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TRANSPORTATION INFRASTRUCTURE AND PRODUCTIVITY: EVIDENCE FROM COLOMBIA

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INFRAESTRUCTURA DEL TRANSPORTE Y PRODUCTIVIDAD: EVIDENCIA DE COLOMBIA

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RESUMEN

En el presente documento se analiza el rol de la infraestructura de transporte en la determinación de la PTF a nivel de planta. Calculamos la PTF a partir de las encuestas anuales manufactureras utilizando procedimientos contables. Encontramos que el acceso a la infraestructura de transporte es un determinante importante de la PTF a nivel de planta. En particular, el crecimiento en la densidad vial (kilómetros de vías alrededor de la planta) tiene un impacto positivo en el crecimiento de la PTF, mientras que un aumento en la congestión (tráfico por día) se relaciona de manera negativa con el crecimiento de la PTF. Luego de corregir para evitar la endogeneidad potencial, nuestros estimados sugieren que la elasticidad de la PTF en relación con el *stock* de vías es aproximadamente uno. Adicionalmente, analizamos el efecto de la infraestructura sobre el nivel y la dispersión de la PTF, encontrando que los mercados con mejor infraestructura son también los más competidos. Ello implica que la PTF entre plantas muestra una menor dispersión y mayores valores para los mínimos y medianas en los mercados asistidos con una red de carreteras más amplia. En otras palabras, sólo los productores más eficientes sobreviven en los mercados en los que los bienes y servicios de menor costo provengan de las plantas ubicadas en otras municipalidades. Así que, la infraestructura contribuye a la eficiencia de la economía en conjunto al forzar la salida de negocios de las plantas menos productivas.

Palabras clave: Productividad total de los factores, infraestructura

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ABSTRACT

This paper analyses the role of transport infrastructure in determining plant level TFP. We calculate TFP from the annual manufacturing surveys using accounting and econometric procedures. We find that differential access to transportation infrastructure is an important determinant of TFP at the plant level. In particular, growth in road density (kilometers of roads around the plant) has a positive impact on TFP growth, while growth in congestion (traffic per day) is negatively related to TFP growth. After correcting for potential endogeneity, our estimates suggest that the elasticity of TFP with respect to the stock of roads is approximately one. In addition, we analyze the effect of infrastructure on the level and of dispersion of TFP and find that markets with better infrastructure are also more contested. This means that TFP across plants shows less dispersion and higher minimum and median values. In other words, only the more efficient producers survive, suggesting a possible channel trough which infrastructure contributes to the overall efficiency of the economy.

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Keywords: Total factor productivity, infrastructure

Transportation Infrastructure and Productivity: Evidence from Colombia*

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Abstract

This paper analyses the role of transport infrastructure in determining plant level TFP. We calculate TFP from the annual manufacturing surveys using accounting and econometric procedures. We find that differential access to transportation infrastructure is an important determinant of TFP at the plant level. In particular, growth in road density (kilometers of roads around the plant) has a positive impact on TFP growth, while growth in congestion (traffic per day) is negatively related to TFP growth. After correcting for potential endogeneity, our estimates suggest that the elasticity of TFP with respect to the stock of roads is approximately one. In addition, we analyze the effect of infrastructure on the level and of dispersion of TFP and find that markets with better infrastructure are also more contested. This means that TFP across plants shows less dispersion and higher minimum and median values. In other words, only the more efficient producers survive, suggesting a possible channel trough which infrastructure contributes to the overall efficiency of the economy.

Key words: Total factor productivity, infrastructure.
JEL Classification: L1, O39, O47, R40, R53.

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I. Introduction

In a well know paper, John Fernald (1999) finds that when growth in roads changes, productivity growth changes disproportionally in U.S. industries with more vehicles. The fact that vehicle-intensive industries benefit more from road building suggests that investment in transportation infrastructure is a key determinant of productivity. More recently, Calderón and Servén (2007) survey the wide body of literature exploring the link between investment in infrastructure and economic growth and find that 16 out of 17 studies for developing countries, and 21 of 29 studies in high income countries, provide empirical support to the hypothesis that infrastructure has a positive effect on growth. Briceño et al. (2004) survey 104 studies and reach a similar conclusion.

As rightly pointed by Estache and Fey (2007) in a recent survey prepared for the World Bank's Growth Commission, this literature suffers from many problems. Most importantly, the relationship between growth (or productivity) and infrastructure is difficult to measure due to the presence of endogeneity. In other words, the causality between infrastructure and productivity can run either way.

Infrastructure services are an input in the production process, so naturally the demand for these services increases with output. If this is the case, higher economic growth would cause greater investment in infrastructure, even if growth comes from efficiency gains or changes in total factor productivity.[1] While this logic is compelling, it is also true that there are channels through which investments in infrastructure can have causal effects on growth. Some papers emphasize the role of public infrastructure on factor accumulation, implying that with better roads agents are more able to increase the stock of physical and human capital. Others see infrastructure as a way of making private capital and labor more productive. Thus, establishing which is the direction of causality and through which channel it operates is an empirical question.[2]

In addition to endogeneity, non-linearities pose additional complexities. Investments in infrastructure can become redundant after some optimal level. This implies that the effect of infrastructure on productivity depends on the existing amount of infrastructure. For example, Fernald (1999) finds that in the case of the U.S. the returns to investment in infrastructure were very high up the point when the basic interstate network was completed and relatively low afterwards. More recently, Hurlin (2006), using a multicountry panel data set, finds that the

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[1] See Straub and Vellutini (2006) for some evidence on how increases in TFP trigger greater demand for infrastructure.

[2] It is not uncommon to find that causality runs in both ways, as in Canning and Pedroni (2004). However, the effect of infrastructure on long term growth seems more robust than the reverse.

highest marginal productivity of investments is obtained when a network is sufficiently developed but not completed.

Infrastructure can also have an impact on the dispersion of productivity across plants, and not just on the average level of productivity. The discussion on second moments has been led by Chad Syverson (2004a, 2004b) who argues that the productivity variation within a narrow industry should be related to the degree of product substitutability. Industries with very segmented geographical markets can support large plant level productivity differences, even in a long-run equilibrium. The general idea is that if it is costly for consumers to switch from one supplier to another (due, for example, to lack of transport infrastructure) then the high productivity plant will be unable to take over the entire market. This means that various productivity levels will coexist within a particular industry.

In other words, transport costs play a role analogous to physical or perceived product differentiation (or in the services bundled with products). In more segmented markets it is more likely that a firm will survive regardless of its productivity level. Markets where there is spoor infrastructure –and, hence, low product substitutability- would show low within-industry median TFP levels. The reason in this case is that in contested markets only the more efficient plants would survive, truncating the low end of the productivity distribution.

In this paper we address these issues using data for Colombia. In particular, we combine the annual Colombian Manufacturing Survey with information from the road network that serves each municipality where a manufacturing plant is located. The evidence supports the view that infrastructure growth has a positive and significant effect on productivity growth, and that more isolated municipalities have industries where the dispersion of productivity levels across plants is higher. The main policy conclusion is that investment in transport infrastructure has a large dividend in terms of productivity growth.

This paper is organized as follows. Section II presents some background information on the evolution of road infrastructure in Colombia. Section III briefly introduces the data we use in this paper. Section IV discusses some measurement issues regarding total factor productivity. Section V develops the empirical strategy in order to assess the relationship between transport infrastructure and TFP, section VI presents the results of the estimation. Section VII concludes.

II. Road infrastructure in Colombia

Private investment in infrastructure has been relatively dynamic in Colombia since the introduction of a comprehensive set of reforms in the early 1990s (Figure 1). Much of the expansion has taken place in the energy sector where regulatory changes have been most significant while investment in transport infrastructure has lagged behind (Figure 2). In fact, the total amount of investment in transport infrastructure does not show a clear trend and most transport investment remains in the hands of the public sector (77 percent between 2000 and 2006). In terms of composition, investment in national roads continues to dominate (71 percent of investment in transport). However, in recent years mass transit systems in urban centers have taken a growing share (see Figures 3 and 4). Low growth in the road network is thus a consequence of low private sector involvement and a shift in priorities in the national budget.

The political economy considerations that explain why investment in transport infrastructure has not been a top government priority is developed elsewhere (see Cárdenas, Gaviria and Meléndez, 2005). The general idea is that other expenditures areas have been more effective in securing budget allocations. More importantly, the process of private sector engagement in the transport sector has proceeded erratically, reflecting stop-go policies and a poor institutional design. The purpose of this paper is to show concrete measures of how these two forces have been costly from the viewpoint of efficiency of the manufacturing sector.

III. The data

To study the link between transportation infrastructure and plant-level TFP we use the annual Colombian Manufacturing Survey (*Encuesta Anual Manufacturera*) combined with data from INVIAS (*Instituto Nacional de Vías*) on the stock of primary (also know as "national") roads, traffic per day, and road quality. In both cases we use data from 1991 to 2001.

Encuesta Anual Manufacturera

This survey is available annually since 1955 and covers manufacturing plants with more than 10 employees and/or production value no lower than $155 million 2005 COP per year (approximately US$80,000) (See DANE, 2006).[3] The survey contains information related to the location of the plant by municipality, as well as standard economic variables such as employment (in number of workers), salaries (including benefits), inventories, energy consumption (in kilowatts per hour), buildings, machinery and equipment, transport equipment, and intermediate consumption (all in monetary units). We use transport equipment to measure vehicle intensity in the production process, which is a key variable for identification purposes.

Our starting point is the unbalanced panel of 181,143 plants constructed by Melendez and Seim (2006) for the years 1977-2001. The panel includes some adjustments to the original survey:

[3] This means that firms enter and exit the survey for reasons related to size, in addition to firm creation and destruction.

- Plants with less than two years of information were excluded (implying a loss of 4,255 plants).
- One year gaps in the plant information of a particular variable were calculated by simple interpolation (affecting 2,292 observations). For longer gaps the entire plant's history was dropped from the database, representing a loss of 1,264 observations.
- Although the EAM surveys plants with more than 10 employees, the specific sample used in this study is restricted to plants with more than 15 employees.

INVIAS

This is central government's agency in charge of building, maintaining, and operating the network of primary (national) roads.[4] In addition, INVIAS collects relevant information on roads length, traffic, and quality even in those cases where there is private sector involvement in the operation (approximately 15 percent of the primary network was in the hands of concessionaires in 2001). The database contains hundreds of road segments (from point A to point B, where A and B are usually -but not always- municipalities). For each segment, we have information on total length and average traffic per day (TPD). This database contains annual information from 1992 to 2003.

Figure 5 shows the total length of the primary road network as well as the percentage of roads that are under concession. The aggregation of all segments in the data base indicates that the network rose to 19,000 km. in 2001 from 17,400 in 1993, implying a mere 1.1 percent per year. In addition, Invias collects information on the conditions of the road network. According to the information for 2001, 71 percent of the network was paved and 29 percent unpaved, reflecting minimal change relative to 1993. In the case of the paved roads in 2001, 68 percent were in good condition, 24 percent in regular condition and 8 percent in bad condition. These figures are 45, 39, and 16 percent, respectively, for the unpaved roads. In sum, only 48 percent of the primary roads in Colombia were paved and in good condition.[5]

Using this database we constructed a measure of road density per year in a 100Km radius (an area of 31,416 squared km.) from each one of the 330 municipalities with plant-level information in the EAM. We also used a 50 00 km radius to check for robustness, as well as the area of the department where the municipality is located. To calculate this variable we added all road segments that lie within the desired area (100 km radius, 50 km radius, and departmental borers). The results of this computation reveal significant differences in road density within the country. For example, in 2001 Cartago (Valle) was the municipality with more roads within the 100 km. radius (1,258 km.), while some municipalities, like San Pablo and Mompós (Bolivar) had

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[4] In recent years, Invias has been taking responsibilities in secondary and even tertiary roads, adding confusion to the institutional design and aggravating the lack of investment in the primary network.

[5] We are in the process of obtaining information on road conditions for other years of our sample.

less than 100 km. of roads within the radius, implying the lack of primary road connecting them with the rest of the country. Interestingly, the top 7 municipalities with more road density are clustered in the coffee producing area around Pereira (Risaralda). Bogotá (the country´s capital) comes in 8th place with a network of 1,152 km. of roads. Figure 6 shows the road density and the population for each municipality. Clearly, larger municipalities (in terms of population) tend to have more roads around them, although there are important exceptions to this rule.

