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DOES COUNTRY SIZE AFFECT THE RELATIONSHIP BETWEEN POPULATION DENSITY AND LABOUR PRODUCTIVITY? THEORY AND EVIDENCE FOR EUROPE

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ABSTRACT: The empirical literature on the relationship between labour productivity and urbanisation economies has considered the presence of variable returns to density, but it has not investigated the existence of a heterogeneous relationship according to country size. This paper proposes a theoretical model which can explain why the relationship between regional labour productivity and population density may differ in strength between small and large countries. To test the proposed theory, we carry out an empirical regression analysis using NUTS2-level data on GDP per capita and population density for the EU28 countries. The results from the empirical analysis corroborate the theoretical model and indicate the relationship is linear and stronger for regions in small countries compared to large countries.

Keywords: Labour Productivity; Population Density; Economic Development; Country Size.

JEL Classification: O11, O14, O15, R11, R12.

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1. INTRODUCTION

Countries within the European Union, such as Greece and Portugal, which suffered recently bailout programs through the joint action of the European Commission, the European Central Bank and the International Monetary Fund, have experienced a decline in population. While population in active age (with age between 15 and 54 years) at the EU level has remained more or less the same, with an average annual rate of 0.003% between 2004 and 2017, population in Greece and Portugal fell at annual average rates of -0.5% and -0.4%, respectively. The fall in population in these two countries is likely to constrain its level of economic development in the long run. This article explores the relationship between labour productivity and population density within EU28 countries, particularly how it may differ between small and large countries.

It has been remarked that a high density of population in a region is a suitable factor for its economic development. Von Thünen (1966, p.293) described the economic effect of population density in the following way. Let there be two regions with the same area but with different numbers of inhabitants, which are in any case evenly distributed in space. We label *A* and *B* the high and low density regions, respectively.

Then, the fact that region *A* exhibits a higher level of overall economic development can be assigned to the level of *quality* and *efficiency* in providing a public good such as formal education to its inhabitants.[1] Hence, it is assumed that education is supplied by means of a network of schools which are regularly distributed in space. For simplicity, we presuppose that the cost associated with a school is entirely a fixed set up cost, operating costs being absent. While the level of *quality* varies inversely with the average distance a student must travel between his residence and the nearest school, the *efficiency* level is related with the average cost to educate one student.

[1] We refer to the instance of formal education here, but other examples of public services such as health care, justice, transportation and others could also be used instead.

If both regions run a school network with the same *quality*, i.e. with the same number of schools and average proximity of schools to students, then region *A* will show an average cost of educating one student which is strictly smaller than the cost borne in region *B*. Therefore, while keeping the quality of formal education constant, the high density region will be able to divert investment funds away from education to the supply of other public goods, such as health, justice and so on, thereby fostering economic development.

Another viewpoint on the economic advantages of regional population density consists in supposing that the costs per student are the same in both regions. This implies that the number of regularly spaced schools will be higher in region *A*, so that the average distance a student must travel daily in order to attend school will be lower in the densely populated region, thus leading to a higher quality of education and to a more productive labour force.

Furthermore, Simon and Glover (1975) built on Von Thünen's (1966) conjecture of a direct relationship between quality/cost efficiency of infrastructure in a region and its population density and tested this relation empirically for the case of roads. The result confirmed the initial theoretical conjecture.

We were able to conclude that the distance which an individual has to travel in order to access the point of supply of a public good (school, hospital, court and so on) is the main cause that hinders the quality of infrastructure and its potential contribution to overall labour productivity. Moreover, we have seen that this travel distance is conditioned by the regional density of population. However, in spite of being important, this determinant is not the unique.

We define a country in economic terms as either being coincident with a region (a *small* country) or resulting from the trade integration of several regional markets (a *large* country). The latter process may go along the political unification of formerly independent small states (as Germany and Italy did in the second half of the nineteenth century) or may simply be an outcome of the internal market integration within an existing large nation-state (as France did in the seventeenth century).[2]

In any case, as it was said by Friedrich List (1841), the integration of formerly separate regions in the internal market of a large country always entails the elimination of internal customs and a drastic improvement in the transport infrastructure linking the regions. As Martin (1998) remarks, an investment in transport infrastructure connecting two regions within the same country has a much more intense effect upon the country market potential than an outlay financing a transport link between a region within the country and an outside region. Consequently, improving internal transport connections is a priority during the economic integration of a large country.

