SSD	28	-18.15	39	-21.30
STP	28	-0.98	30	-2.54
SWZ	26	-4.09	29	-5.66
TCD	26	-9.91	34	-18.37
TGO	27	-10.28	31	-17.35
TUN	19	-5.86	25	-14.28
TZA	25	-6.97	34	-24.29
UGA	25	-8.95	34	-21.31
ZAF	24	-3.98	28	-5.43
ZMB	28	-12.82	31	-9.73
ZWE	28	-10.71	30	-8.64

Table B7: Average transportation time shocks by country and scenario

	Without Maritime pref Improvements in: Roads land borders ports		With Maritime pref Improvements in: Roads land borders ports	
Country:	In	Out	In	Out
Burundi	-7.37	-13.96	-7.35	-25.62
Botswana	-7.47	-14.06	-7.87	-20.62
Côte d'Ivoire	-27.64	-7.49	-27.62	-9.04
Algeria	-2.76	-6.53	-2.26	-21.38
Egypt, Arab Rep.	-7.73	-12.88	-7.53	-9.53
Ghana	-6.44	-11.10	-7.45	-21.40
Kenya	-0.01	-0.22	0.00	-2.45
Lesotho	-0.65	-5.94	-1.21	-13.46
Morocco	-0.31	-6.59	-0.51	-7.17
Mozambique	-0.36	-9.80	-0.21	-7.45
Mauritius	-1.67	-4.36	-1.41	-5.87
Namibia	-2.74	-8.73	-3.90	-20.86
Niger	0.00	-1.28	-0.01	-0.24
Nigeria	-0.85	-1.83	-1.26	-1.86
Rwanda	-0.06	-0.18	-0.24	-0.60
Senegal	-0.34	-3.86	-0.29	-3.87
Eswatini	0.00	0.00	0.00	0.00
Tunisia	-3.83	-18.64	-3.81	-12.62
Tanzania	-17.49	-7.36	-17.49	-9.93
Uganda	-28.73	-5.23	-29.20	-6.29
South Africa	-0.20	-7.43	-0.23	-20.53
Burkina Faso	-7.67	-10.53	-7.66	-18.42
Cameroon	-2.73	-5.01	-2.62	-10.16
Congo, Rep.	-0.36	-2.37	-0.37	-6.13
Cabo Verde	-1.72	-2.81	-2.66	-3.39
Ethiopia	-3.44	-13.02	-3.75	-25.42
Madagascar	-3.10	-6.88	-4.23	-13.96
Malawi	-0.54	-6.28	-0.76	-6.51
Zambia	-14.96	-16.38	-14.85	-12.15
Zimbabwe	-28.66	-31.33	-28.59	-30.42

Notes: Transportation time changes induced by the different infrastructure improvement detailed in the previous sections. "In" stands for reduction of transportation time for incoming shipments (this includes domestic sales); whereas "Out" stands for transportation time for outcoming shipments (this only includes international shipments).