For each road segment we have information on average traffic per day. We use this information to construct a weighted average of traffic per day around a particular municipality using as weights the share of a given road segment in the road network for each municipality. Figure 7 shows that average traffic per day is higher in municipalities with greater road density, but the correlation is far from perfect, suggesting that there are municipalities with high road density and low road traffic. As we will show, this seems to be an ideal situation for plant level efficiency.

IV. Measurement of Total Factor Productivity (TFP)

Throughout the analysis, we use two measures of TFP at the plant level. The first one is derived from a growth accounting exercise, while the second is an application of the non-parametric estimation method developed by Levinsohn and Petrin (2003).

We start by showing the results of the growth accounting exercise where plant *i* TFP is computed as the log of its real output (in constant pesos using the 3-digit industry PPI) minus a weighted sum of its logged labor (in number of workers), non-vehicle capital (in constant pesos), vehicle capital (in constant pesos), materials (in constant pesos using the 3-digit industry PPI), and energy inputs (in kilowatts per hour). That is,

$$tfp_{it} = q_{it} - \alpha_{lt} l_{it} - \alpha_{kt} k_{it} - \alpha_{vt} v_{it} - \alpha_{mt} m_{it} - \alpha_{et} e_{it} \quad \textbf{(1)}$$

where the weights α_j are the cost shares or input elasticities, $j \in \{l, k, v, m, e\}$. Although the inputs are plant specific, we use 3-digit industry level input cost shares, obtained as weighted averages of the cost shares of the plants in that industry. In other words, we are assuming that all plants in the industry share the same technology, and thus have the same industry-level cost shares.

The measurement of the inputs involves certain assumptions that are worth mentioning. For each type of capital (construction, buildings, machinery and equipment, and transport equipment) we follow Eslava et al. (2006) and measure investment as:

$$I_{it} = \widetilde{K}_{it} - \widetilde{K}_{it-1} + \widetilde{D}_{it} - \widetilde{\Pi}_{it} \quad \textbf{(2)}$$

where I is gross investment, $\widetilde{K}_{it}$ is the value of capital reported by plant at the end of year t, $\widetilde{D}_{it}$ is the accounting depreciation reported by the plant and $\widetilde{\Pi}_{it}$ is the inflation adjustment also reported by the plant (after 1995). Using this investment measure we then apply perpetual inventory to construct consistent capital stock series. In particular, for each type of capital we compute

$$K_{it} = (1 - \delta_{it})K_{it-1} + {}^{I_{it}}/_{P_t} \qquad \textbf{(3)}$$

where P_t is the deflator for capital formation (specific to each type of capital). Notice that the procedure involves adding the accounting depreciation but subtracting the economic one, represented by δ. We use depreciation rates for each type of capital calculated by Pombo (1999) at the 3-digit industry level for the period 1991-1997.

To anchor these calculations we need the plant's initial capital stock. To simplify matters we use the first reported value deflated by the capital formation deflator (we use a simple average of the deflators in the initial year of operations and the year before).

In the computation we also make the assumption of constant returns to scale, so the factor weights add one. Also, we use gross output instead of value added. These assumptions are easy to relax and do not change our results. Another feature worth mentioning is that we use revenue-based output, instead of physical quantities.

The calculation of the input cost shares is another issue where choices have to be made, especially in the case of capital. We follow Robert E. Hall and Jorgenson (1967) and Hall (1990) and define the cost share of capital as the value of the current stock of capital multiplied by an estimate of the user cost of capital r_t divided by the value of output. We use a measure of user cost of capital specific to the type of capital at the 3-digit industry, defined as

$$r_{it} = \left(\frac{q_t * \epsilon_t}{p_{it}}\right) * (\rho_t + \delta_t - \Delta(q_t * \epsilon_t)) * \left(\frac{1 + vat_t + \tau_t}{1 - \omega_t}\right) \qquad \textbf{(4)}$$

where q is the price of capital goods in the US obtained from the IMF's International Financial Statistics, ϵ is the nominal exchange rate (pesos per US dollar), and p is the producer price index for the plant's output (available at the 3-digit industry level). This first term is analogous to the cost of imported capital goods in terms of the plant's output. The second term is the nominal interest rate ρ plus the depreciation rate δ minus the change in the price of capital goods expressed in domestic currency. This term is equivalent to the real interest rate. The third term is a tax factor where vat is the tax rate on the VAT, τ is the average tariff rate and ω is the marginal income tax rate. To keep notation simple we do not index the type of capital good (machinery, construction, and vehicles) but we construct the index separately for each type of capital for each industry.

In the case of the other inputs we simply take the shares in the value of output of total labor costs (salary and non-salary), value of materials, and actual cost of energy (consumption in kilowatts per hour times the price per kilowatt per hour at the departmental level, obtained from DANE, 2002).

Our second method for calculating the plant level TFP is taken from the procedure developed by Levinsohn and Petrin (2003). In this estimation, equation 1 is transformed into:

$$q_{it} = \alpha_{it} l_{it} + \alpha_{kt} k_{it} + \alpha_{vt} v_{it} + \alpha_{mt} m_{it} + \alpha_{et} e_{it} + tfp_t + \eta_t \qquad \textbf{(5)}$$

where the key difference is the error term that now becomes $tfp_t + \eta_t$. The first term (tfp_t) is the transmitted productivity component and the second term (η_t) is an error term uncorrelated with input choices. In the estimation k_t and tfp_t are considered state variables, whereas $l_t, v_{t,} e_t$ are freely variable inputs. The main difference between tfp_t and η_t is that the former is a state variable that impacts the firms' decisions.[6] As Petrin, Poi, and Levinsohn (2004) note, tfp_t is not observed by the econometrician, and can impact the choices of inputs, leading to the well known simultaneity problem in production function estimation. Estimations that ignore the correlation between inputs and this unobservable factor (like OLS) will yield inconsistent results. In the estimations, materials (m_t) is used a proxy of unobservable productivity shocks.

To show the results of both estimations we aggregate plant level *tfp* (logged total factor productivity) at the 3-digit industry level, using the plants' shares in the value added of that industry as weights. Once we have *tfp* at the industry level we take first differences to obtain the percent change in total factor productivity, which is reported in Figure 8 for the accounting exercise and in Figure 9 for the econometric procedure.

Figure 10 plots the average annual growth in TFP together with the cost share of vehicles for each 3-digit industry, which is a variable of interest for the purposes of this paper. There is considerable dispersion in terms of productivity changes across sectors. Interestingly, the sectors which are more vehicle-intensive tend to have lower productivity growth (according to the accounting measure). This preliminary observation suggests that it is worth looking in depth at the relationship between TFP and the availability of transport infrastructure.

One potential problem with our measure of vehicle intensity is that vehicle equipment owned by the plant may not capture well vehicle-intensity in those cases where plants outsource transport services. In this case, transport services will appear as intermediate consumption and not as a specific production factor. However, national accounts and input-output matrices allow us to calculate (at the 2-digit CIUU level) the share of transport services in total intermediate

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[6] These estimations allow for the separation of production and nonproduction workers.

consumption. Interestingly, the sectors where this share is higher are also the ones where there is greater vehicle-intensity (see Figure 12) measured by vehicle ownership. In other words, sectors that use more transport services from third parties also tend to have higher (own) transport equipment cost shares.

V. Transportation infrastructure and Total Factor Productivity (TFP)

In this section we focus on the interaction between the stock of vehicles and roads to assess the role of the transport infrastructure on TFP. So far we have considered the stock of vehicles in use by the plant as a key input in the production process. In practice, however, vehicles need roads to deliver transportation services which are really what matters for productivity.

If roads are an input in the production process, then our measure of TFP in equation 1 overstates the actual technological change. Explicitly considering roads as another input we could rewrite TFP as

$$tfp_{it} = \alpha_{gt} g_{it} + \widetilde{tfp}_{it} \qquad \textbf{(6)}$$

Where observed TFP depends on unobserved technology $\widetilde{tfp}_{it}$ plus the contribution of roads g_{it} to output, treated as another factor of production. Note that in our specification roads are specific to plant *i*, mainly because the location of the plant determines the stock of roads that are relevant in the specific production process. As mentioned above, we start by making the arbitrary assumption that the relevant roads are defined by the network within a 100km radius from the location of the plant, and explore the contribution of this network to TFP at the plant level.

Estimation of the coefficient α_{gt} is not straightforward. For example, ordinary least-squares estimates suffer from simultaneity bias because, as noted by Fernald (1999) and others, if investment in roads depends on aggregate income and hence productivity, then plant level productivity shocks affect the road network by affecting aggregate productivity shocks. To both illustrate the problem and find ways around the endogeneity bias it is useful to differentiate the previous equation and multiply and divide the first term by the elasticity of output with respect to vehicles α_{vt}.

$$dtfp_{it} = \varphi\, \alpha_{vt}\, dg_{it} + d\widetilde{tfp}_{it} \qquad \textbf{(7)}$$

Where φ is the relative output elasticities of roads and vehicles α_{gt}/α_{vt}. This is a useful transformation because the services of roads enter as an external effect related to vehicle use. The next step is to aggregate this expression for the entire economy using as weights the plant shares in aggregate nominal output. Since plants are generally dispersed across the country the relevant aggregate of the stock of roads is the national network g_t. Thus, the previous expression transforms into

$$\overline{dtfp_t} = \varphi\, \overline{\alpha_{vt}}\, dg_t + \overline{dt\widetilde{fp}_t} \quad \textbf{(8)}$$

where bars denote national level averages. Note that we are assuming that all plants have the same ratio of elasticities with respect to *g* and *v*, and that this ratio remains constant in time. In other words, these elasticities can change as long as they remain proportional. The endogeneity problem becomes more evident with the national averages: growth in roads may depend on the technological change. More importantly, if the aggregate regressions suffer from endogeneity bias, then so do the plant level regressions. Now, following Fernald (1999) lets consider the following decomposition:

$$dt\widetilde{fp}_{it} = \beta_i\, \overline{dt\widetilde{fp}_t} + \varepsilon_{it} \quad \textbf{(9)}$$

Where the residuals ε_{it} are by construction orthogonal to the aggregate technological shock, and hence to growth rate in *g*. The term $\beta_i\ \overline{dt\widetilde{fp}_t}$ measures the conditional expectation of the technology shock in plant *i*, given the aggregate shock. Following our previous assumption regarding production technology at the plant level, we make the assumption that the β_i's are common to all plants in the same 3-digit CIIU industry. If β_i equals one, then the average plant will have a productivity shock identical to the aggregate shock.

Substituting equations (8) and (9) into (7) gives the following estimating equation:

$$dtfp_{it} = \varphi\, \alpha_{vt}\, dg_{it} + \beta_i\ \overline{dt\widetilde{fp}_t} + \varepsilon_{it}$$

$$dtfp_{it} = \varphi\, \alpha_{vt}\, dg_{it} + \beta_i\, (\overline{dtfp_t} - \varphi_t\, \overline{\alpha_{vt}}\, dg_t) + \varepsilon_{it}$$

$$dtfp_{it} = \varphi\, \alpha_{vt}\, (dg_{it} - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}}\, \beta_i\, dg_t) + \beta_i\, \overline{dtfp_t} + \varepsilon_{it} \quad \textbf{(10)}$$

Notice that the transformation allows the replacement of the unobserved technology shock $\overline{dt\widetilde{fp}_t}$, which can be affected by dg_{it} and is thus the source of endogeneity bias. The estimating equation has the key attribute that the disturbance term is orthogonal to dg_{it} and dg_t.

To gain insight in the interpretation of this equation it is useful to make some simplifying assumptions. First, if all the β_i are equal to one (i.e., a countrywide technological shock of one percent has a one percent expected effect on the technological shock of each plant) we can express equation 10 as:

$$dtfp_{it} - \overline{dtfp_t} = \varphi\, \alpha_{vt}\, (dg_{it} - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}}\, dg_t) + \varepsilon_{it} \quad \textbf{(11)}$$

which simply says that the idiosyncratic component of plant level productivity growth $dtfp_{it} - \overline{dtfp_t}$ depends on the relative vehicle intensities and the growth of the stock of roads in the proximity of the firm dg_{it} and in the country as a whole dg_t. For the firm that has the same vehicle intensity as the country average, $\alpha_{vt} = \overline{\alpha_{vt}}$, an increase in the stock of roads relevant for that plant above the growth in the national stock will result in a greater than average productivity growth.

