Access to Markets and Technology Adoption in the Agricultural Sector: Evidence from Brazil

Diego Astorga*

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Abstract

This paper studies how better market access through infrastructure improvements leads to the adoption of new agricultural technologies. In particular, I study the case of Brazil, and how the construction of the federal highway network from 1950 to 2000 affected the modernization of the agricultural sector. To address endogeneity concerns, I use the creation of Brasilia, and the project to connect it to the state capitals, as a natural experiment. I build a predicted network of highways by computing the cheapest way to connect the state capitals with Brasilia and use it to instrument market access. I find that municipalities where market access increased adopted new agricultural inputs such as fertilizers and pesticides, improving agricultural productivity as a result. Market access also increased the machinery and equipment used for production, but only when Brazil deregulated its agricultural markets and opened to international trade, after 1990.

Keywords: agricultural productivity, infrastructure, market access, mechanization

JEL codes: O13,O18,F14

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1 Introduction

The adoption of new technologies and machinery in the agricultural sector is considered instrumental for development. Recent literature has highlighted the importance of the agricultural sector in explaining differences between incomes across countries (Gollin, Parente and Rogerson (2002); Gollin, Lagakos and Waugh (2013); Caselli (2005); Restuccia, Yang and Zhu (2008)).[1]

These studies suggest that developing countries would benefit the most from adopting technology to increase their agricultural productivity. However, the adoption rates of better agricultural technology and machinery remain low in many developing countries, specially in sub-Saharan Africa (Foster and Rosenzweig, 2010).

This paper assesses how infrastructure improvements can lead to a higher agricultural productivity as a result of better market access. I define market access as the sum of the potential markets that a municipality can have access to, weighted by how costly is for that municipality to arrive to those markets, and by how important these destinations are. Using data on expenditures and the value of goods from the agricultural censuses, from 1950 to 2006, in combination with geo-coded decennial maps of the expansion of the federal highways of Brazil since 1950, I estimate the causal impact of the expansion of federal highways in Brazil on the mechanization (measured by the value of machinery and equipment and number of tractors) and usage of inputs (measured by the expenditures in fertilizers, seeds and herbicides) of its municipalities. I also study whether the effects of infrastructure varied depending on the trade liberalization and the deregulation of the agricultural market undertaken by the country.

The case of Brazil provides an interesting context for several reasons. First, over the past 60 years, Brazil has made efforts to integrate the whole country by building infrastructure, with highways as one of the principal investments. Before 1951, the few existing roads in Brazil were limited to the coastal areas of the southeast and northeast, with the rest of the country being poorly connected by local roads from the main population centers. Between 1952 and 2000, there was a 471% increase in total road length (Bird and Straub, 2014) Yet, improvements in logistics and transport infrastructure are still identified as one of the key priorities for the agricultural sector (Baer, 2001).

Second, a common problem when estimating the effects of highway constructions on economic outcomes is the endogeneity in the decision of where to construct the highway. Project developers may decide the route of the highway by targeting specific regions according to their development prospects, which may create an estimation bias.[2] I use the creation of Brasilia and the project to connect it to the state capitals as a natural experiment to circumvent this problem. When Brasilia was constructed, in the middle

[1]Particularly, the size of the gap in income per worker between wealthy countries and poor countries depends on the sector of study. On average, differences in income per worker are only moderately larger in the non-agricultural sector. Meanwhile, in the agricultural sector, workers are many times more productive in rich countries than in the poor ones (Restuccia, Yang and Zhu, 2008).

[2]Estimates can be downward biased if the targeted places crossed by the highways were on a worst trend than their neighbors, for example, or upward biased if the focus was to further develop the regions with more growth prospects already.

of the country, it had no real communication between it and any other location. Hence, the government started a project to build eight radial highways to connect the new capital with the state capitals. I construct a predicted network that connects Brasilia with all the state capitals through eight hypothetical highways. These highways are the ones that would have been constructed if the government had prioritized minimizing the linear distance of the whole network.[3] I use this predicted network to instrument, not only the travel cost from one municipality to another, but also the total market access that the municipalities had in each decade. The instrumented market access is the result of the access given by this predicted network of highways that connects Brasilia with all the other state capitals rather than the actual network of highways.

Results indicate the importance of taking the endogeneity of market access and the existence of foreign demand in to account. OLS estimates are downward biased, consistent with a central government, that worrying over integrating the country, was constructing highways in municipalities that had a lower trend in agricultural development. With respect to foreign markets, not taking them into account generates instead an upward bias, as the domestic market access was underreporting the real market access for localities near to ports, who were increasing substantially their agricultural productivity.

The baseline estimates indicate that the agricultural GDP per hectare increased by 1.26% yearly due to the augmented market access. This accounts for 52% of the total growth seen in the economy over the period of 1950 to 2006. For the salary of the agricultural workers and the value of land per hectare, the increase for market access accounted for 49% and 36% of the total yearly growth respectively. The numbers are similar for the technology of inputs: 41% on seeds, 54% on fertilizers and almost 80% on herbicides. However, I find no effect of the market access on the investment measured as the value of machinery per hectare and the number of tractors.

I explore if the reasons for this zero effect were the export restrictions, the high import tariffs to intermediate goods and the ceiling prices experienced by Brazil from 1960 to 1980, which provided low incentives to invest in new equipment or machinery. Once I focus on the period after the trade liberalization and no price-controls, I find a significant and economically important effect for both variables. Because of market access, the value of machinery per hectare grew 0.63% a year (15% of the total yearly growth) and for the number of tractors per hectare, it represented an increase of 2.2% (27%). My results, therefore, highlights the importance of the interaction between market access and trade policies for the technology adoption in agriculture.

This pattern is consistent with two potential channels. One the one hand, machinery and equipment involve a bigger fixed cost than inputs such as fertilizers, so the profitability of the investment in this type of technology should be higher to make it worthwhile; which for the case of Brazil occurred after its trade liberalization. A possible second channel is municipalities specializing in export-oriented crops that are more

[3]This idea of constructing a predicted network to build an instrument has been used in other papers too. Faber (2014), Alder (2015) are examples of this procedure. In the case of Brazil, Morten and Oliveira (2016) used it to instrument the trade cost from origin to destination.

capital-intensive because of the increase in market access after 1990. Both channels are briefly discussed and its a question of interest for further research to see the specific role that both channels played. Results are robust to alternative definitions of external demand, different subsamples and different values of trade elasticities.

This paper mostly relates to the literature about the barriers to technology adoption and mechanization in agriculture. The suggested reasons for the low take-up in poor countries include lack of knowledge about the technology and the process of learning, credit or insurance constraints, high costs of technology adaptation and behavioral biases.[4] In an attempt to reduce these barriers, several interventions have been studied, such as fertilizer subsidies (Duflo, Kremer and Robinson, 2011), credit and rainfall insurance (Bardhan and Mookherjee (2011) and Karlan et al. (2014)) and more recently, the improvement of rural road infrastructure (Aggarwal et al. (2018), Aggarwal (2018) and Shamdasani (2016)).In this paper, I focus instead on a large-scale infrastructure project, namely, the federal highway network in Brazil. The size of the project could definitely be important as it has macro effects, such as the reallocation of people within the country, that the rural program might not have.[5]

The closest paper in this regard is Atack and Margo (2011), which studies the effect that the railroad expansion in the United States had on converting unproductive land into farmland from 1850 to 1860. However, the authors study the extensive margin on agriculture decisions, while I focus on the intensive margin over a larger period of time with faster technological growth (1950–2006). The second difference is technical: Atack and Margo (2011) compare between treatment and control counties. I follow the approach of Donaldson and Hornbeck (2016) that uses a measure of market access, which takes into account the fact that even "control" areas are being affected by the large-scale infrastructure. Finally, I also provide evidence of the relevance that the access to external markets and the trade policies followed by the country have for the technology adoption in agriculture.

The empirical strategy followed in this paper borrows from Bird and Straub (2014) and Morten and Oliveira (2016) who use the construction of Brasilia as a natural experiment. While Bird and Straub (2014) use linear distance to a predicted network to study the effects of the highway on the concentration of economic activity, Morten and Oliveira (2016) use a Fast Marching Method algorithm to instrument the travel cost between all the pairs of origin–destination municipalities and use it to estimate elasticities of trade and migration. I follow closely the approach of the latter but use it not only to instrument the travel cost between pair of municipalities but also to instrument the measure of market access constructed in the paper.

Lastly, this paper connects with the vast literature on the effect of market access in developing countries, in particular inter-regional transport costs, on outcomes such as growth or gains from trade (e.g, Banerjee, Duflo and Qian (2012), Bird and Straub

[4]For a review of the reasons see Jack (2011) and Foster and Rosenzweig (2010).