The drastic fall of inter-region transport costs during the economic integration of a large country makes likely that some kind of regional specialization will emerge along this process. The well-known Smithian quote (Smith, 1776, Book I, Chapter III) - "That the division of labour is limited by the extent of the market"- can be applied here. The division of labour may emerge in a situation where a worker performs a productive process composed by n technically separable and complementary tasks (see Becker and Murphy, 1992). If this worker finds $n-1$ fellows with whom he can exchange intermediate goods, i.e. who locate up to a maximum transaction distance from him, then they all can form a team where each workers performs a specialized task, the outcome of the specialization being a drastic rise in labour productivity. This is the so-called "occupational specialization" which depends on a sufficient population density in the region where the workers live. This is just a different way to give a reason for the association between regional population density and labour productivity along the line which we followed above.

However, while keeping population density constant across regions, a "geographic specialization" may arise just by expanding the maximum transaction distance across workers through a major

[2] A similar process takes place nowadays at the European level within the EU.

improvement of transport connections linking regions in the context of the internal trade integration of a large country (see Wallerstein, 1974). In this case, each region within the large country specializes in a different good and the individual worker has to travel to every other region in order to be able to achieve his productive task.

By contrast with travelling within a region, which is strongly and inversely related with regional population density, travelling across regions within a large country does not bear a clear association with the number of inhabitants, since they arise instead from the low level of inter-regional transport costs. Since travelling is generally considered to be a disutility for the individual and an hindrance for its productive activity, one should expect that the direct association between regional population density and labour productivity should be stronger for regions within "small" countries (which are themselves more coincident with singular "regions") than for regions contained in "large" countries, where an internal trade integration was formerly achieved.

In this paper, we propose a theoretical model which can explain why the relationship between regional labour productivity and population density differs in strength between small and large countries. We then develop an empirical regression model using regional NUTS2-level data for the EU28 with the aim of testing the proposed theoretical model. The results from the empirical regression analysis corroborate the theoretical model. While the empirical literature on the relationship between labour productivity and urbanisation economies (typically measured by population or employment density) has considered the presence of variable returns to density (see Melo et al., 2009 for a review), we have not yet come across any studies investigating a heterogeneous relationship according to country size.

The paper is organised as follows. Section 2 describes the theoretical model. Section 3 describes the empirical regression analysis carried out to test the theoretical model and reports and discusses the main results. Section 4 provides some concluding remarks.

2. THE MODEL

We will assume that the European Union is made up by a set of countries, where each country i owns m_i regions with $m_i \in \{1,2,3,4,\ldots\}$. For simplicity, it is presupposed that regions do no vary either in geographical size or in population/labour force within the same country i, so that these magnitudes can be expressed by S_i and L_i. By contrast, they are allowed to vary across countries. In general, if we consider countries i and j, we will have $S_i \neq S_j$ and $L_i \neq L_j$.

Given the fact that regions strongly vary in area and population within European countries, the former simplifying assumption may seem too restrictive. However, the variation of regions across countries is at least as great as variation within the same country, so that the former can be viewed as accounting for the latter. As it was expressed by Von Thünen (1966),

> *"Looking at Europe, we see differences between country and country in living standards, population density, grain price and land rent which are as great as those between districts of the Isolated State.* (p. 194)"

The aggregate production function of a region within country i is

$$Y_i = H_{m_i} L_i^{\alpha} S_i^{(1-\alpha)} \tag{1}$$

Where

$Y_i \equiv$ regional output
$L_i \equiv$ regional population/labour force
$S_i \equiv$ area of region
$H_{m_i} \equiv$ aggregate productivity term

The aggregate productivity term H_{m_i} is determined at the country level taken a whole and it prevails in each region within it. It can be formally written as

$$H_{m_i} = \left(\frac{v}{\hat{d}_i} \right)^{\gamma}, \text{ with } \gamma > 0 \qquad (2)$$

Where

$v \equiv$ gross benefit of consuming a set of public services (education, health care, justice, ...)
$\hat{d}_i \equiv$ average distance an individual has to travel in order to access a set of public services

Through the assumption that transport costs within a country are kept low, we presuppose that a country with m_i regions specializes each one of them in the supply of a particular public service. Within each region, a specific public service is provided through regularly spaced plants to consumers whose residences are also uniformly distributed in space.