A simple case that helps in providing an intuitive interpretation is when the national and plant specific road stocks grow at the same rates $dg_{it} = dg_t$. In this case, equation 11 becomes,

$$dtfp_{it} - \overline{dtfp_t} = \varphi\, \alpha_{vt}\, (1 - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}})\, dg_t + \varepsilon_{it} \quad \textbf{(12)}$$

In other words, changes in the stock of roads should be associated with greater than average changes in productivity in plants with above average vehicle intensities $\alpha_{vt} > \overline{\alpha_{vt}}$.

Before we proceed to the estimation of equation 10 to obtain a consistent estimate of the contribution of roads to TFP, it is useful to extend the model to consider explicitly the effect of road traffic and congestion. It is well known that roads are not a pure nonrival public good. With more traffic, roads provide less services and thus would make a lower contribution to productivity. In other words, to measure roads effectively we would have to adjust length of the network by measures of traffic, such as traffic per day per road segment. One possible way of capturing this idea is to use the following specification for effective services provided by the roads relevant for each plant g_{it}^e,

$$g_{it}^e = g_{it} - \kappa\, c_{it} \quad \textbf{(13)}$$

Where c is a measure of congestion (we use logged traffic per day instead of total miles driven by trucks, automobiles and other motor vehicles used by Fernald, 1999). Note that this is a measure of congestion specific to the plant, corresponding to traffic per day in the roads available in a 100km radius from the plant. The parameter κ measures how quickly the road services received by an individual producer fall as aggregate traffic per day rises in its relevant road network. If roads are a pure public good, κ equals zero.

Including congestion, the estimating equation becomes

$$dtfp_{it} = \varphi\, \alpha_{vt}\, (dg_{it}^e - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}}\, \beta_i\, dg_t^e) + \beta_i\, \overline{dtfp_t} + \varepsilon_{it}$$

$$dtfp_{it} = \varphi \, \alpha_{vt} \, (dg_{it} - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}} \, \beta_i \, dg_t) - \varphi \, \alpha_{vt} \, \kappa \, (dc_{it} - \frac{\overline{\alpha_{vt}}}{\alpha_{vt}} \, \beta_i \, dc_t) + \beta_i \, \overline{dtfp_t} + \varepsilon_{it} \qquad \textbf{(14)}$$

and has the same interpretation as equation 10, except than now we incorporate the fact that above-average congestion for firm *i* can lower its productivity growth relative to country averages. This is specially the case if firm *i* is more vehicle intensive than the average firm. At the national level, growth in congestion (dc_t) is highly correlated with GDP growth (Figure 12).

VI. Estimation

We now proceed with the estimation of equation 14. We begin with a simplified version in which we make several assumptions. In our first set of estimations we aggregate plant-level information into 3-digit CIIU sectors. This is our benchmark specification because by using sectors instead of plants we can assume that $dg_{it} = dg_t$ (the relevant road network for 3 sectors is the national network as plants are dispersed throughout the entire economy). Also, we ignore the issue of congestion, which is equivalent to assuming that κ equals zero.

Columns 1 and 2 in Table 1 show the results of this estimation using our two TFP measures: accounting residual (TFP1) and nonparametric derivation (TFP2). Our coefficient of interest, φ, comes out positive and significant under both TFP measures. Given the large dispersion in TFP changes across sectors, and the serial autocorrelation of the errors we use robust errors and cluster by 3-digit CIIU sector. In other words, we allow for serial error correlation within the same 3-digit sector, but we impose independence in the errors across sectors. We also estimate the model clustering by year (across sectors). The estimated φ in this case is similar, but the standard errors are higher (coefficients are not significant at 10% confidence).

Based on the estimated φ, we use equation 8 to compute the elasticity of TFP with respect to the stock of roads ($\varphi \, \overline{\alpha_{vt}}$) at the national level. The last row in Table 1 reports these elasticities which are equal to 1.03 in the case of TFP1 and 0.77 in the case of TFP2. This is a very important result because it says that at the 3-digit level of aggregation and after correcting for potential endogeneity, an increase of 1 percent in the stock of roads increases total factor productivity in manufacturing between 1.03 and 0.77 percent depending on the measurement of TFP. These elasticities correspond to national averages.

Given that the road elasticity of TFP can change considerably from sector to sector it is worth estimating this parameter at the sector level. According to equation 14, the elasticity total factor productivity with respect to the stock of national roads is given by the expression $\varphi \, (\alpha_{vt} - \overline{\alpha_{vt}} \beta_i)$. This means that for those sectors which have below-average vehicle intensities the elasticity can be negative.

Plant-level estimations

Results with sector level data do not use the wealth of information we have both in terms of plant level TFP and the stock of roads available in a 100 km radius around the municipality where the plant is located. To use this information we move to the estimation of equation 14 with the complete dataset. At the same time, we remove the assumption that roads are a pure public good and include congestion in the specification. The results are reported in columns (3) and (4) in Table 1. In the estimation we use robust errors (clustered by plant) and add plant-level fixed effects. The estimated parameter of interest is much smaller under this specification, suggesting that the implied elasticities (of *g* on *tfp*) are much lower. In particular, when using TFP1, the estimated φ is 2.65 and statistically significant. This implies that the elasticity of TFP at the plant level with respect to national roads is 0.08. In other words, a one percent increase in the national network (measured in Km.) results in an increase of 0.08 percent in plant level TFP.

Figure 13 provides measures of the elasticity of TFP with respect to both types of road infrastructure (national and plant-specific) estimated at the plant level but shown averaged at the 3-digit CIIU level. The main conclusion is that the there is considerable heterogeneity in the impact of transport infrastructure, both national and local, on TFP at the firm and sector level.

This specification also allows for the estimation κ which is another key parameter of interest because it measures the effect of traffic on the services provided by the stock of roads. If this coefficient is significantly different from zero we reject the idea that roads are a pure public good. On the contrary, roads are rival goods, so the greater the traffic a particular firm faces, the lower its productivity growth. Interestingly, our estimated value of κ is -0.95 and statistically significant (column 3 in Table 1), implying that a one percent increase in traffic reduces plant level TFP by 0.076 percent ($\varphi\, \overline{\alpha_{vt}}\kappa$). However, these results are not statistically significant when the non-parametric TFP measurement is used (column 4 in Table 1).

The plant level estimation of equation 14 provides other results of interest. Figure 14 compares the plant-level estimated elasticities of *g* on *tfp* aggregated at the sector level –shown in the vertical axis- with the idiosyncratic component of the change in TFP in each firm ($dtfp_{it} - \beta_i\overline{dtfp_t}$) -measured in the horizontal axis and also aggregated at the sector level. This last term is the change in TFP at the firm level that is not explained by the average national change in TFP. It appears that firms (and sectors) with greater elasticity of *g* on *tfp* are also the ones with larger changes in *tfp* relative to national averages.

Alternative definitions of the firm-specific road infrastructure

Results above assumed that roads relevant in the specific production process of a plant are those within 100 km from its location. This is an arbitrary assumption because the relevant market could be larger (or smaller). To overcome some of the limitations of this assumption we also used a 50 km radius (corresponding to an area of 7,853 square km). Column 1 in Table 2 shows the results under this specification and shows that the elasticity of TFP with respect to roads is reduced to half its previous value, although remains positive and significant. As expected, the elasticity with respect to congestion does not change much.

Column 2 uses the road network with the 100 km radius but also includes a regional dummy. In particular, we classify municipalities in six regions which in addition to geography can be considered as ethnically and culturally homogeneous: Amazonía, Orinoquía, Andina, Pacifica, Caribe and Bogotá (we treat Bogotá as a region as 36.2% of the plant-year observations are in this city). Results under this specification are very similar to the ones in Column 3 in Table 1, both in terms of the size and significance of the coefficients.

Finally, column 3 shows the results defining the Department as the relevant area criteria in order to measure the specific road network for each firm. This definition can be justified on the grounds that there are transaction costs in moving goods across department lines. The drawback, however, is that there are considerable differences in departmental areas so that for some firms we are making the assumption that the relevant market is much smaller than for others. In any case, φ does not come out significant, although κ remains significant at 99% confidence.

TFP Dispersion

Following Syverson (2004a), our final estimations have to do with the effect of road infrastructure on the level and dispersion of TFP. The maintained hypothesis is that with more transport infrastructure markets are more connected and there is more competition across plants. Under these circumstances only the more efficient producers survive. This means that there is less dispersion in TFP levels across plants (measured, for example, by the interquartile range or IQR), while the least efficient plants (say at the 10th percentile) show higher efficiency than in other less contested markets. More competition also implies that the level of TFP (as measured by the median) is higher in markets with more access to roads.

For a specific plant, market density can be given by the size of the local market (proxied by the population in that municipality) and the accessibility to other municipalities (proxied by the road network). For all sectors, municipalities and years we measure logged TFP´s IQR (distance between the third and first quartile), 10th percentile, and median.

For illustrative purposes we begin by discussing these variables in the case of sector 311 (food products excluding beverages). We use this sector because many municipalities have plants producing this type of manufacturing goods. Figure 15 shows that, in sector 311, the IQR (averaged for all years) tends to be higher in those municipalities with lower road density. In fact, there is a 50 percent difference between the TFP of the firm in the 75th percentile and the one in the 25th percentile in a municipality like Tumaco (with poor infrastructure). That difference can fall to 25 percent in municipalities with relatively higher road density. Figure 16 shows the variance in the IQR (from year to year), in various municipalities, again just in sector 311. Interestingly, plant level TFP in municipalities with more roads not only has a lower IQR but also a more stable one. This means that the distance in TFP between more efficient and less efficient plants does not change much from year to year. Finally, the median TFP in sector 311 is higher in better connected municipalities (Figure 17).

Figures 18-21 show the same descriptive statistics now for all manufacturing sectors per municipality. It is harder to extract conclusions from these figures alone, but clearly there are more sectors in those municipalities with a larger road network. A priori, it seems plausible to argue that the variance of the IQR is lower in municipalities with more roads (Figure 19). Also, the 10th percentile TFP seems to be higher in those municipalities with a better road network (Figure21).

However, a final proof of these hypotheses requires some formalization. In particular, we estimate the following equation:

$$y_{it} = \gamma_0 + \gamma_1 g_{it} + \gamma_2 p_{it} + \varepsilon_{it} \quad \textbf{(15)}$$

where y_{it} represents alternatively each one of the three descriptive statistics (IQR, median, and 10th percentile) and p_{it} is population of municipality *i* at time *t* (*g* is the stock of roads). Tables 2 and 3 show the results of these estimations. We pool annual observations from 3-digit sectors at the municipal level. In other words -for each sector and municipality- we regress the tfp's inter-quartile range, the 10th percentile and the median on population and the road network. Presumably, a market with more individuals and roads is more contested and thus supports plants that have higher and less dispersed efficiency levels..

To have sufficient variation we use measures of the dependent variables only when there are at least five plants per sector per municipality (Table 2) or ten plants (Table 3). The results reveal the higher the road density, plants in particular a sector and municipality tend to have less dispersed TFPs. Also, the minimum level and the median value of TFP seem to be higher. Nonetheless, these results are not robust to changes in the estimating procedure. When fixed (per sector and municipality) and random effects are used results vanish (Tables 4 to 7).

VII. Conclusions

This paper analyses the role of transport infrastructure in determining plant level TFP. Using data from the manufacturing surveys and the road network and traffic for Colombia, we find that higher road density has an unambiguously positive effect on TFP, while road congestion decreases TFP.

An interesting result is that the effects of congestion and road density are of similar magnitude. In practice, this means that a one percent increase in the road network is offset by a one percent increase in congestion. Therefore, measures aimed at increasing the network and/or reducing traffic have a potentially very high dividend. Recent lack of growth in the road network, compounded with the increase in congestion, is very costly in terms of manufacturing efficiency.

Although less robust, our evidence also suggests that plants located in markets with more access to a larger road network tend to show less dispersion in their TFP, a higher median TFP and a higher level in the 10^{th} percentile. Thus, markets with better infrastructure are also more contested. In this markets, only the more efficient producers survive, suggesting a possible channel trough which infrastructure contributes to the overall efficiency of the economy.