[5]Morten and Oliveira (2016) in fact show that for Brazil, there was an effect on migration because of the highways. Jedwab and Storeygard (2018) also argue that rural road infrastructure might not be comparable with large-highway infrastructure projects, given the scope and cost of both projects.

(2014),Faber (2014), Storeygard (2016), Donaldson and Hornbeck (2016), Morten and Oliveira (2016) , Alder (2015), Jedwab and Storeygard (2018)).[6] Instead of focusing on the overall or aggregate impact of the infrastructure project, I focus on the technology decisions and mechanization on agriculture. This is a feature often neglected when computing the gains from trade and market integration, which often assumes that changes in the location productivity are orthogonal to changes in market access. The results found in the paper serve to highlight the potential importance of including technological change as an endogenous decision in models studying the welfare gains of infrastructure projects.

The remainder of the paper is organized as follows. Section 2 details the background of the Brazil highway infrastructure in the period studied, and the main data and outcomes used in the analysis. Section 3 focuses on the empirical strategy, such as the construction of market access, the constructed instrument of market access exploiting Brasilia as a natural experiment, and a discussion of the main empirical estimation. Section 4 details the baseline results, while Section 5 analyzes how the estimates changed for those two periods explained before in Brazil. Section 6 summarizes the robustness checks done in the paper and Section 7 concludes.

2 Background and Data

2.1 The Construction of Brasilia and the Highway Network

Although Brasilia construction started in 1956, the idea of Brasilia was already in the mind of the government decades before. The idea of a capital city can be traced back to when the first Constitution of Brazil was established in 1891, but it was not until 1922 that the National Congress approved the creation of the new capital within a site, at the time called *Quadrilatero Cruls*, close to the border of the states of Goias and Minas Gerias. This *Quadrilatero* would eventually become Brasilia. In spite of this early idea, the transfer of the capital to the interior took many years more because of logistical, economic, and political barriers. Only when Juscelino Kubitschek was elected for president in 1956, the construction of Brasilia began, that same year. The city was officially inaugurated on April 21, 1960.

Brasilia's creation fostered the development of the highway network by consolidating the idea of a national transportation system. Before 1951, the existing roads in Brazil were limited to coastal areas of the southeast and northeast of the country (Morten and Oliveira, 2016; Bird and Straub, 2014). The first idea of a national transportation system began to be considered during the administration of Gertulio Vargas (1934_1946). It started to materialized between 1951 and 1957, when the Brasilia-Belo Horizonte highway was established, along with some parts of the Brasilia-Anapolis highway, connecting the soon-to-be capital Brasilia with the city of Belo Horizonte and Sao Paulo respectively. The construction of Brasilia, under Juscelino Kubitschek's administration,

[6] For a complete review see, Berg et al. (2017), Redding and Turner (2015), and Donaldson (2015).

drove Brazil to increased efforts to construct a true national highway system. A plan was determined and implemented so that the highways would be built, in order to connect Brasilia with all the capitals of the Brasilian states, as well as the north and south regions.[7]

The resulting federal highway network nowadays consists mainly of four types of highways, which can be differentiated depending on the direction they run towards: the ones connecting north to south; the ones linking the east to west; and the ones going diagonally, whether northeast to southwest or northwest to southeast. Finally, the last type of road is the radial highways, which consist of a total of eight highways that run radially from Brasilia towards the country's extremes in the eight directions (north, northeast, east, southeast, south, southwest, west and northwest), connecting Brasilia with the rest of the country. These radial highways will be the ones used in the instrument, so the relevance of the instrument relies on the importance of these highways relative to the network as a whole.

2.2 Data

2.2.1 Roads:1950–2000:

I combine two set of sources to obtain the geo-referenced vector-based maps of the federal highway network from 1950 to 2000. First, for the period 1960 to 2000, I acquire the maps from the Brazilian Ministry of Transportation. These maps were constructed based on statistical yearbooks from the Ministry's Planning Agency. No official map was available at the Ministry's office for 1950. To solve this problem, I collect a road map of selected roads in Brazil in 1954 from the Library of Congress in Washington.[8] I geo-reference the image of the roads in 1954 using ArcGIS software, without taking into account the roads representing the Brasilia-Belo Horizonte highway and the Brasilia-Anapolis highway, which were built after 1950.[9]

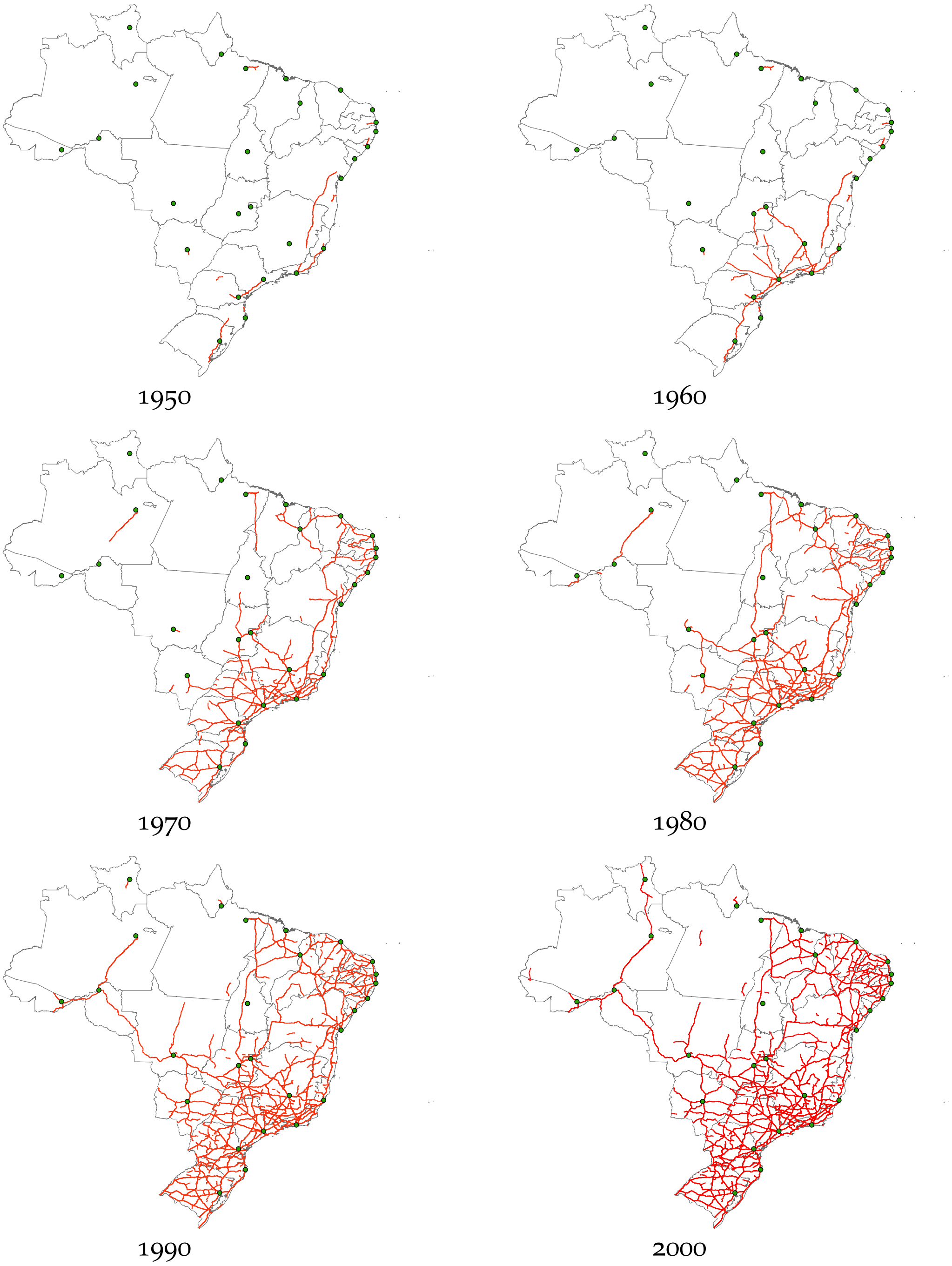
Figure 1 shows the expansion of the highway network across the decades.During the 1950s, most new connections were between locations along the Atlantic coast; from the 1960s onward, more corridors started to link to the interior of the country. Most of the expansion of the network occurred between 1960 and 1980. During the 1960s, construction was focused in the south and southeast, while in the 1970s and 1980s, the northeast and the center-west of the country became increasingly connected. The region of the north was the one that experienced the latest integration process in the period studied, with only a few corridors made during the 80s and the 90s.

[7] I use 1950 as a conservative date for any effect resulting from the construction of Brasilia, to net out the two projects that started prior to the inauguration of the city.