We can classify the distances travelled by a representative consumer into two groups:

1. The internal distance in each region is approximated by the region area S_i.
2. The distance separating each pair of regions within a country. This is assumed to be constant across regions and countries and expressed by ρ .

Hence, $\frac{S_i}{n_i}$ stands for the average internal distance which a consumer has to travel in order to access a particular public service supplied by a network with n_i regularly spaced plants within region i. We assume that n_i is constant across regions and public services within country i. Therefore, we can write the average distance which a consumer living in country i must travel in order to obtain the public services which are supplied in country m_i regions as

$$\hat{d}_i = m_i \left(\frac{S_i}{n_i} \right) + (m_i - 1)\rho \tag{3}$$

By substituting (3) in (2), the aggregate productivity term in country i becomes

$$H_{m_i} = \left[\frac{v}{m_i \left(\frac{S_i}{n_i} \right) + (m_i - 1)\rho} \right]^{\gamma} = \left[\frac{vn_i}{m_i S_i + (m_i - 1)\rho n_i} \right]^{\gamma} \tag{4}$$

We assume that the amount of resources per user which is allocated to the provision of public services is the same across regions and countries so that it can be expressed by the positive constant k. We further presuppose that the production cost of each public service unit in country i is entirely fixed (its operating costs are assumed to be zero) and it is expressed by F_{m_i}. We presuppose that a plant fixed cost strictly decreases with the level of regional specialization of public services and thus with the number of regions m_i within country i. Consequently, we have

$$F_1 > F_2 > F_3 > \dots \tag{5}$$

Then, the number of evenly spaced plants which provide a particular public service within the regions belonging to country i is determined by the following equality

$$k = \frac{n_i F_{m_i}}{L_i}$$

or equivalently

$$n_i = \frac{kL_i}{F_{m_i}} \tag{6}$$

By inserting (6) in (4), the aggregate country i productivity term becomes

$$H_{m_i} = \left[\frac{v\left(\frac{kL_i}{F_{m_i}}\right)}{m_i S_i + (m_i - 1)\left(\frac{kL_i}{F_{m_i}}\right)} \right]^{\gamma} \tag{7}$$

Let $D_i \equiv \frac{L_i}{S_i}$ be labour productivity in each region owned by country i. Then, the productivity term of a country formed be m_i regions can be simplified as

$$H_{m_i} = \left[\frac{vkD_i}{m_i F_{m_i} + (m_i - 1)\rho k D_i} \right]^{\gamma}$$

Henceforth in this paper, we will drop the subscript i so that the productivity term can be written simply as

$$H_m = \left[\frac{vkD}{mF_m + (m-1)\rho kD} \right]^{\gamma} \tag{8}$$

For the sake of simplicity, we will classify the countries in two groups: small and large. In the case of a small country, by setting $m = 1$ in (8), the country productivity term becomes

$$H_1 = \left(\frac{vkD}{F_1} \right)^{\gamma} \tag{9}$$

This country production function (which is coincident with a single region) is, according to (1) and (9)

$$Y_1 = \left(\frac{vkD}{F_1} \right)^{\gamma} L^{\alpha} S^{(1-\alpha)}$$

Therefore, labour productivity in a small country can be expressed as

$$y_1 = \frac{Y_1}{L} = \left(\frac{vkD}{F_1}\right)^{\gamma} D^{(\alpha-1)}$$

By setting $\gamma = 1$, labour productivity in a small country becomes

$$y_1 = \left(\frac{vk}{F_1}\right) D^{\alpha} \tag{10}$$

Then, it is clear that the elasticity of labour productivity in relation to population density in a small country is $\alpha \in (0,1)$.