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Table 1

Estimates of the effect of transport infrastructure on TFP growth

	3-digit CIIU sectors		Plant Level	
	TFP 1 (1)	TFP 2 (2)	TFP 1 (3)	TFP 2 (4)
ϕ	31.64* (11.47)	23.57* (10.38)	2.65** (1.35)	1.24 (1.38)
κ			-0.95*** (0.49)	-0.26 (0.56)
N	260	260	27.379	27.379
Adjusted R^2	0.312	0.256	0.033	0.007
Variance Cluster	Ciiu 3	Ciiu 3	Plant	Plant
$\partial tfp / \partial g$	1.03	0.77	0.08	0.04

Table 2

	Plant Level		
	TFP 1 (1)	TFP 1 (2)	TFP 1 (3)
ϕ	1.34* (0.75)	2.74** (1.37)	0.83 (1.77)
κ	-1.33*** (0.42)	-0.92*** (0.50)	-4.46*** (0.89)
N	27.379	27.379	27.379
Adjusted R^2	0.031	0.033	0.036
Variance Cluster	Plant	Plant	Plant
$\partial tfp / \partial g$	0.04	0.09	0.03

Table 3

Estimates of the effect of transport infrastructure on TFP levels and dispersion

	TFP 1, IQR			TFP 1, 10th percentile			TFP 1, median		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log Road density	-0.024		-0.041*	0.042***		0.055***	0.042***		0.011
	(0.018)		(0.022)	(0.016)		(0.020)	(0.016)		(0.018)
log Population		0.007	0.012*		-0.002	-0.009		0.024***	0.023***
		(0.005)	(0.006)		(0.006)	(0.007)		(0.005)	(0.006)
constant	0.587***	0.330	0.525***	0.808***	1.118***	0.855***	1.177***	1.120	1.064***
	(0.124)	(0.079)	(0.122)	(0.107)	(0.089)	(0.130)	(0.106)	(0.081)	(0.115)
N	1392	1392	1392	1392	1392	1392	1392	1392	1392
Adjusted R^2	0.001	0.003	0.001	0.002	0.001	0.004	0.004	0.014	0.014

Using robust standard errors (in parenthesis).
Dropping sectors with less than five plants and municipalities with less than twenty observations.
*denotes significance at the 10% level, **at the 5% level, and ***at the 1% level.

Table 4

Estimates of the effect of transport infrastructure on TFP levels and dispersion

Fixed effects per year

	TFP 1, IQR			TFP 1, 10th percentile			TFP 1, median		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log Road density	-0.022		-0.039*	0.046***		0.058***	0.048***		0.017
	(0.019)		(0.022)	(0.018)		(0.020)	(0.016)		(0.018)
log Population		0.007	0.012*		-0.001	-0.009		0.025***	0.023***
		(0.005)	(0.006)		(0.006)	(0.007)		(0.005)	(0.006)
constant	0.570***	0.320***	0.508***	0.861***	1.185***	0.905***	1.190***	1.159***	1.077***
	(0.127)	(0.085)	(0.126)	(0.123)	(0.090)	(0.130)	(0.107)	(0.083)	(0.116)
N	1392	1392	1392	1392	1392	1392	1392	1392	1392
Adjusted R^2	0.005	0.005	0.007	0.019	0.015	0.020	0.040	0.050	0.051

Table 5

Estimates of the effect of transport infrastructure on TFP levels and dispersion
Using robust standard errors (in parenthesis)

	TFP 1, IQR			TFP 1, 10th percentile			TFP 1, median		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log Road density	-0.016		-0.016	0.065**		0.091***	0.013		0.002
	(0.021)		(0.013)	(0.027)		(0.030)	(0.025)		(0.027)
log Population		-0.002	-0.001		<0.001	-0.013		0.005	0.005
		(0.009)	(0.013)		(0.008)	(0.008)		(0.007)	(0.008)
constant	0.553***	0.480***	0.554***	0.626***	1.056***	0.642***	1.387***	1.393	1.380***
	(0.139)	(0.145)	(0.138)	(0.181)	(0.119)	(0.196)	(0.166)	(0.111)	(0.169)
N	777	777	777	777	777	777	777	777	777
Adjusted R^2	0.001	0.001	0.001	0.005	0.001	0.008	0.001	0.001	0.001

Dropping sectors with less than ten plants and municipalities with less than twenty observations.
*denotes significance at the 10% level, **at the 5% level, and ***at the 1% level

Table 6

Estimates of the effect of transport infrastructure on TFP levels and dispersion
Fixed effects per CIIU 3 and municipality

	TFP 1, IQR			TFP 1, 10th percentile			TFP 1, median		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log Road density	-0.030		-0.181	-0.655***		0.081	-0.805***		-0.329**
	(0.121)		(0.192)	(0.184)		(0.233)	(0.115)		(0.147)
log Population		0.156	0.245		-1.162***	-1.202***		0.005	-0.776***
		(0.198)	(0.262)		(0.168)	(0.209)		(0.007)	(0.160)
constant	0.645	-1.737	-1.783	5.353***	17.214***	17.235***	6.758***	1.393	14.435***
	(0.796)	(2.753)	(2.782)	(1.209)	(2.343)	(2.350)	(0.755)	(0.111)	(1.752)
N	777	777	777	777	777	777	777	777	777
Adjusted R^2	0.001	0.001	0.001	0.006	0.001	0.008	0.001	0.001	0.001

Table 7

Estimates of the effect of transport infrastructure on TFP levels and dispersion

Random effects per CIIU 3 and municipality

	TFP 1, IQR			TFP 1, 10th percentile			TFP 1, median		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log Road density	-0.018		-0.024	0.005		0.029	-0.131**		-0.154**
	(0.059)		(0.079)	(0.033)		(0.066)	(0.054)		(0.064)
log Population		-0.001	0.003		-0.010	-0.015		-0.013	0.009
		(0.020)	(0.026)		(0.018)	(0.019)		(0.017)	(0.020)
constant	0.565	0.449	0.558	1.019***	1.206***	1.073**	2.335***	1.667***	2.354***
	(0.395)	(0.300)	(0.398)	(0.216)	(0.257)	(0.430)	(0.360)	(0.246)	(0.374)
N	777	777	777	777	777	777	777	777	777
Adjusted R^2	0.001	0.001	0.001	0.003	0.001	0.001	0.004	0.014	0.001