[8] Available on-line from the web page: https://www.loc.gov/resource/g5400.ct002977/?r=-0.061,0.411,1.256,0.762,0

[9] I also abstract few roads from the image of the selected roads in 1954 that do not appear in the 1960 vector map, as these "selected roads" are not part of the federal highway network. One possibility would have been to add this selected roads to all the decades, to have a better proxy of the network of roads as a whole, not only the federal highway network. However, such maps were not available for all decades,hence why this paper focuses on the effect of macro-infrastructure (i.e., the federal highways).

FIGURE 1
EVOLUTION OF THE HIGHWAY NETWORK



2.2.2 Agricultural Census

The main datasets used in the empirical analysis are the agriculture census of Brazil. These censuses collects information on agricultural establishments, forests and/or aquaculture from all municipalities in the country.

I obtained the agricultural census information from two different sources: : the archives of the Brazilian Institute of Geography and Statistics (henceforth IBGE), and the IBGE website. From the archives of the IBGE, I obtained the scanned version of the censuses from 1950, 1960, 1970, 1975, and 1980.[10] I digitalized the main variables used in the paper and appended it to the information from the last two censuses done in the country (1996 and 2006) that were available already in digital form in the IBGE website.

Since the analysis is at the municipality level, I need to have municipalities that are comparable over time. This need for consistent areas across time is especially relevant in the case of Brazil: in 1950 it had 1890 municipalities, compared to 5565 in 2010. In order to solve the need for comparable areas, I follow the procedure of Ehrl (2017), that provides a code to construct time-consistent 'Minimum Comparable Areas' (AMC by its acronym in portuguese) for any two periods in Brazil. I construct the AMCs from 1950 to 2010. These areas will be the main units of analysis in the entire paper; however, for exponential purposes, I will call them municipalities instead of AMC's, keeping in mind that these are "time consistent municipalities". The main variables that I use are:

1. Input technology: I use the disaggregated expenditures to see the changes in consumption of inputs in the municipalities across time. In particular, I am interested in the expenditure on seeds, fertilizers, and insecticides or herbicides, as they reflect the investment in technologies that are designed to help increase agricultural productivity.[11]

2. Machinery and equipment: I use the value of machinery and equipment, and the total number of tractors to see how mechanized the localities were because of the market access.

3. Other set of outcomes: I study another group of outcomes to document other changes that were produced in the agricultural sector because of the expansion in infrastructure. Still from the agricultural census data, I study the value of land[12] and the expenditures in salaries per worker, as proxies for the increase in profits and the welfare of the workforce of the localities. I also collect a measure of the agriculture GDP by municipality, constructed by the Institute of Applied Economic Research (IPEA in Portuguese) as a proxy for agricultural productivity.

Conceptually, having access to markets can affect mechanization in two ways. Having access to more demand markets would increase the expected benefits of production and therefore it would be more likely that a firm would be willing to pay the fixed cost for adopting better inputs or machinery. The second channel that is possible is better access to input markets, as more access to suppliers can reduce the price of the inputs necessary for production, providing incentives to the firm to increase their input usage

[10] I also have the agricultural census of 1985, however, I decide not to use it in the analysis because of the lack of disaggregated data on both value of assets and expenditures.

[11] In the case of Brazil,these inputs can be regarded as technology. The progress of agriculture into the *Cerrado* (a region that was deemed unfertile in the 1970's but today is regarded as one of the most fertile in the country) was ,in part, due to prodigious doses of lime and fertilizer used in that region.

[12] There is a problem with the value of land, and the value of machinery and equipment in 1996, as they are not available at the municipal level. Because of that, for these variables, the period of 1996 is omitted.

Table 1
Compound Annual Growth Rate-Main Variables

Expenditures per hectare	1950-1960	1960-1970	1970-1980	1980-1996	1996-2006	1950-2006
Seeds	0.06	0.03	0.09	0.03	0.06	0.04
Fertilizers	0.06	0.11	0.13	-0.01	0.13	0.07
Herbicides	0.07	0.09	0.11	0.06	0.16	0.08
Value of Assets per hectare	**1950-1960**	**1960-1970**	**1970-1980**	**1980-1996**	**1980-2006**	**1950-2006**
Value of Machinery	0.02	0.05	0.12		0.03	0.04
Number of tractors per hectare	0.24	0.54	0.56	0.03	-0.002	0.08
Other outcomes 1950	**1950-1960**	**1960-1970**	**1970-1980**	**1980-1996**	**1996-2006**	**1950-2006**
Value of Land	0.03	0.04	0.18		0.02	0.05
Salaries per worker	-0.01	0.01	0.05	0.03	0.07	0.03
Agricultural GDP per hectare	0.02	0.01	0.07	0.01	0.03	0.02
GDP of Brazil	0.07	0.07	0.09	0.01	0.04	0.05
Observations		1,775	1,775	1,775	1,775	1,775

Notes: No data for the value of machinery per hectare and the valur of land per hectare, as the value of assets by categories was not available in 1996 by municipality.

and quality. In the study, I would be focusing in the aggregate affect of market access on technology adoption.

Table A.1.1, in the Appendix, reports the mean and the standard deviation of each variable. All outcomes that are in BRL reals are in constant reals for the year 2000. All variables have increased consistently over the decade, consistent with Brazil transitioning to an agribusiness model of farming, in each period becoming more mechanized (Baer, 2001).

Table 1 analyzes the compound annual growth rates of the variables over the decades. The period from 1970 to 1980 registered the biggest increase in most of the expenditures and the value of assets analyzed, with the last period (1996 to 2006) being more important for the expenditure on fertilizers, herbicides, and salaries per worker.

3 Empirical Strategy

I study how increased market access affected the mechanization and use of inputs in the municipalities of Brazil between 1950 and 2006. Before describing the full specification used in the empirical analysis, it is important to understand what I mean by market access and the different components this definition entails.

3.1 Construction of Market Access

I follow a definition of market access for municipality i, similar to what Donaldson and Hornbeck (2016) propose in their empirical estimation:

$$MA_{it} = \sum_{j \neq i} \tau_{ijt}^{-\theta} shareGDP_{jt} \tag{1}$$

Equation 1 refers to how costly it is for municipality of origin i to trade with each destination j τ_{ijt}, weighted by how important these destinations are. I use as weights for destination *j* the share GDP of Brazil that corresponds to that destination ($shareGDP_{jt}$). The last component θ is known as the "trade cost elasticity", measures how sensitive the exports are to an increase in the trade cost. Market access MA_{it} varies from 0 to 1, a market access of 0 in municipality i means that municipality i does not have access to any other location in the country and is completely isolated, and a market access of 1 means the complete opposite of being fully connected with all destination and having access to the whole country.

3.1.1 Geographic Trade Cost

To obtain a measure of geograhic trade costs τ_{ijt}, I first compute the bilateral traveling cost $c(i,j)_t$ between all the pairs of origin–destination municipalities in each decade using the fast marching method algorithm (henceforth FMM). First, I discretized the map of Brazil and its federal highways into a grid. Each grid decade is composed of 510x485 grid cells, with each cell being close to 10x10 squared km. I assign all cells with a federal highway a traveling cost of one, and all other cells with no federal highway a traveling cost 3.5 times higher, to reflect roughly the travel-speed limits in Brazil.[13]

With these costs assigned, for every pair of origin–destination municipalities, I determine what would be most efficient route by applying the FMM algorithm.[14] I sum up the traveling cost of cells along the optimal route to get a traveling cost from each origin–destination pair. As in Allen and Arkolakis (2014), I normalized the scale of $t(i,j)_t$, so that the cost of traveling the entire width of Brazil by highway would be one and take the formulation for the geographic trade cost as an exponential form:

$$\tau_{ijt} = e^{c(i,j)_t}$$

This exponential form has the interpretation that the instantaneous trade cost are of iceberg form, a common assumption in many models of trade.

3.1.2 Trade Cost Elasticity

Different values of θ will have a mechanical influence on the estimated impact of market access, by changing the definition of market access. I empirically estimate θ by means of a gravity equation, using archival data of yearly trade flows between states in Brazil from the statistical yearbooks of Brazil from 1942 to 1949 and 1968 to 1974.

I use a standard gravity equation, represented in Equation 2, to estimate the elasticity of trade flows between origin *i* and destination *j* after controlling for origin-year, ς_{it}, and

[13] According to the Ministry of Transport in Brazil, speed limits on local roads are 30 km/h by car, whereas federal highways are between 100 km/h and 120 km/h. Pellegrina et al., 2017 in his paper of reasons for agricultural specialization in Brazil, chooses a speed cost of 3 (very close to the value used in the paper) and as robustness, he uses the Google API to compute the extra cost of moving through local highways obtaining similar results in both procedures.