In the case of a large country with two regions, by setting $m = 2$, (8) becomes

$$H_2 = \left(\frac{vkD}{2F_2 + \rho kD}\right)^{\gamma} \tag{11}$$

Labour productivity in each region belonging to the large country is

$$y_2 = \frac{Y_2}{L} = \left(\frac{vkD}{2F_2 + \rho kD}\right)^{\gamma} D^{(\alpha-1)}$$

By setting again $\gamma = 1$, labour productivity in the large country is

$$y_2 = \frac{vkD^{\alpha}}{2F_2 + \rho kD} \tag{12}$$

In order to calculate the elasticity of the labour productivity in relation to population density we evaluate $\frac{d \ln y_2}{d \ln D}$. The log of (12) is

$$\ln y = \ln(vk) + \alpha \ln D - \ln\left(2F_2 + \rho k e^{\ln D}\right) \tag{13}$$

The derivative of (13) is

$$\frac{d \ln y_2}{d \ln D} = \alpha - \frac{\rho kD}{2F_2 + \rho kD} < \alpha \tag{14}$$

Expression (14) stands for the result we intended to demonstrate in the first place: the elasticity of labour productivity in relation to population density is lower for regions which are a part of large countries than for those included in small countries. The reason for this fact lies in that, in large countries, a significant share of the distance travelled (corresponding to travels across regions associated with the productive specialization of each region) does not vary much with regional population density.

From (14), it follows that the elasticity for large countries remains positive. If we solve in order to D the inequality

$$\alpha - \frac{\rho k D}{2F_2 + \rho k D} > 0$$

We obtain the following condition

$$D < 2\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{F_2}{\rho k}\right) \qquad (15)$$

It is easy to understand that condition (15) is trivially satisfied through the choice of adequate units of measure of population.

3. TESTING THE THEORETICAL MODEL USING NUTS2-LEVEL DATA FOR THE EU28

To test the theoretical model presented in the previous section, we develop a regression model for the relationship between labour productivity, measured by GDP per capita in Purchasing Power Standard (PPS), and population density using regional data at the level of NUTS2 regions for the EU28. The variables were obtained from EUROSTAT’s regional database for the year 2015. The regression analysis considers NUTS2 regions for all EU28 member states together, and separately for small and large countries.[3] We start by inspecting visually the relationship between regional productivity and population density for small and large countries separately using simple scatter plots. The scatter plots in Figure 1 below suggest the relationship between regional labour productivity and population density is stronger for small countries.

(Insert here Figure 1)

To test the relationship, we estimate a linear regression model as follows:

$$GDPpc_{i,j} = b_1 + b_2 Dens_{i,j} + \gamma_j + \varepsilon_{i,j} \qquad (16)$$

Where the subscripts *i* and *j* denote the NUTS2 region and its country, respectively. *GDPpc* measures NUTS2 GDP per capita, our proxy for labour productivity, while *Dens* measures NUTS2 population density. To assess whether this relation differs between small and large countries we also estimate the same model for these countries separately. To account of country specific heterogeneity we include country-specific fixed-effects γ_j. The results are reported in Table 1.

(Insert here Table 1)

The models' explanatory power is good ranging between 53% and 72%. There is a positive relation between NUTS2-level population density and labour productivity. The elasticity for the full sample of countries is 0.109, indicating that increasing regional population density by 1% is associated with an increase in regional labour productivity of 0.11%. When we estimate the model separately for small and large countries, we observe that the magnitude of the relation is considerably larger for smaller countries: 0.193 vs. 0.088 (as we expected from the scatter plots above).

[3] The size threshold used is 100,000 km^2. Small countries: Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Slovenia. Large countries: Bulgaria, Finland, France, Germany, Greece, Italy, Poland, Romania, Spain, Sweden, United Kingdom.

We also experimented estimating the regression model using a quadratic function for the effect of population density to test for possible diminishing returns. The results reported in Table 2 show that the coefficients are not statistically significant, which in turn suggests the relationship between labour productivity and population density is not quadratic.