Figure 1

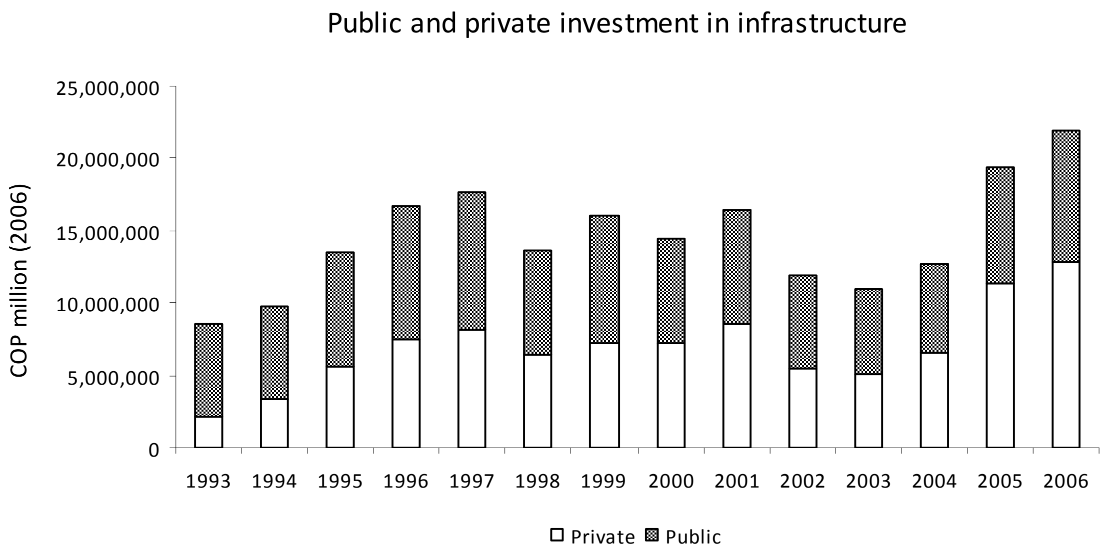


Figure 2

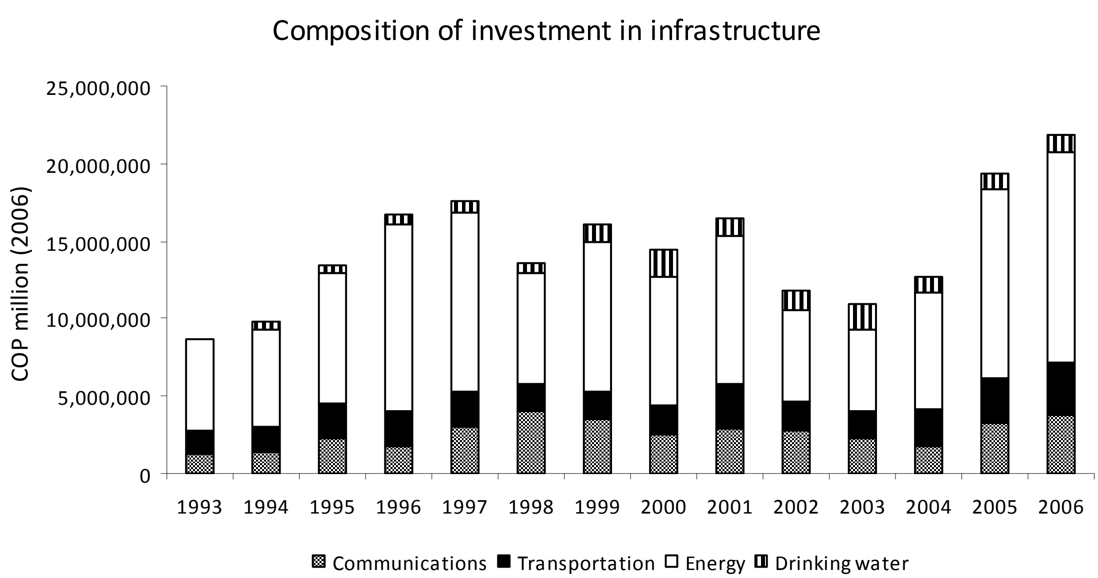


Figure 3

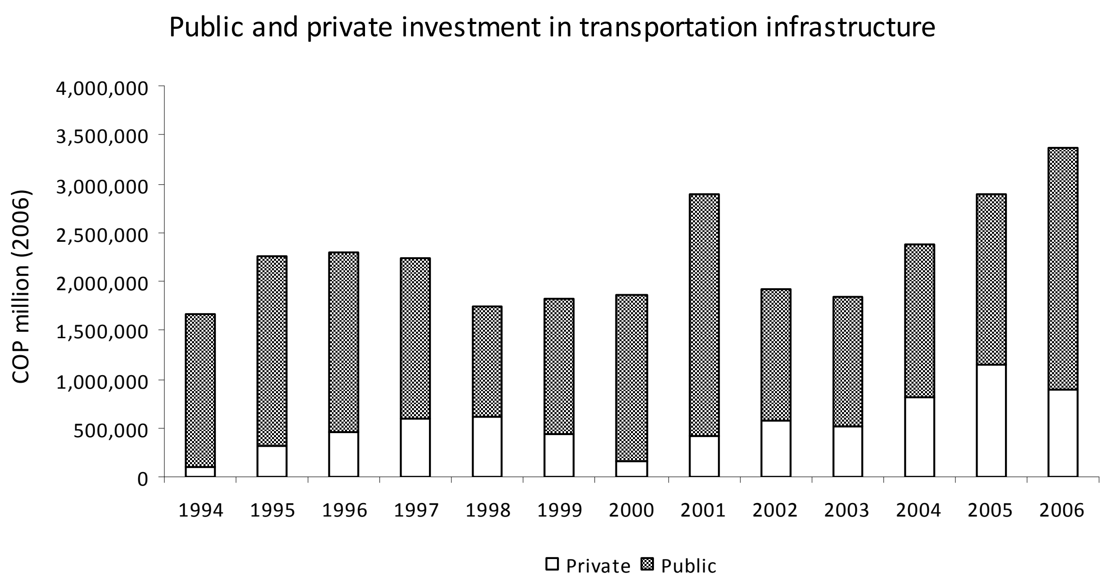


Figure 4

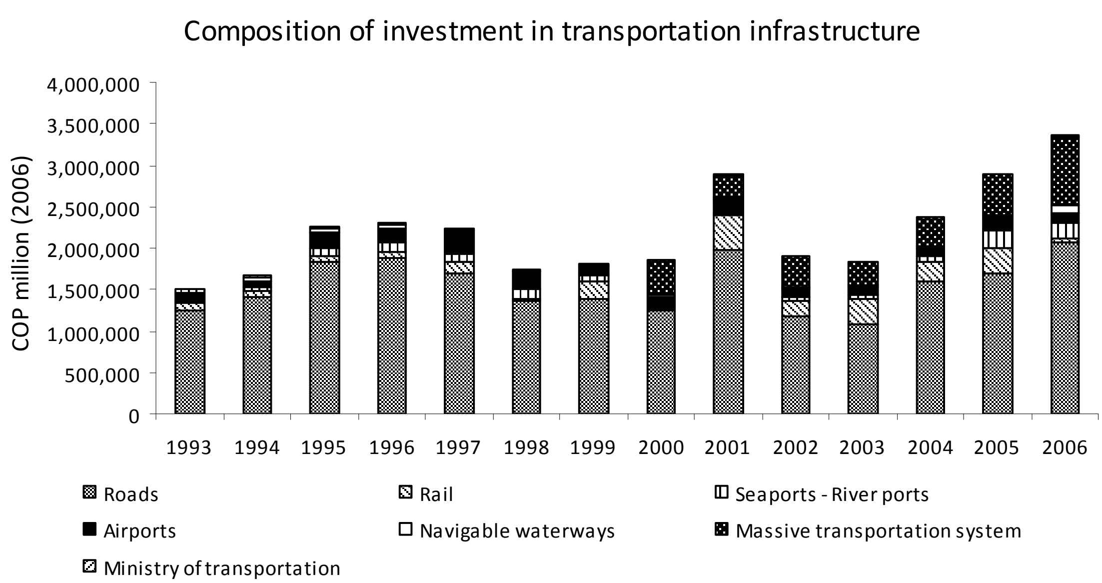


Figure 5

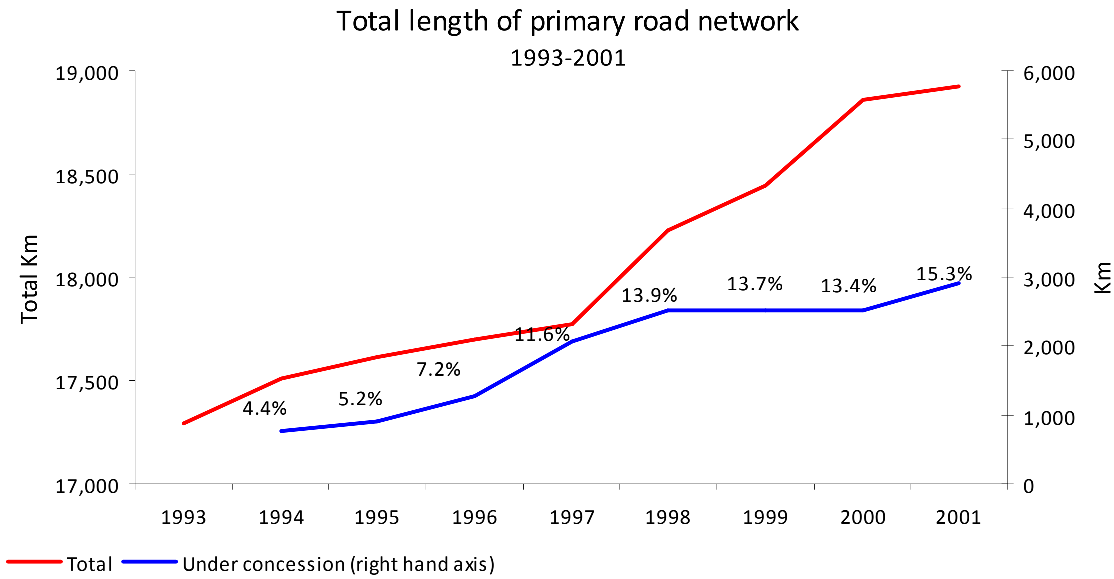

Total length of primary road network
1993-2001
19,000
18,500
18,000
17,500
17,000
Total Km
6,000
5,000
4,000
3,000
2,000
1,000
0
Km
4.4%
5.2%
7.2%
11.6%
13.9%
13.7%
13.4%
15.3%
1993
1994
1995
1996
1997
1998
1999
2000
2001
Total
Under concession (right hand axis)

Figure 6

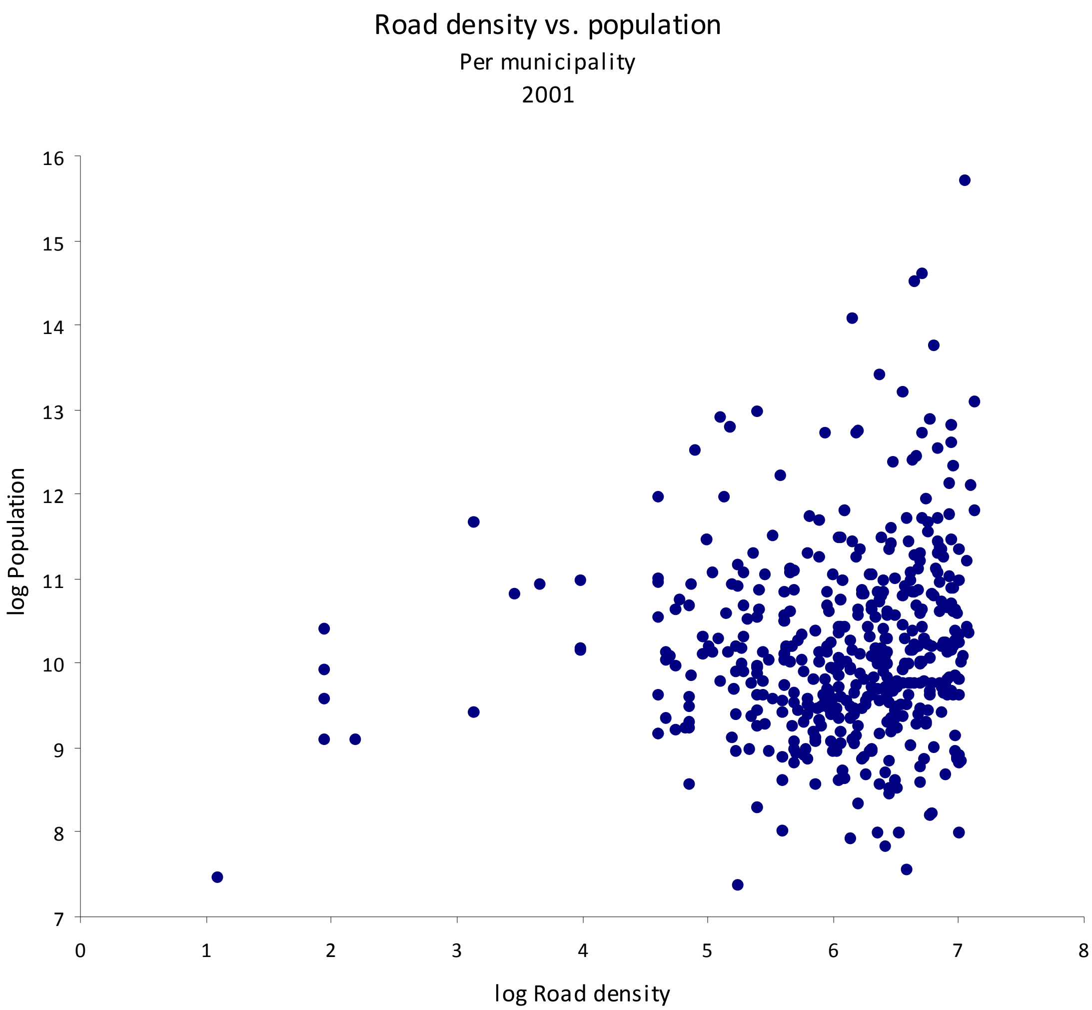

Road density vs. population
Per municipality
2001
16
15
14
13
12
11
10
9
8
7
0
1
2
3
4
5
6
7
8
log Population
log Road density

Figure 7

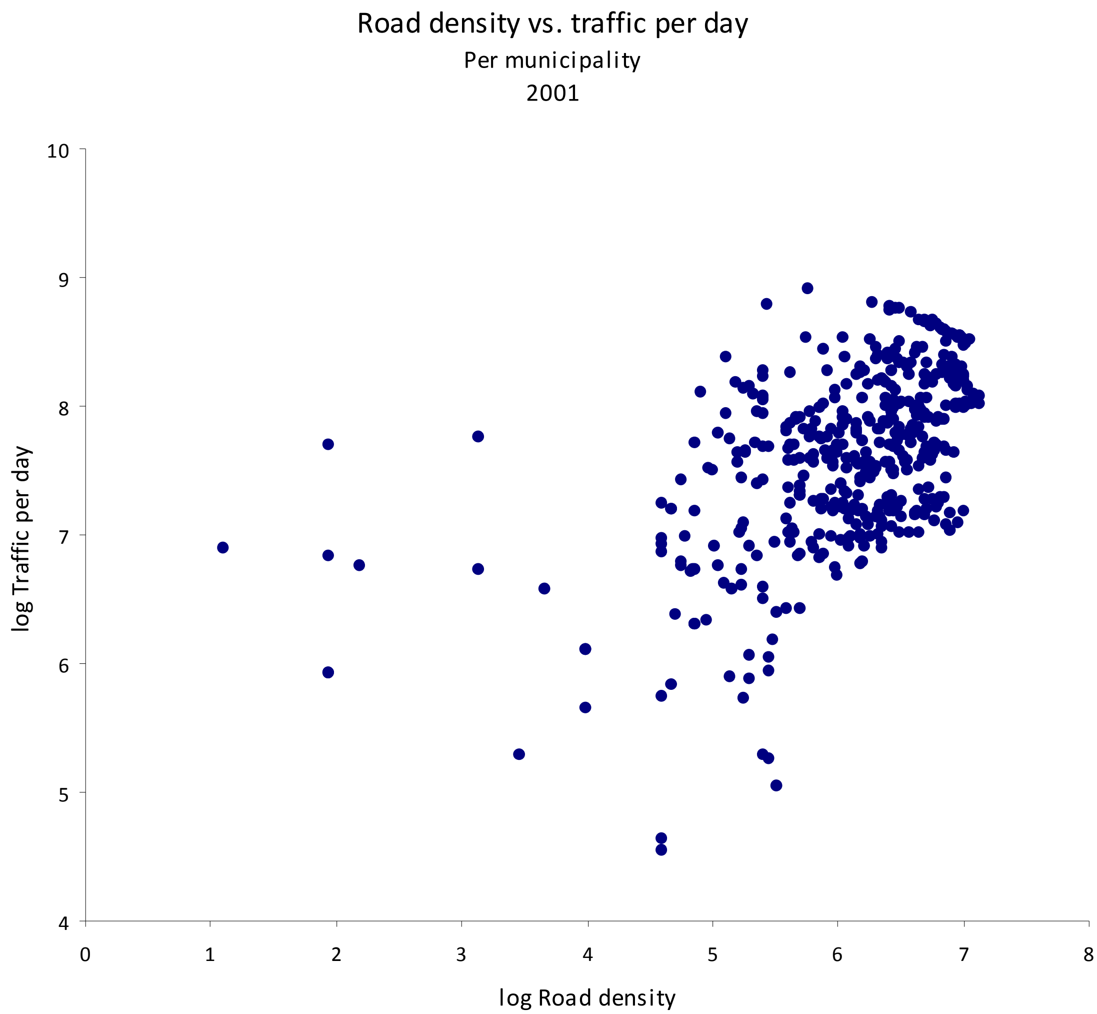

Road density vs. traffic per day
Per municipality
2001
log Traffic per day
log Road density
10
9
8
7
6
5
4
0
1
2
3
4
5
6
7
8

Figure 8: TFP growth, 1993-2001

Measure according to accounting residual (TFP 1)