[14] The FMM can be interpreted as a generalization of Dijkstra's algorithm to continuous spaces. Both algorithms essentially find the most efficient way to go from point A to point B.

destination-year fixed effects, ς_{jt}. The τ_{ijt}s are the geographic trade cost from the state capital i to the state capital j, obtained by the FMM algorithm as explained before.

$$ln\ \chi_{ijt} = \theta ln\tau_{ijt} + \varsigma_{it} + \varsigma_{jt} + \nu_{it} \tag{2}$$

OLS estimates of Equation 2 can still be biased, as connections between states can be done with some intention of fostering trade in regions that were already trading a lot, or between regions that were usually not that linked commercially. If the central planner creates highways in order to connect regions that had a lower propensity to trade, the elasticity would be understated, as lower transport costs would not reflect as much increase in trade flows as they should. On the contrary, if roads are placed between locations with higher propensity to trade between each other or with an already large commercial relationship, the OLS estimates would be overstated. Thus, I instrument the trade costs in order to account for this endogeneity concern.

3.1.3 Instrumental Variable for Trade Cost

To solve this bias, I propose an instrumental variable strategy. As an instrument, I use the construction of Brasilia and the plan to connect it with the other state capitals in 1956 as a natural experiment, as suggested by Morten and Oliveira (2016). I create the predicted network of highways that would have been the one constructed if the government, conditional on successfully connecting Brasilia with all the state capitals, had prioritized minimizing the linear distance of the whole network. To predict this network, given that the actual federal roads connecting Brasilia with the state capitals are organized in eight radial highways, I divide Brazil into eight segments and connect Brasilia with all the state capitals within the segment, minimizing the linear distance. Figure 2 represents the final predicted network.

FIGURE 2

PREDICTED NETWORK-RADIAL HIGHWAYS - COMPLETE

With that network constructed, I rerun the FMM algorithm to compute the travel cost from each origin capital i to each destination capital j along the predicted network ($\tau_{ij}^{Predicted}$). I also set all cells equal to the non-road cost to get the travel cost with no highways (τ_{ij}^{Empty}). With these two trade costs, I can construct an instrument such that:

$$\tau_{ijt_{\text{IV}}} = \begin{cases} \tau_{ij}^{Empty}, & \text{if } t \leq 1950. \\ \tau_{ij}^{Predicted}, & \text{otherwise.} \end{cases} \tag{3}$$

The trade costs before the construction of Brasilia are the trade costs of traveling through Brazil with no highways, and the trade costs after Brasilia was constructed are the trade costs associated with the predicted highway network.[15]

The logic for the instrumented trade cost is that this trade cost depends only on the route of the predicted network, which itself is independent to any specific characteristic of the municipalities that are crossed by the highway, other than that these municipalities happened to be on the best path to connect Brasilia.

By estimating a 2SLS regression, I can obtain an estimate of the trade cost elasticity θ. Results of the estimation can be seen in Table A.2.1, in the Appendix. The 2SLS provides a trade cost elasticity θ of 3.39, which is higher than the OLS elasticity (2.80), suggesting

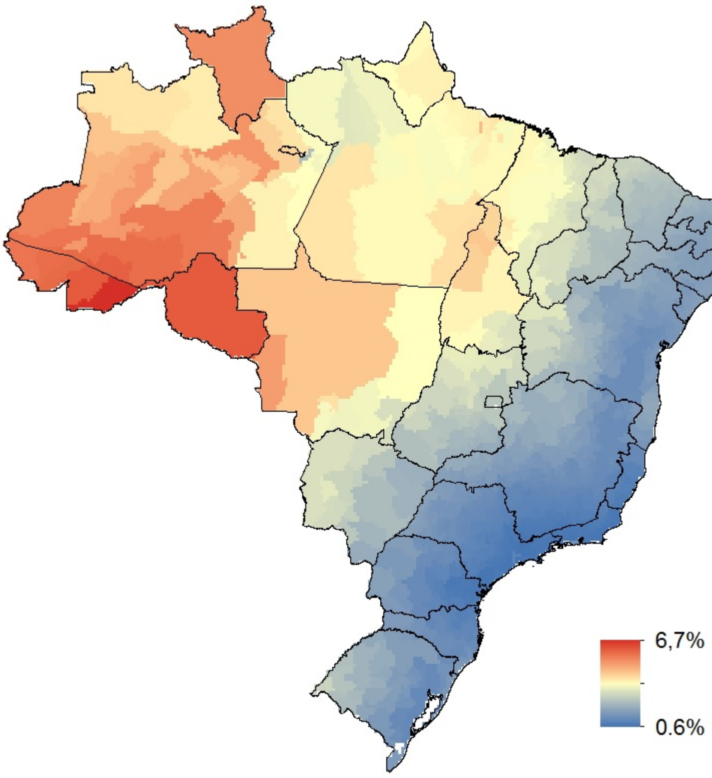
[15]Formally, Equation 2 would be the second stage equation, and the first stage equation would be: $ln\ \tau_{ijt} = \lambda ln \tau_{ijt_{\text{IV}}} + f_{it} + f_{jt} + \mu_{ijt}$

that the highways were connecting the state capitals that were more disconnected from the rest. The OLS and the IV estimates are both significant under the standard significance levels. This elasticities are similar to what Morten and Oliveira (2016) find in their paper using 1999 state-to-state trade flow data based on state tax data (2.91 for the OLS and 3.26 for the IV), and fall under the range of elasticities proposed by Simonovska and Waugh (2014). The first stage is also strong with a F-statistic of 106.9 and relevant; a 10% increase in the instrumented transport cost is correlated with a 8.8% increase in the actual transport cost.

3.1.4 Market Access

With that trade elasticity θ, the computed trade cost τ_{ijt} and the GDP of each destination,[16] it is possible to compute the measure of market access in Equation 1. Figure 3 reflects the growth rates per municipality for the whole period of 1950 to 2000. As expected, the municipalities that were more distant from the coast are the ones that have benefited the most from the expansion of the highways toward the interior. In term of growth rates, for the period studied, the average municipality has experienced an increase in its market access of 1.5% yearly. In the Appendix, Figure A.3.1 present the level of normalized market access at 1950 and 2000.

FIGURE 3
YEARLY GROWTH RATE OF MARKET ACCESS:1950–2000



[16]The GDP per municipality is also taken from IPEA.

3.2 Empirical Estimation

With the market access constructed, I use a continuous difference in difference strategy:

$$ln\ outcome_{it} = \beta lnMA_{it} + (X_i t)'\delta + \gamma_i + \gamma_{st} + \epsilon_{it} \tag{4}$$

The parameter β would measure the elasticity of the outcome of interest with respect to market access. I control for a quadratic polynomial of the linear distance in kilometers to the coast line of Brazil, interacted with a time trend. The reason for this is that the coast-line was already much more connected even before Brasilia, and most of the main regions of Brazil were on the coast. So it is expected that municipalities close to the coast would have more market access by design. These municipalities could have a different trend from the ones in the interior. I add municipality fixed effects, which absorb the fixed characteristics that could be related to both the access to markets and the outcomes.

I also control for state fixed effects that vary over time, so that every state can have a different trend. By doing so, the elasticity β is identified by comparing the municipalities with different market access in the same state. The reason for this method is that key states have historically been very important compared to others where development has lagged behind. So, allowing for state time fixed effects gives more flexibility by controlling for all the changes that occurred at the state level, assuming that these changes are uniforms across municipalities within the same state.

3.2.1 Instrumented Market Access

Still, equation 4 cannot be interpreted however as the casual effect of market access on agricultural technology adoption. There could be some time changing unobservable factors driving the result or endogeneity problems such as reverse causality. For example, think of a municipality that first invested in a new seed successfully. Because of the increase in production, it has more incentives to demand the construction of highways, to be able to go to other markets. In this case, technology adoption would induce market access and not the other way.

I again use the reallocation of the capital to Brasilia, but this time to construct an instrument for market access. Using the trade cost from Equation 3, I can construct an instrument for market access:

$$MA\_IV_{it} = \sum_{j \neq i} \tau_{ijt_{\mathbf{IV}}}^{-\theta} shareGDP_{j1950} \tag{5}$$

In here MA_IV is the market access of municipality i if there were no federal highways on the period before Brasilia, and for all the years posterior to 1956, it takes the values of the market access if the whole predicted network of figure 2 was set in place and where the only federal highways in existence. Instead of using the GDP at period t for computing market access on the instrument, I fixed the value to the GDP of 1950, as highways can influence local growth by other means across time such as migration for example. By fixing the value of GDP to the one in 1950 I exclude those types of macro-effects. I also drop all the capital states, as they were the ones targeted to be connected with Brasilia and can be by that reason endogenous.[17] With this instrument in hand I followed a panel IV strategy to causally identify the effect of market access on the agricultural productivity, and the technology adoption (inputs and mechanization).[18]

4 Results

4.1 OLS estimates

Table 2 shows the correlation in the data between the market access and the studied outcomes. It suggest a positive relationship between market access and the intensity of input usage, as a 10% increase in market access is correlated with an increment in expenditures per hectare of 4.9% for seeds, 21% for fertilizers and 7.4% for herbicides. This 10% increase is also associated with 5.2% higher value of land per hectare and 4.5% more tractors per hectare. However, although positive, no significant relationship is find between the market access and the value of machinery and equipment per hectare or the wages per worker. Also, agricultural GDP per hectare shows essentially no relationship with the market access of the municipality.