(Insert here Table 2)

The models reported above estimate mean effects assuming a linear relationship between labour productivity and population density. However, this may not be an appropriate assumption. To relax this assumption we estimate a semiparametric partially linear model (e.g. Ruppert et. al, 2003; Wood, 2006), which allows for a more flexible functional relation between NUTS2-level labour productivity and population density by including the later in the non-parametric term of the model. Figure 2 below illustrates the nonparametric fit of the regional labour productivity and regional population density for all countries, small and large countries separately. The shaded area represents the interval determined by the two standard error lines above and below the estimate of the smooth curve. The shape of the curves does not suggest a nonlinear fit, as also indicated by the test with null hypothesis that the nonparametric fit can be approximated by a parametric linear fit. The test of equal parametric and non-parametric fits indicates that we cannot reject the null hypothesis of equal parametric and non-parametric fits: the p-value for all countries, small countries and large countries is 0.24, 0.09, and 0.29, respectively, suggesting that the linear parametric models estimated earlier are appropriate.

(Insert here Figure 2)

4. CONCLUDING REMARKS

This paper proposes a theoretical model which can explain why the relationship between regional labour productivity and population density may differ in strength between small and large countries. While there have been many studies estimating the relationship between labour productivity and urban agglomeration, typically measured by population/employment size or density, we know very little about the potential role of country size on the magnitude of this relationship. The reasoning for our theoretical model is that travelling (or more generally transport of people and goods) is normally considered to be a disutility and a hindrance for productive activity, and as a result one can expect that the direct association between regional population density and labour productivity should be stronger for regions within “small” countries than for regions contained in “large” countries. To test the theoretical model, we also developed empirical regression analyses using NUTS2-level data on GDP per capita and population density for the EU28 countries. We estimated parametric and semiparametric linear models using the regional data to investigate the relationship between labour productivity and population density for all EU28 countries and “small” and “large” countries separately. The results obtained validate the theoretical model by suggesting that the relationship is stronger for regions in small countries compared to large countries. The models also indicate that the linear fit is appropriate for our sample.

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FIGURES AND TABLES

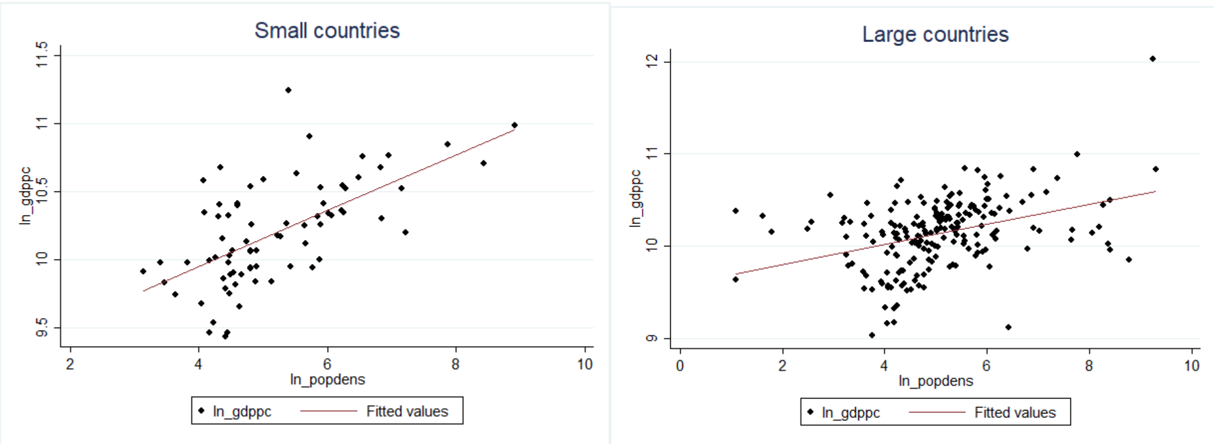

FIGURE 1: Labour productivity and population density for small countries (left) and large countries (right).