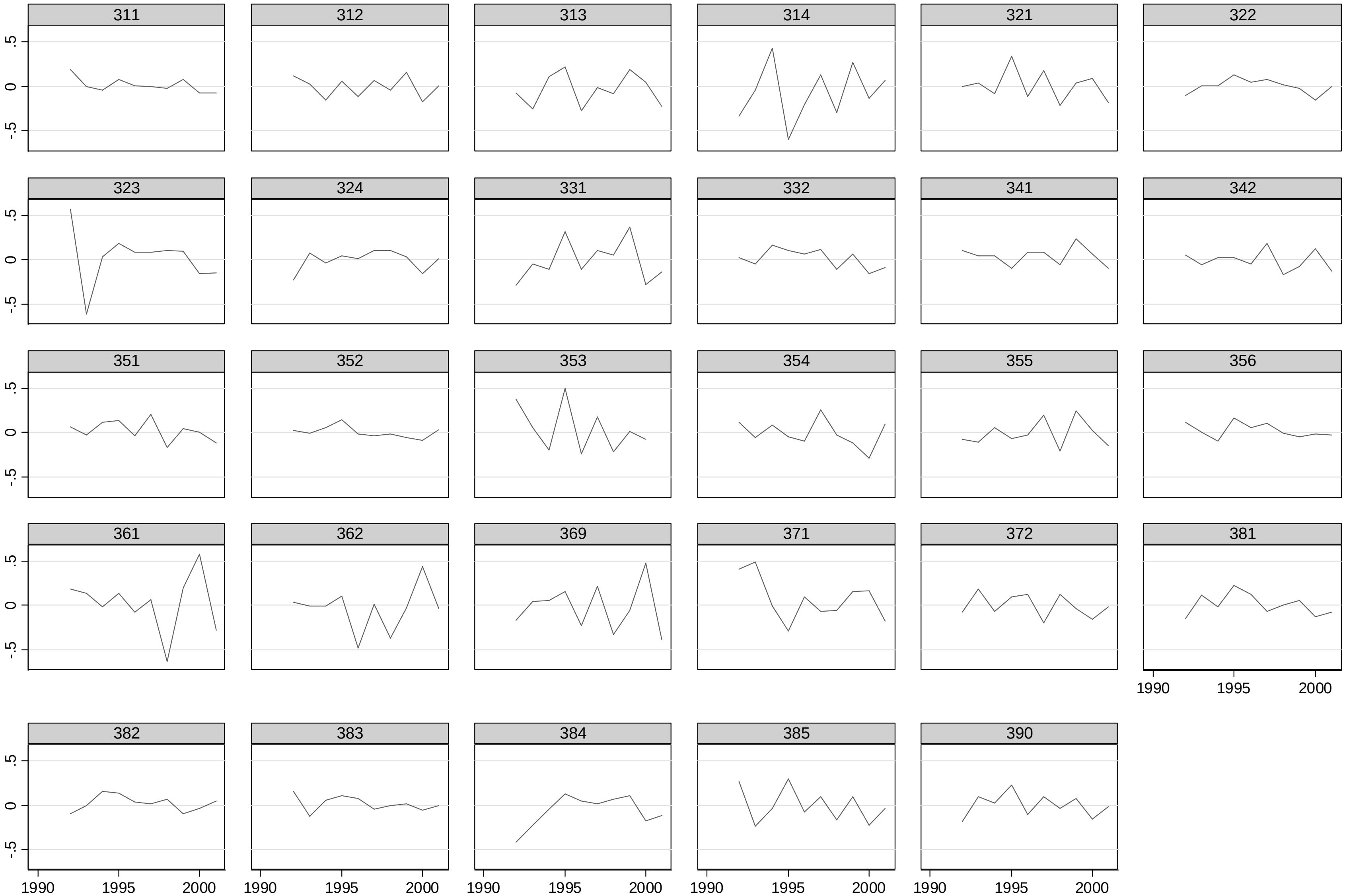


Figure 9: TFP growth, 1993-2001

Measure according to Levinsohn-Petrin non parametric estimation (TFP 2)

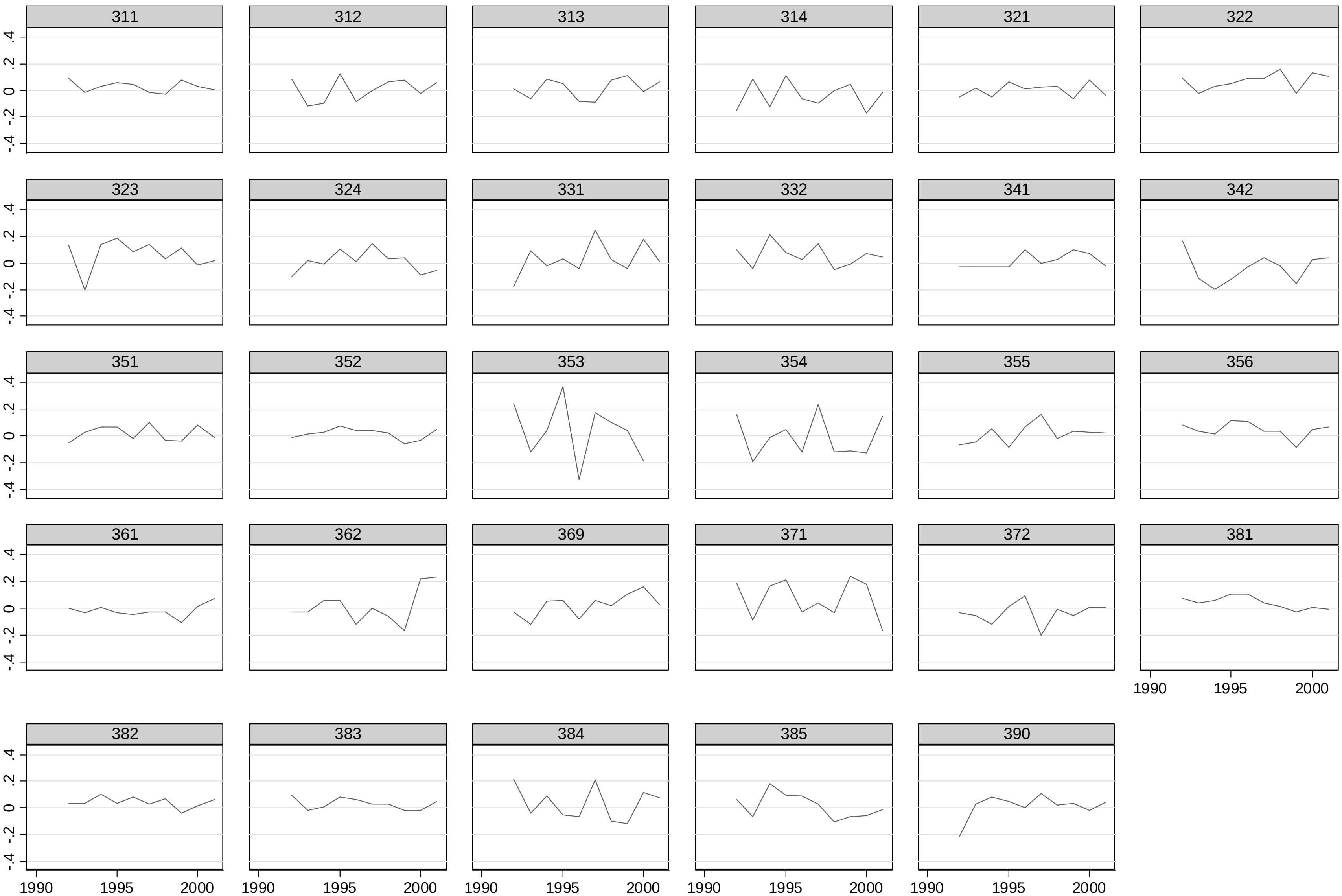
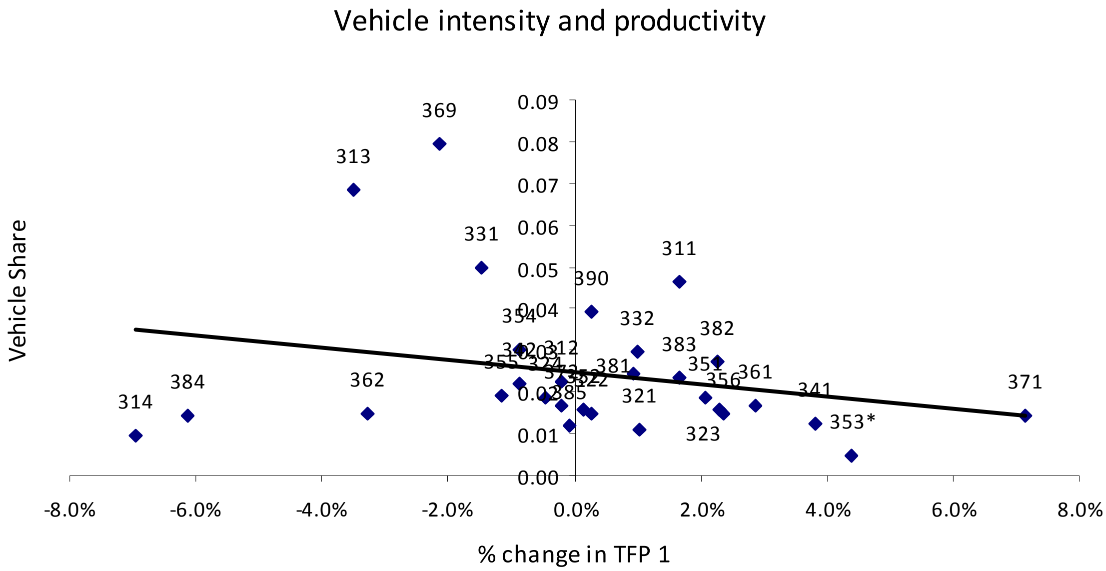