[17] Results does change if this municipalities are not dropped of the sample

[18] The second stage would be equation 4, and the first stage will be given by: $ln\ MA_{it} = \alpha ln\ MA\_IV_{it} + (X_it)'\Gamma + \delta_i + \delta_{st} + \vartheta_{it}$

Table 2
OLS estimates

	Panel A: Productivity (logs)		
	Agri GDP per hectare	Salaries per worker	
log Market Acess	-0.009	0.057	
	(0.118)	(0.114)	
Observations	11,147	11,147	
R-squared	0.465	0.529	
Clusters	1,744	1,744	
	Panel B: Log of Expenditure per Hectare		
	Seeds per hectare	Fertilizers per hectare	Herbicides per hectare
log Market Acess	0.492**	2.162***	0.746***
	(0.201)	(0.287)	(0.216)
Observations	11,147	11,147	11,147
R-squared	0.475	0.747	0.650
Clusters	1,744	1,744	1,744
	Panel C: Log of Value of Assets per Hectare		
	Value of Land	Value of Machinery	Number of Tractors
log Market Acess	0.520***	0.052	0.450***
	(0.098)	(0.137)	(0.174)
Observations	10,450	10,450	10,699
R-squared	0.861	0.719	0.854
Clusters	1,749	1,749	1,742

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

As stated before the association found in the data does not imply causality. By construction, the measure of market access is being affected by the travel costs, which depend themselves on the endogenous expansion of the highway. If the highways were made to connect municipalities with a lower trend in growth, then the results would be underestimated.

4.2 IV estimates

4.2.1 First Stage

To study the casual effects of market access on the agricultural productivity and the adoption of technologies, I propose an panel IV method as explained before. I construct an instrument for market access using Equation 5. Using all the decades (from 1950 to

2000) I find that a 10% increase in the instrumented market access is correlated with a 2.9% increase the real market access. The instrument is strong, as the F statistic (17.5) rejects the hypothesis of having a weak instrument as show in the second column of 3.

TABLE 3
FIRST STAGE: DEPENDENT VARIABLE-LOG MARKET ACESS

		By decade:				
	All Periods	1960	1970	1980	1990	2000
log Market Acess IV	0.412***	0.139***	0.392***	0.482***	0.549***	0.539***
	(0.077)	(0.017)	(0.024)	(0.022)	(0 .020)	(0.019)
Observations	10,482	3,498	3,498	3,498	3,498	3,498
Robust weak-F stat	17.5	1.83	15.6	31.8	26.6	37.1
Partial R-squared	0.126	0.061	0.209	0.291	0.378	0.371
Clusters	1,749	1,749	1,749	1,749	1,749	1,749

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

I further analyze the performance of the instrument decade by decade. The reason for this is due to the fact that the instrumented market access takes to values, one value for the initial period of 1950 (where the assumption is that there is no roads) and a different value for all the periods after 1956 (which assumes all the predicted network is in place). As the expansion of the real radial network and the other federal highways was gradual, one would expect the instrument to do better in the later periods. Table 3 is in accordance with that expectation. The instrument seems weak if we only analyze the decade of 1960, however as we progress towards the decade of 2000, the instrument gets significantly stronger and statistically more relevant.

4.2.2 2SLS Results

The estimates of the second stage are presented in Table 4.The estimated elasticities in general are much higher than the ones obtained in the OLS. Moreover, market access has a significant effect in the agriculture productivity of the municipalities, as a 10% increase in market access implies a 19% increase in the agricultural GDP per hectare of the municipality. It also affected positively the profits of the workers and the agricultural activity in general, as a 10% increase in market access means a 24.31% increase in salaries per worker and 29.4% in the value of land per hectare.

TABLE 4
IV ESTIMATES

	Panel A: Productivity (logs)		
	Agri GDP per hectare	Salaries per worker	
log Market Acess	1.946***	2.431***	
	(0.556)	(0.534)	
Observations	11,147	11,147	
R-squared	0.432	0.497	
Clusters	1744	1744	
	Panel B: Log of Expenditure per Hectare		
	Seeds per hectare	Fertilizers per hectare	Herbicides per hectare
log Market Acess	0.745	4.252***	9.690***
	(1.104)	(1.594)	(1.478)
Observations	11,147	11,147	11,147
R-squared	0.475	0.743	0.531
Clusters	1744	1744	1744
	Panel C: Log of Value of Assets per Hectare		
	Value of Land	Value of Machinery	Number of Tractors
log Market Acess	2.939***	-0.273	0.684
	(0.473)	(0.551)	(1.231)
Observations	10,450	10,450	10,699
R-squared	0.838	0.719	0.853
Clusters	1749	1749	1742

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

The usage of technology also changed with market access. Municipalities with a 10% increase in their potential markets would increase their expenditure on fertilizers, and herbicides (per hectare) in 42% and 96% respectively. There is no clear relationship between the access to markets and the use of machinery. Meanwhile the value of machinery and equipment per hectare shows a negative relationship with the market access, the number of tractors per hectare, which is another proxy, shows a different sign. Moreover, none of the coefficients is significant at the usual levels.

Aside from not finding a relationship between market access and mechanization, one thing that calls for attention is the size of the elasticities, specially the one of the herbicides. The average market access in the municipalities increased by 1.5% yearly which, in the case of the expenditures of herbicides per hectare, would translated in a compound annual growth rate of 14.53%. Comparing this with the compound annual growth rates of Table 1, it would translate into a growth rate that almost doubled the yearly growth rate experienced in the country (0.08) over the period of study.

I study whether these results change once introduce the external market access to the measurement of total market potential. The market access built from Equation 1 does not take into account the importance of external markets and trade with other countries. This can be relevant due to the importance that the export markets have had in the case of the Brazilian agriculture sector. For example, if we consider the external market access as a part of the total market access, those municipalities that get better connected to a city with a port would increase more their market potential than if it is only measured by the domestic market access.

4.3 External Market Access

For constructing the external market access I followed an approach similar to the construction of the domestic market. I first construct an average external market access of Brazil with respect all the other countries (C).

$$MAE_{Bt} = \sum_{C \neq Brazil} \tau_{BC}^{-\theta_x} \frac{GDP_{Ct}}{GDP_{Brazil,t}} \tag{6}$$

For the size of the countries, I divide the GDP of the country by the GDP of Brazil (as in the domestic market access) for better correspondence with the previous measure. For the trade cost τ_{BC}, I use the ratio of the external distance from Brazil to country C, over the internal distance of Brazil. For these distances, I follow the approach of de Sousa, Mayer and Zignago (2012) who calculate distance between two countries based on bilateral distances between cities weighted by the share of the city in the overall country's population for external distance and reuse the procedure within the country for internal distances. The value of trade elasticity to distance is taken from estimates by Head and Mayer (2004) in their review chapter $(\theta_x = 1)$.[19]

Once I construct the average external market from Brazil to the rest of the World, I compute the external market that correspond to each municipality. Similar to the domestic market, I use the geographic travel cost from each municipality i to each port τ_{ipt}, the internal trade cost elasticity estimated earlier (θ) and the size of the port. For the size of the port, I use the average external market of Brazil in Equation 6 multiplied by the importance of that port in 1950 (share of total exports done by the port in 1950).

$$MAExternal_{it} = \sum_{p \in Ports} \tau_{ipt}^{-\theta} * share_{p1950} * MAE_{Bt} \tag{7}$$

Other possible measure would be instead of summing across all ports, to just take the distance to the closest port. In the Appendix A.4 I present the estimates for this specification. Results are mostly robust to this alternatives. I prefer the definition in

[19]The GDP's of the different countries are taken from the Maddison Project Database in the University of Groningen (see Bolt et al. (2018). For the bilateral distances (in kilometers), I use the GeoDist data from CEPII (see Mayer and Zignago (2011)).

Equation 7, since it takes into account that not all ports matter the same for accessing external markets. Other than distance to the country of destination, the capacity of the port and its management can play a big role.