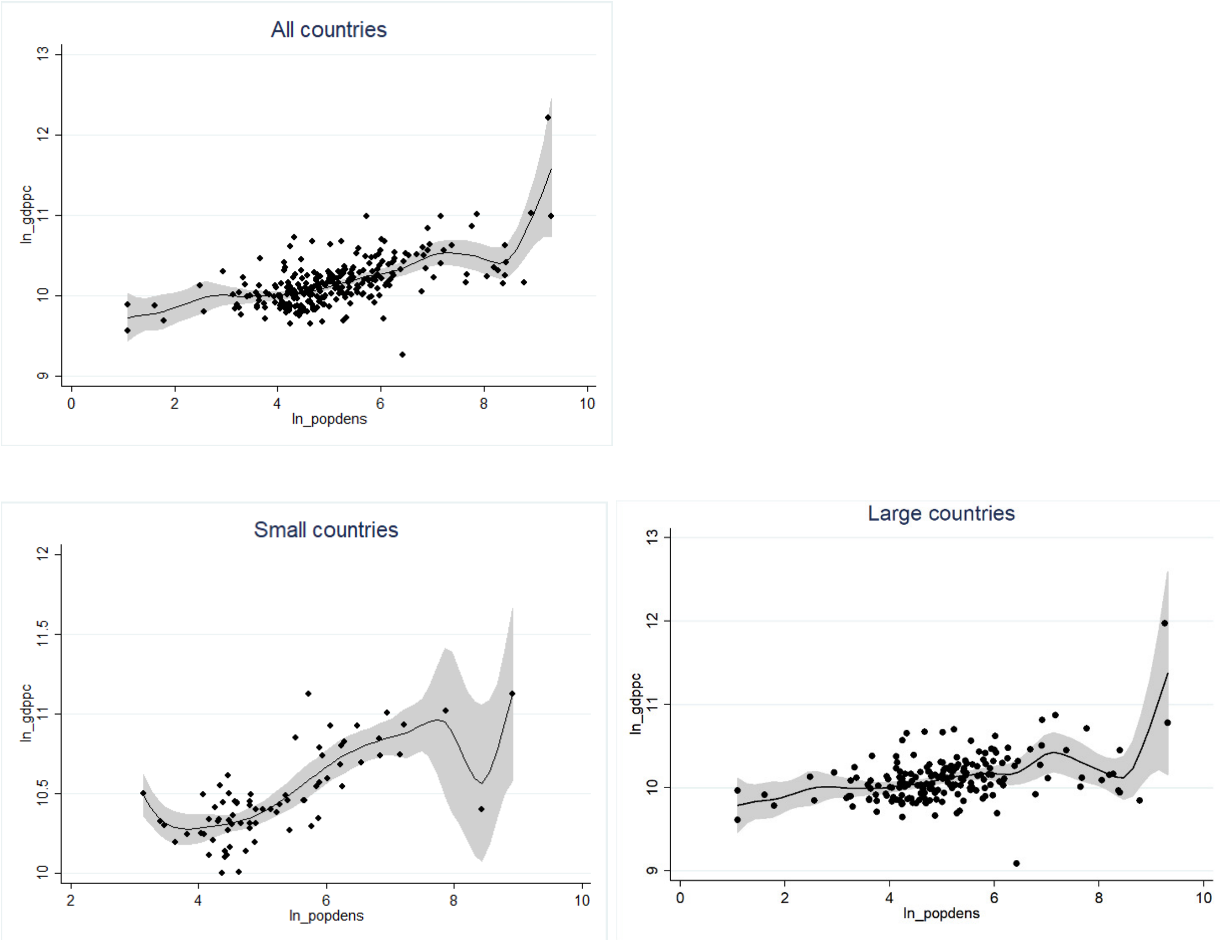

FIGURE 2: Labour productivity (vertical axis) and population density (horizontal axis) using a semiparametric partially linear model.

TABLE 1: Pooled OLS of NUTS2 regions for all countries, small and large countries.

Ln(GDPpc)	**OLS - All countries**	**OLS - Small countries**	**OLS - Large countries**
constant	9.949***	9.539***	8.970***
Ln(popdens)	0.109***	0.193***	0.088***
Controls for countries	YES	YES	YES
Observations	276	75	201
R^2 overall	0.604	0.781	0.554
R^2 adjusted	0.556	0.715	0.528

*** p<.01 indicates significance at 1%.

TABLE 2: Pooled OLS of NUTS2 regions for all countries, small and large countries – quadratic function.

Ln(GDPpc)	**OLS - All countries**	**OLS - Small countries**	**OLS - Large countries**
constant	10.218***	9.587***	10.244***
Ln(popdens)	0.007	0.176	0.011
$Ln(popdens)^2$	0.009	0.001	0.007
Controls for countries	YES	YES	YES
Observations	276	75	201
R^2 overall	0.608	0.781	0.557
R^2 adjusted	0.562	0.710	0.529

*** p<.01 indicates significance at 1%.