Figure 10


Vehicle intensity and productivity
Vehicle Share
% change in TFP 1

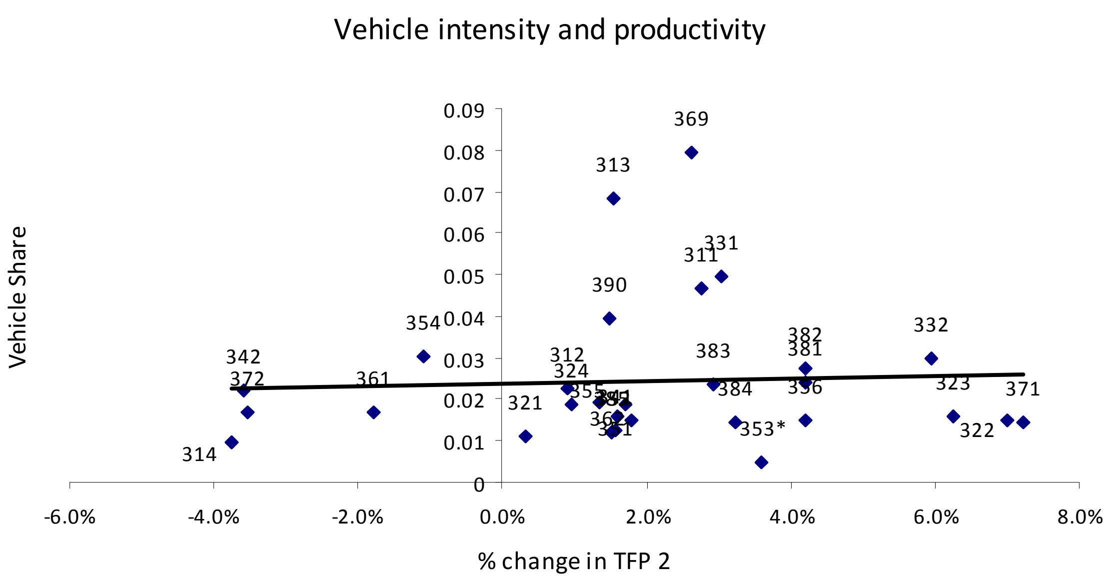

Vehicle intensity and productivity
Vehicle Share
% change in TFP 2

Figure 11

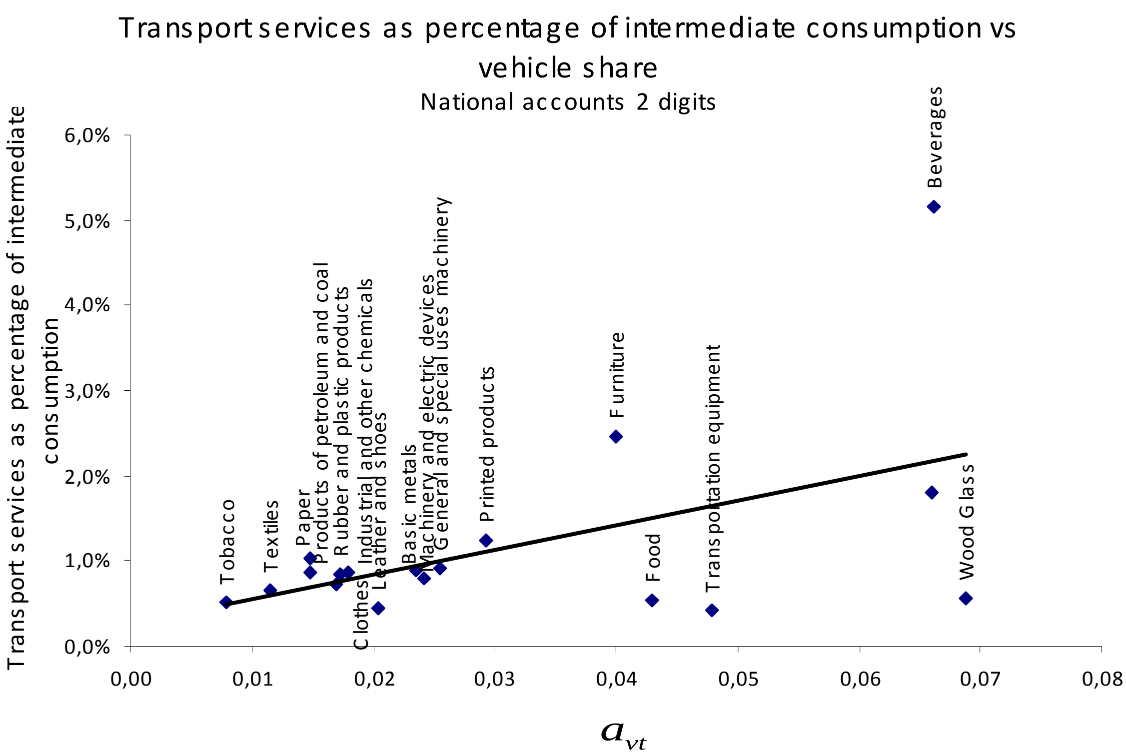


Figure 12

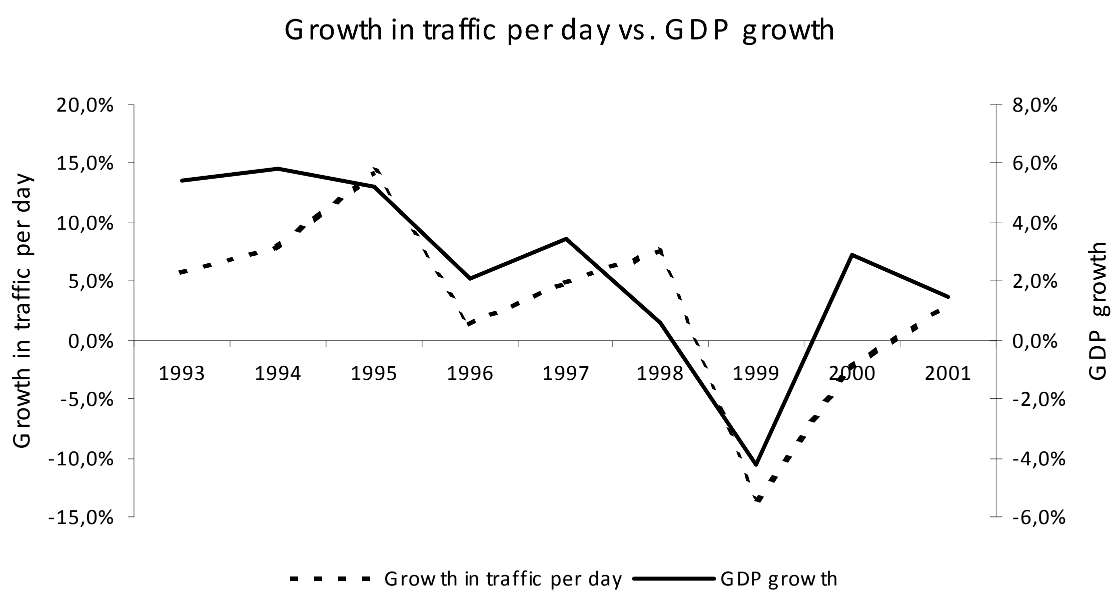


Figure 13

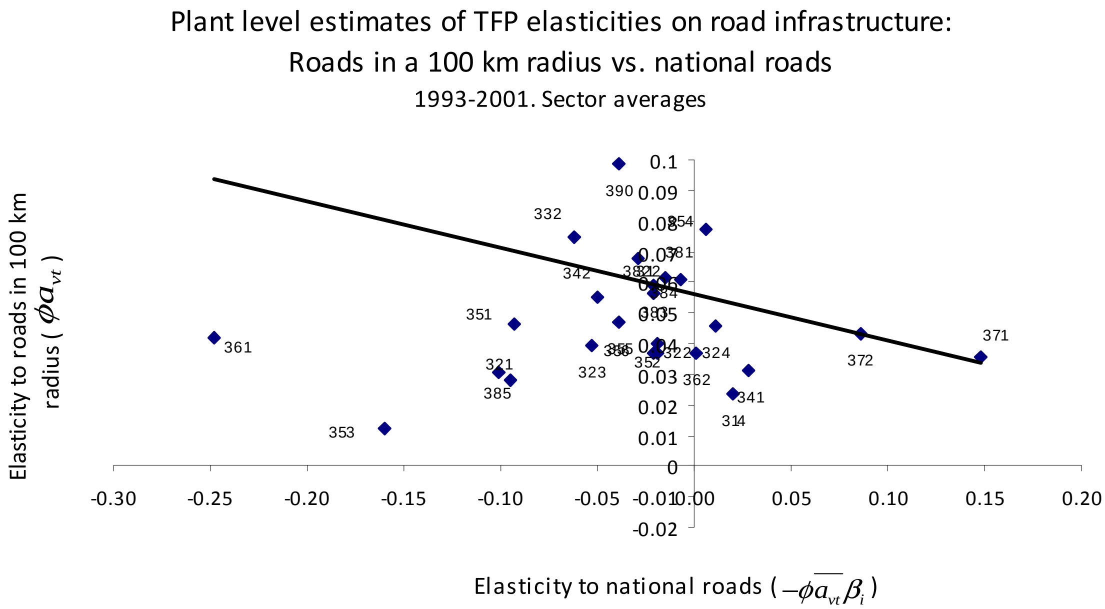


Figure 14

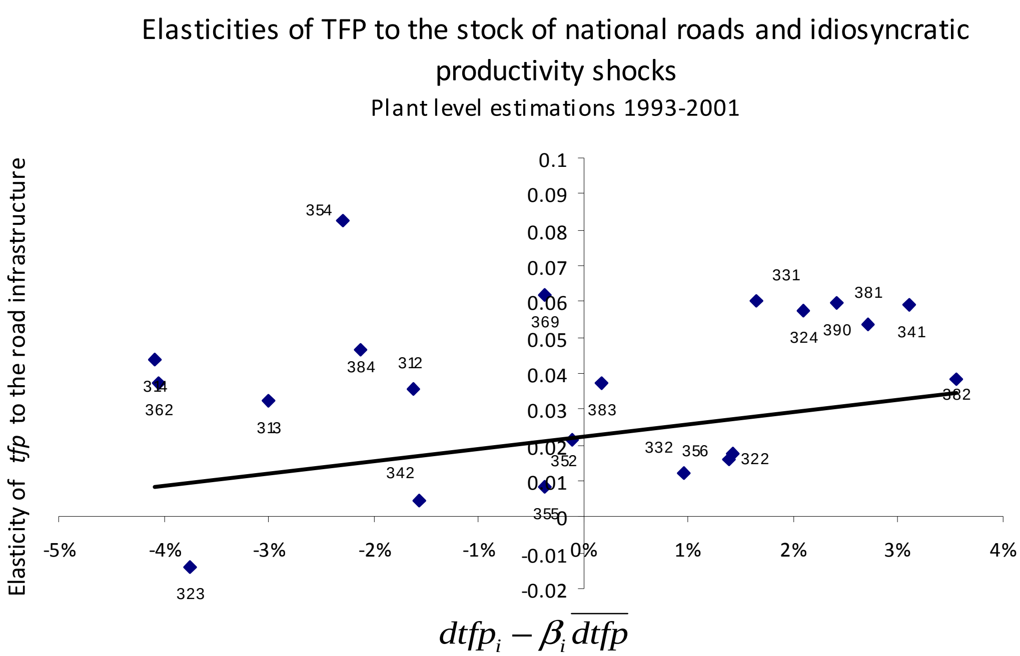


Figure 15

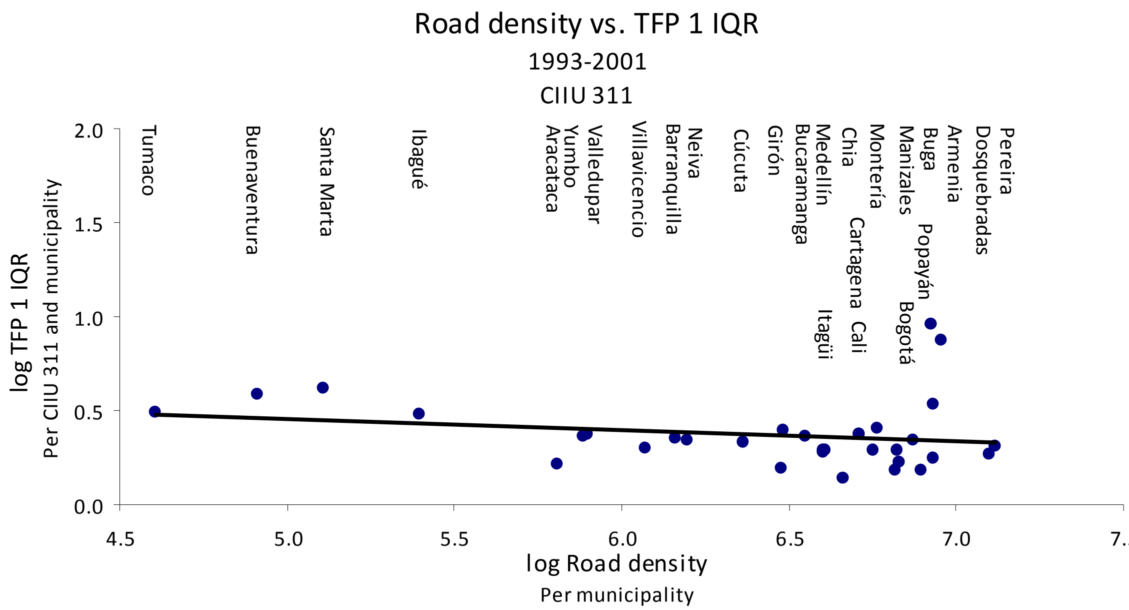


Figure 16

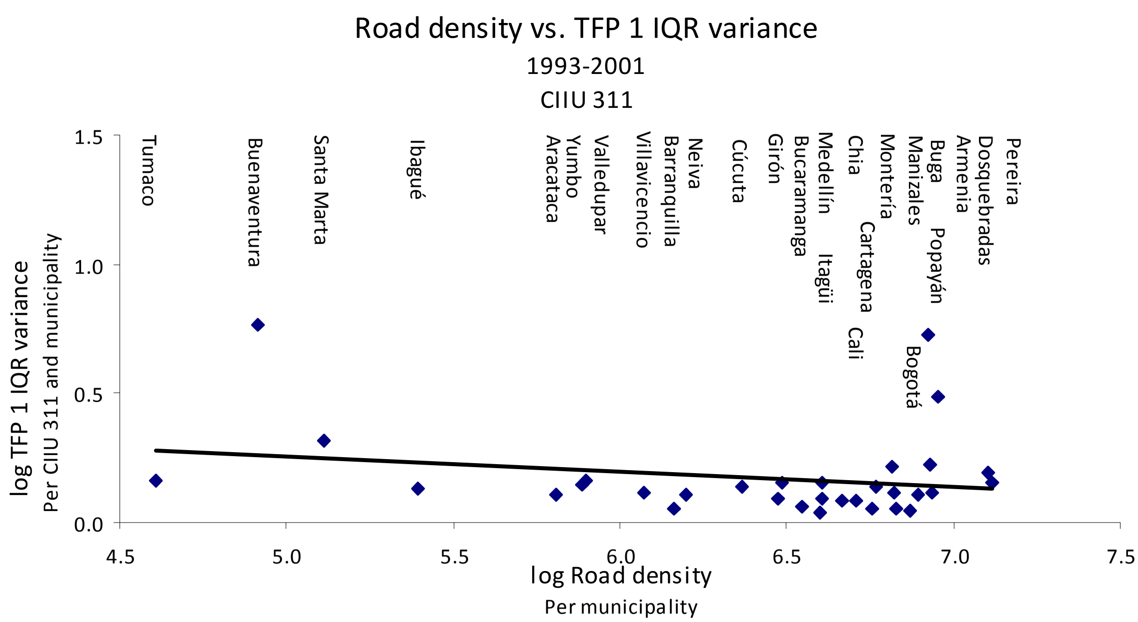


Figure 17

Road density vs. TFP 1 median
1993-2001
CIIU 311

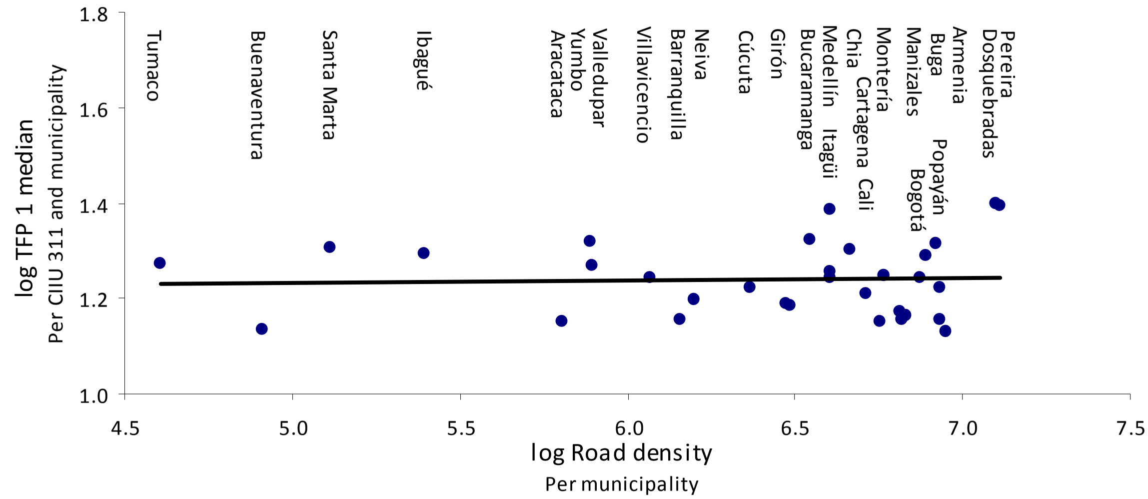


Figure 18

Road density vs. TFP 1 IQR
3-digit CIIU manufacturing sectors
1993-2001