Table 5 present the estimates for the IV specification once the market access includes not only the domestic but also the external market access.

TABLE 5

IV ESTIMATES-WITH EXTERNAL MARKETS

	Panel A: Productivity (logs)		
	Agri GDP per hectare	Salaries per worker	
log Market Acess	0.840***	1.022***	
	(0.233)	(0.234)	
Observations	11,147	11,147	
R-squared	0.450	0.517	
Clusters	1744	1744	
	Panel B: Log of Expenditure per Hectare		
	Seeds per hectare	Fertilizers per hectare	Herbicides per hectare
log Market Acess	1.193**	2.373***	4.152***
	(0.471)	(0.646)	(0.529)
Observations	11,147	11,147	11,147
R-squared	0.471	0.743	0.605
Clusters	1744	1744	1744
	Panel C: Log of Value of Assets per Hectare		
	Value of Land	Value of Machinery	Number of Tractors
log Market Acess	1.096***	0.209	0.654
	(0.198)	(0.241)	(0.484)
Observations	10,450	10,450	10,699
R-squared	0.853	0.719	0.853
Clusters	1749	1749	1742

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Standard errors are clustered at municipality level.

*** p<0.01, ** p<0.05, * p<0.1

While taking into account the external market does not change the direction of the effects, it changes its size. It appears that the market potential increased by more than what the domestic market access reflected as municipalities experienced better connections to the ports over time. This in turn would create an upward bias of the estimates. These results highlight the importance of taking in to account the access to the World in the context of domestic and international trade.

How large are these elasticities? To have an idea, the average market access of the municipalities increased by 1.5% yearly over the period. That would translate in a yearly increase of 1.26% for the agricultural GDP per hectare, which accounts for 52% of the total variation seen in the data over the period. Table 6 reports the average effect of market access on the outcomes studied. The average effects are sizable and reasonable for all the variables studied.

Table 6
Average Effect-Market Access

	Growth Rate-Percent	Average Effect Percent	Proportion
Productivity			
Agricultural GDP per hectare	2.42	1.26	0.52
Salaries per worker	3.12	1.53	0.49
Expenditure per hectare			
Seeds per hectare	4.32	1.79	0.41
Fertilizers per hectare	6.57	3.56	0.54
Herbicides per hectare	7.87	6.23	0.79
Value of Assets per hectare			
Value of Land	4.59	1.64	0.36
Value of Machinery	4.27	0.31	0.07
Number of Tractors	8.02	0.98	0.12

Notes: All expenses in inputs, value of assets, and the Agricultural GDP are in constant BRL reals of 2000. Standard errors are clustered at municipality level.

5 Effect of market access, mechanization and openness to trade

A possible reason for the lack of a significant relationship between the market access and mechanization could be the different policies towards the agricultural markets that Brazil experienced over the 56 year period of study.

Broadly speaking, between the decades of 1960 to 1980, some policies towards agriculture generated a disincentive to modernize while some supported it. The country followed a model of import substitution, with its domestic manufacturing industries as the focus of the economy. The high import tariffs to intermediate goods, export restrictions, quotas for agricultural products, and ceiling prices for different crops to provide cheap food for the urban dwellers,generated a disincentive for change in the agriculture sector. At the same time, subsidies and credit to exports of processed agricultural products were put in place and provided incentives for modernization Baer (2001).

With the market-oriented reforms in the late 1980s, Brazil began a period of a greater openness to trade and less state intervention. This period was characterized for the elimination of import and export restrictions, a removal of domestic price controls in agricultural markets and a modernization of the operating procedures at customs. All of these changes generated access to modern agricultural inputs at lower prices, and more access to external markets. It was in this period that Brazil became one of the main exporters of agricultural products.

Table 7
Estimates-Before and After 1990

	(1)	(2)	(3)	(4)
		IV		
	OLS: All Periods	All Periods	Closed Period	Open Period
Productivity				
Agricultural GDP per hectare	-0.112	0.840***	0.623***	1.344***
	(0.081)	(0.233)	(0.240)	(0.293)
Salaries per worker	-0.003	1.022***	0.647**	1.693***
	(0.078)	(0.234)	(0.255)	(0.313)
Expenditure per hectare				
Seeds per hectare	0.342**	1.193**	0.627	2.310***
	(0.148)	(0.471)	(0.500)	(0.538)
Fertilizers per hectare	1.292***	2.373***	1.969***	3.191***
	(0.205)	(0.646)	(0.676)	(0.725)
Herbicides per hectare	0.260*	4.152***	3.409***	5.619***
	(0.152)	(0.529)	(0.553)	(0.734)
Value of Assets per hectare				
Value of Land	0.138*	1.096***	0.960***	1.400***
	(0.072)	(0.198)	(0.214)	(0.192)
Value of Machinery	-0.081	0.209	0.121	0.419*
	(0.092)	(0.241)	(0.272)	(0.221)
Number of Tractors	0.287**	0.654	0.461	1.462**
	(0.127)	(0.484)	(0.547)	(0.592)

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Closed period refers to the census years from 1960 to 1980, when price controls and tariffs in the agriculture sector were standard. Open period refers to census years of 1996 and 2006. Standard errors are clustered at municipality level. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

5.1 Discussion of the Differences between Input Usage and Mechanization

Table 7 reports the estimated elasticities to the market access (including the external market access). Columns 1 and 2 refer to the OLS and the IV results for all the period,[20] Columns 3 and 4 refers to the estimates in the close and the open period. All the elas-

[20]Column 2 then shows the estimates from Table 5 and Column 1 are the results of the OLS in the same sample, which were not shown as detailed as the IV results to avoid repetition.

ticities are larger in the open period. This reflects the importance of the interaction of trade liberalization and the de-regulation of the agricultural markets with the access to markets.

For the open period, the estimates for the value of machinery and the number of tractors appear significant and important. A 10% increase in market access is related to a 4.2% increase in the value of machinery and equipment per hectare and a 1.5% increase in the number of tractors per hectare. As on average there was an yearly increase on the market access of 1.5% in the municipalities, it would mean an increase of 0.63% yearly in the value of machinery and 2.25% in the number of tractors. These increments would account for 15.7% and 28% of the yearly growth rates that the value of machinery per hectare and the number of tractors per hectare experienced over the whole period.

The fact that market access is important for the usage of inputs in both periods but it is only relevant for mechanization in the open period, suggest a difference between the two types of technologies studied in the paper. This difference can be explained by two possible channels. On one hand, machinery implies a higher fixed costs than the usage of fertilizers or herbicides. Therefore, for farms to mechanized more, they require a higher expected profitability to compensate for these costs. Precisely, policies oriented towards trade liberalization and no domestic price controls made the market access profitable enough to differentially affect the investment in machinery. Other potential explanation can be the one of export-oriented crop specialization. Locations with more market access were able to specialize more in commodities demanded by the foreign markets which were just more intensive capital.

In reality both channels can be playing a role. While it is true that export-oriented crops are one of the most capital intensive in the agricultural sector, especially for the case of soy in Brazil, it can not explain the development of agribusiness for the domestic-oriented crops such as rice, corn and recently beans.[21] As Baer (2001) expresses:

> "The export crops were the first to modernize and to be incorporated into agribusiness complexes. However, in spite of distributive inequalities, in absolute terms the domestic market for food products is quite large. Thus, as soon as some of the policy constraints were relaxed, modernization was introduced into segments of agriculture for the domestic market (e.g., rice and corn)

Distinguishing the role that these channels play in the modernization of agriculture and the increase on its productivity is an interesting question that is left open for future research.

[21] The country is often considered as an example of agricultural success, as it is the second largest agricultural exporter in the world, focusing on commodities such as coffee, sugar, soybeans, and tobacco, and it is a major producer of maize, rice, and beef (although these products are mostly absorbed domestically). This development went hand in hand with a more traditional and less mechanized agriculture that persists across regions, especially in the Amazon basin and the northeast part of the country (OECD, 2015).

6 Robustness Checks

I summarize various robustness checks, which tables are in the Appendix A4. Table A.4.1 reports the estimates using for the external market access the minimum distance to any port, instead of the distance to all the available ports weighted by their importance. Results are robust to this change in size and sign, although the elasticity on the value of machinery stop being significant in the open period.

Other potential concern is the sample selection. The estimates for the value of assets (both land and machinery) and the value of tractors, are done in a different sample than the rest of the variables.[22] I restrict the sample to those municipalities that had positive values in all the outcomes studied. Results as shown in Table A.4.2 are stable, except for the open period where estimates doubled or even tripled (in the case of agricultural GDP per hectare, salaries per worker and value of land) the baseline estimates.

I also estimate the elasticities before and after 1990, for the measure of domestic market access only. The estimates in Table A.4.3 go in the direction and the size expected. Domestic market access still has a positive effect on the value of machinery and number of tractors after the trade liberalization, which suggest that internal trade also had a role in this mechanization process.

Lastly, I explore the sensitivity of the results using different trade cost elasticities, ranging from 1 to 10. The estimates as shown in Figure A.5.1 and A.5.2, are stable from trade cost elasticities bigger than one, which are values consistent with the literature.[23]

7 Conclusion

This article estimates how the increment in market access of Brazil helped to improve the agricultural productivity and affected the adoption of technologies that are key for productivity, such as machinery, fertilizers, seeds and herbicides. To do so, I use the construction of Brasilia as a natural experiment to construct an instrument for the market access.

I explore the importance of taking into account the foreign demand when measuring market access and find that, for the context of Brazil, not accounting for it generates an upward bias of the estimates, as the domestic market access failed to measured correctly the real market access for localities near to ports.

The preferred estimates indicate that the agricultural GDP per hectare increased by 1.26% yearly due to the augmented market access. This accounts for 52% of the total growth seen in the economy over the period of study. For the salary of the agricultural workers and the value of land per hectare, the increase for market access accounted for

[22] As explained before, the value of assets by categorie was not available on-line for the census of 1996. For the number of tractors, the number of municipalities with zero tractors was too large, especially in 1950 with half of the municipalities not reporting a tractor, which made difficult the analysis on Brazil as a whole.

[23] In their meta-survey of estimates in the literature Head and Mayer (2014) prefered a mean value of 6.74, with a median of 5.03. Simonovska and Waugh (2014) find trade elasticity that range between 2.79 and 4.46.

49% and 36% of the total yearly growth respectively. The numbers are similar for the technology of inputs: 41% on seeds, 54% on fertilizers and almost 80% on herbicides.

In contrast to these results, I find no effect of market access on the value of machinery and the number of tractors for the whole period. I explore if the reason for this zero effect was the export restrictions, the high import tariffs to intermediate goods and the ceiling prices experienced by Brazil in different degrees from 1960 to 1980, which provided low incentives to invest in new equipment. Accordingly, once I focus on the period after the trade liberalization and no price-controls, I find a positive and significant effect both for both variables.

The results are robust to alternative definitions of external demand, different subsamples and different values of trade elasticities. They highlight the fact that the extension of macro-infrastructure such as highways tend to be accompanied with technological progress, which is usually not taken into account when computing the gains from trade or welfare, which could potentially biased the estimated gains downwards. Incorporating technology decisions and innovations that are endogenous to market access in models such as Donaldson and Hornbeck (2016) is an interesting path for further research.

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A Appendices

A.1 Data Variables

TABLE A.1.1
DESCRIPTIVE STATISTICS

Expenditures per hectare	Total	1950	1960	1970	1975	1980	1996	2006
Seeds	0.005	0.001	0.002	0.002	0.004	0.005	0.007	0.012
	(0.069)	(0.003)	(0.004)	(0.004)	(0.005)	(0.011)	(0.008)	(0.014)
Fertilizers	0.023	0.002	0.003	0.009	0.021	0.026	0.024	0.075
	(0.211)	(0.011)	(0.012)	(0.012)	(0.020)	(0.039)	(0.044)	(0.045)
Herbicides	0.010	0.001	0.001	0.003	0.005	0.007	0.011	0.042
	(0.174)	(0.002)	(0.003)	(0.006)	(0.009)	(0.013)	(0.022)	(0.457)
Value of Assets per hectare	**Total**	**1950**	**1960**	**1970**	**1975**	**1980**	**1996**	**2006**
Value of Machinery	0.080	0.024	0.028	0.043	0.098	0.121	-	0.240
	(0.219)	(0.027)	(0.055)	(0.084)	(0.282)	(0.227)	-	(0.393)
Number of tractors	219.746	4.703	34.539	93.451	182.009	307.059	454.442	462.016
	(913.440)	(13.816)	(96.776)	(282.427)	(626.575)	(953.601)	(1497.679)	(1410.558)
Other outcomes	**Total**	**1950**	**1960**	**1970**	**1975**	**1980**	**1996**	**2006**
Value of Land	1.193	0.255	0.336	0.478	2.226	2.056	-	3.002
	(3.221)	(0.450)	(0.445)	(0.898)	(6.066)	(3.796)	-	(3.406)
Salaries per worker	0.622	0.306	0.272	0.315	0.477	0.504	0.822	1.657
	(2.427)	(0.312)	(0.300)	(0.351)	(0.517)	(0.534)	(1.148)	(6.132)
Agricultural GDP by hectare	0.378	0.182	0.222	0.239	0.353	0.463	0.508	0.679
	(1.715)	(0.214)	(0.269)	(0.268)	(0.470)	(0.612)	(0.685)	(4.374)
Observations		1,775	1,775	1,775	1,775	1,775	1,775	1,775

Notes: There are 1775 comparable municipalities across the 7 agricultural census used. All the values of assets, salaries and expenditures are in constant Reais of 2000 (thousands).

A.2 Trade Cost Elasticity

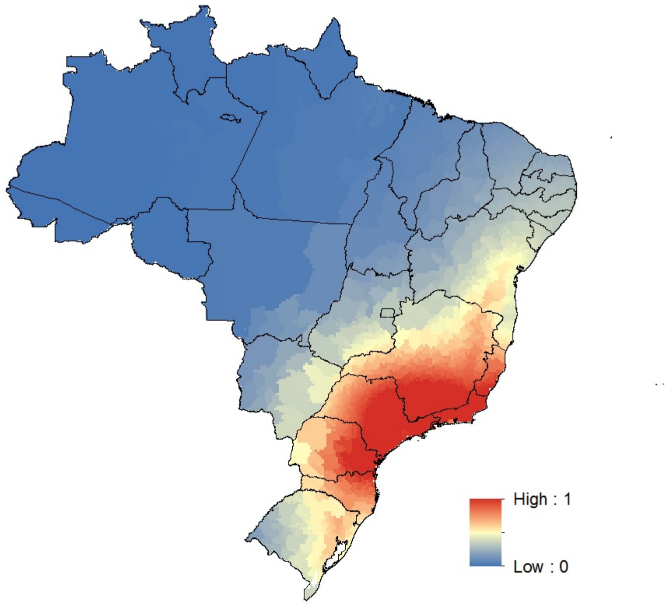
Table A.2.1
Trade Cost Elasticity Estimates

VARIABLES	(1) Log Exports OLS	(2) Log Exports IV	(3) Log Trade Costs
Log Trade Cost	-2.801***	-3.393***	
	(0.139)	(0.373)	
Log Trade Cost IV			0.883***
			(0.085)
Origin-time fe	Y	Y	Y
Destination_time fe	Y	Y	Y
F Stat-Excluded Instruments			106.9
Partial R2			0.718
Observations	3609	3609	3609

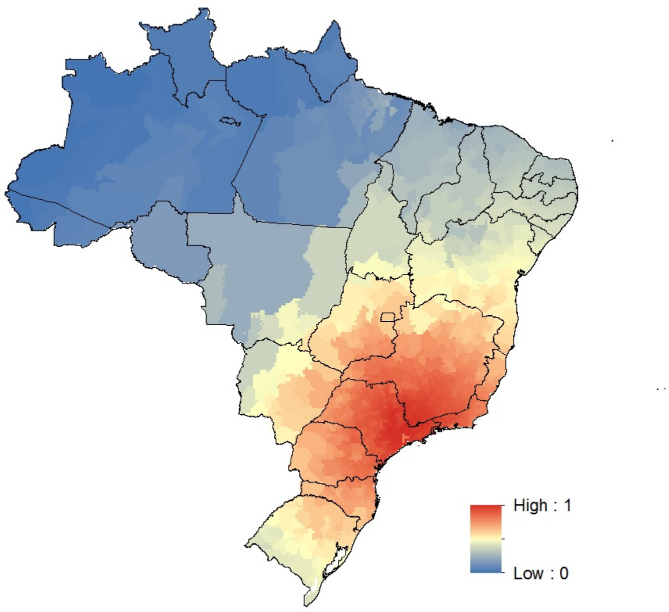
Notes: Exports are in constant BRL Reals of 2000. Errors are clustered at the origin-destination-year level.
*** p<0.01, ** p<0.05, * p<0.1