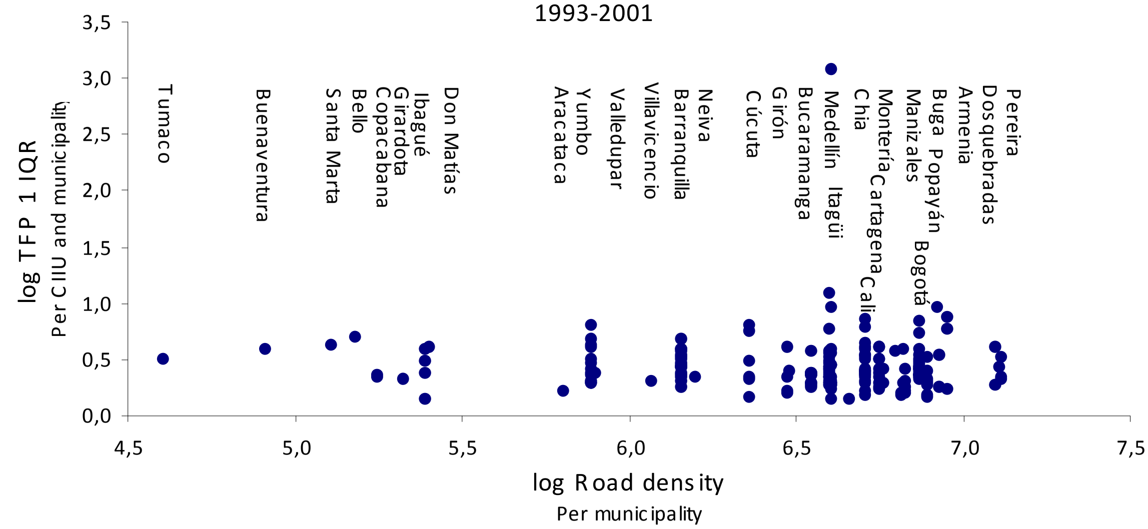


Figure 19

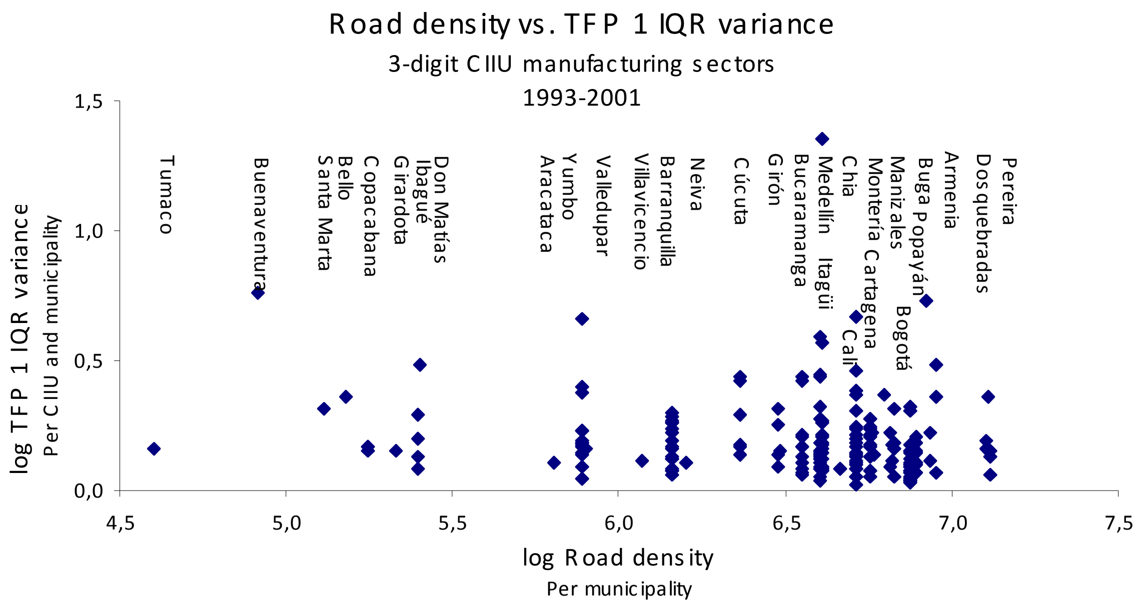


Figure 20

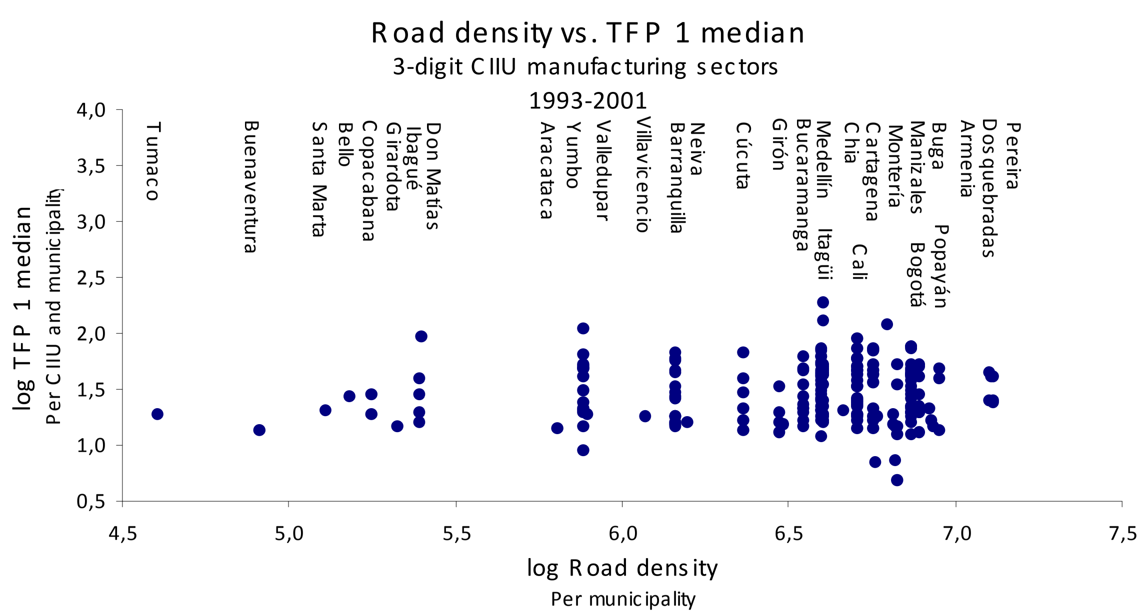
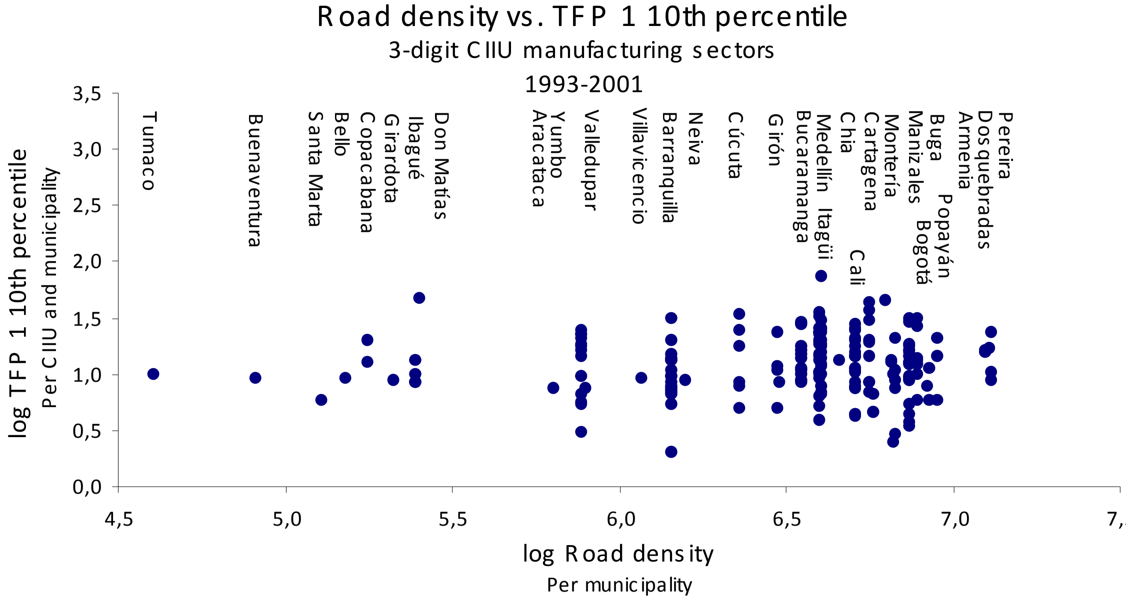


Figure 21


Road density vs. TFP 1 10th percentile
3-digit CIIU manufacturing sectors
1993-2001
log TFP 1 10th percentile
Per CIIU and municipality
log Road density
Per municipality
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
4,5
5,0
5,5
6,0
6,5
7,0
7,5
Tumaco
Buenaventura
Santa Marta
Bello
Copacabana
Girardota
Ibagué
Don Matías
Aracataca
Yumbo
Valledupar
Villavicencio
Barranquilla
Neiva
Cúcuta
Girón
Bucaramanga
Medellín
Itagüi
Chia
Cali
Cartagena
Montería
Manizales
Bogotá
Buga
Popayán
Armenia
Dosquebradas
Pereira