A.3 Market Access

FIGURE A.3.1
NORMALIZED MARKET ACCESS



1950



2000

A.4 Robustness Check

A.4.1 Alternative Measure of External Market Access

TABLE A.4.1
ESTIMATES

	(1)	(2)	(3)	(4)
			IV	
	OLS: All Periods	All Periods	Closed Period	Open Period
Productivity				
Agricultural GDP per hectare	0.108	0.827***	0.718***	1.634***
	(0.078)	(0.207)	(0.210)	(0.328)
Salaries per worker	0.144*	0.862***	0.235	2.304***
	(0.082)	(0.218)	(0.228)	(0.348)
Expenditure per hectare				
Seeds per hectare	0.706***	1.208***	0.582	2.762***
	(0.154)	(0.438)	(0.454)	(0.602)
Fertilizers per hectare	1.494***	2.519***	2.232***	3.840***
	(0.210)	(0.584)	(0.591)	(0.832)
Herbicides per hectare	0.571***	4.070***	3.459***	6.759***
	(0.155)	(0.521)	(0.543)	(0.845)
Value of Assets per hectare				
Value of Land	0.050	0.761***	0.665***	1.112***
	(0.076)	(0.166)	(0.173)	(0.194)
Machinery and Equipment	0.100	0.300	0.303	0.318
	(0.090)	(0.207)	(0.230)	(0.219)
Number of Tractors	0.483***	0.750**	0.547	1.877***
	(0.123)	(0.374)	(0.406)	(0.601)

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Closed period refers to the census years from 1960 to 1980, when price controls and tariffs in the agriculture sector were standard. Open period refers to census years of 1996 and 2006. Standard errors are clustered at municipality level. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

A.4.2 Restricted Sample

Table A.4.2
Estimates

	(1)	(2)	(3)	(4)
		IV		
	OLS: All Periods	All Periods	Closed Period	Open Period
Productivity				
Agricultural GDP per hectare	-0.233**	0.834***	0.688**	3.101***
	(0.095)	(0.322)	(0.329)	(0.773)
Salaries per worker	-0.044	0.997***	0.574*	3.333***
	(0.087)	(0.333)	(0.341)	(0.744)
Expenditure per hectare				
Seeds per hectare	0.243	0.918	0.371	3.433***
	(0.160)	(0.674)	(0.710)	(1.168)
Fertilizers per hectare	1.166***	2.621***	1.984**	6.277***
	(0.223)	(0.927)	(0.962)	(1.648)
Herbicides per hectare	-0.006	4.951***	4.364***	10.247***
	(0.172)	(0.835)	(0.866)	(2.027)
Value of Assets per hectare				
Value of Land	-0.056	2.003***	1.886***	3.698***
	(0.081)	(0.313)	(0.333)	(0.753)
Machinery and Equipment	-0.002	0.765**	0.498	2.260***
	(0.106)	(0.344)	(0.366)	(0.646)
Number of Tractors	0.194	0.531	0.372	1.653**
	(0.129)	(0.542)	(0.585)	(0.807)

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Closed period refers to the census years from 1960 to 1980, when price controls and tariffs in the agriculture sector were standard. Open period refers to census years of 1996 and 2006. Standard errors are clustered at municipality level. Standard errors are clustered at municipality level.
*** p<0.01, ** p<0.05, * p<0.1

A.4.3 Domestic Market Access

Table A.4.3
Estimates

	(1)	(2)	(3)	(4)
			IV	
	OLS: All Periods	All Periods	Closed Period	Open Period
Productivity				
Agricultural GDP per hectare	-0.009	1.946***	1.177**	2.533***
	(0.118)	(0.556)	(0.591)	(0.558)
Salaries per worker	0.057	2.431***	2.347***	2.482***
	(0.114)	(0.534)	(0.661)	(0.569)
Expenditure per hectare				
Seeds per hectare	0.492**	0.745	-0.555	2.776***
	(0.201)	(1.104)	(1.293)	(1.012)
Fertilizers per hectare	2.162***	4.252***	3.208*	5.333***
	(0.287)	(1.594)	(1.814)	(1.392)
Herbicides per hectare	0.746***	9.690***	8.658***	9.705***
	(0.216)	(1.478)	(1.585)	(1.405)
Value of Assets per hectare				
Value of Land	0.520***	2.939***	2.743***	3.226***
	(0.098)	(0.473)	(0.571)	(0.347)
Machinery and Equipment	0.052	-0.273	-1.101	1.248***
	(0.137)	(0.551)	(0.709)	(0.382)
Number of Tractors	0.450***	0.684	-0.201	2.445**
	(0.174)	(1.231)	(1.476)	(1.062)

Notes: All estimates are controlling for municipality fixed effects, state-time fixed effects and a quadratic polynomial of the linear distance to the coast in km interacted with time. All expenses in inputs, value of assets, and the Agricultural GDP are in logs terms and in constant BRL reals of 2000. Closed period refers to the census years from 1960 to 1980, when price controls and tariffs in the agriculture sector were standard. Open period refers to census years of 1996 and 2006. Standard errors are clustered at municipality level. Standard errors are clustered at municipality level.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

A.5 Road maps

Figure A.5.1

Beta coefficients for different trade elasticities-OLS

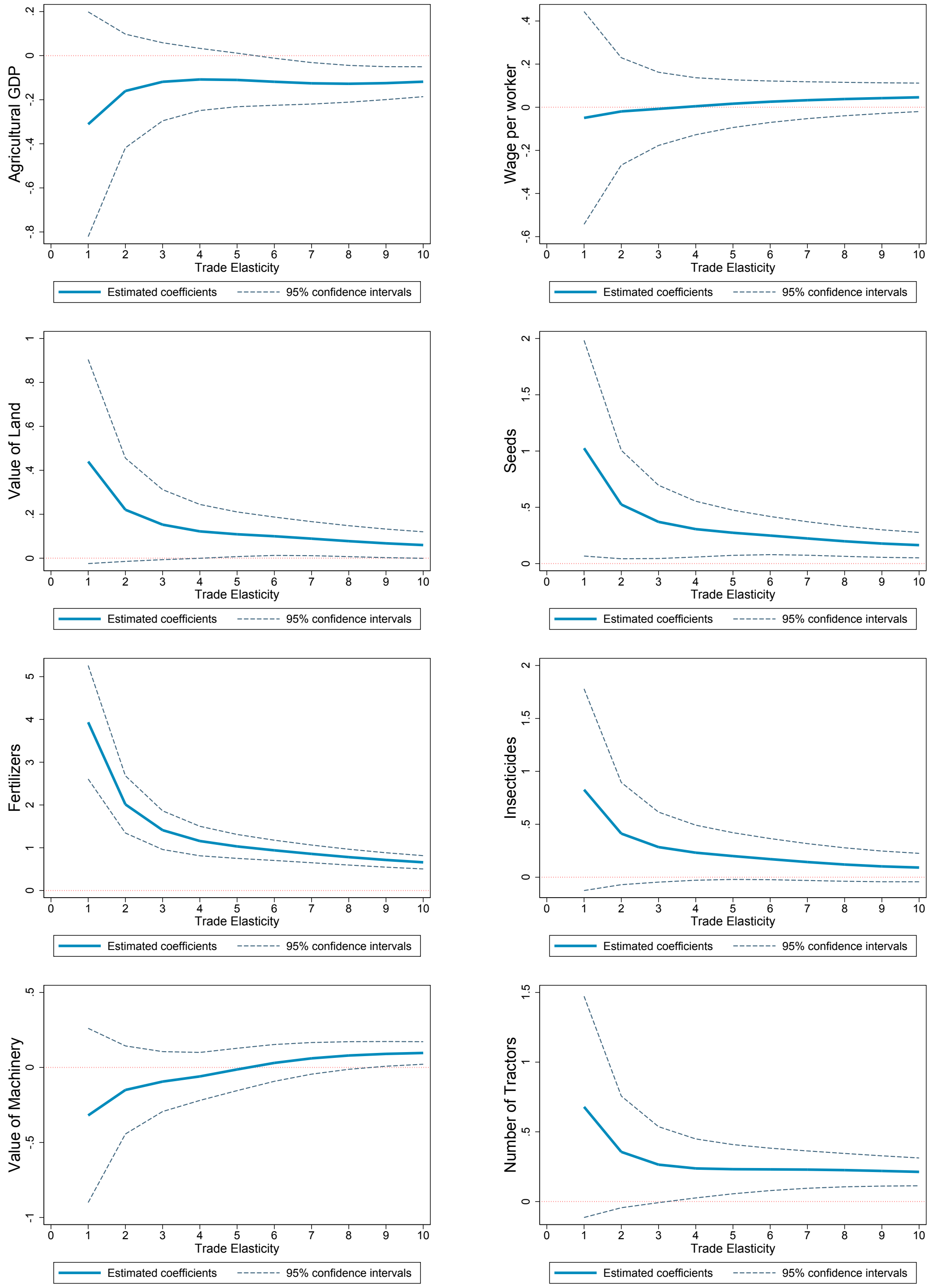


Figure A.5.2

Beta coefficients for different trade elasticities-IV