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Quantitative methods applied to agricultural, environmental, and transport economics in Colombia

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Peer-Reviewed Journals

1- Studies in Agricultural Economics (Institute of Agricultural Economics Nonprofit Kft. (AKI)), **Published**
Country: Hungary
SCimago Journal Rank Indicator (**Q2**), Agricultural and Biological Sciences (Category), **Impact Factor 2.000.**

2022 Perdomo Calvo, Jorge Andrés; Arteche, Josu and Ansuategi, Alberto "**Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies**". Studies in Agricultural Economics, 144 (3), 104-1112. DOI: 10.7896/j.2370

https://studies.hu/returns-to-scale-and-technical-efficiency-in-colombian-coffee-production-implications-for-colombias-agricultural-and-land-policies/

2-Travel Behaviour and Society (Elsevier Editorial System, EES), **Published**
Country: Netherlands, Western Europe
SCimago Journal Rank Indicator (**Q1**), Social Sciences; Transportation (Subject Area and Category), **Impact Factor 5.85.**

2017 Perdomo Calvo, Jorge Andrés "**The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia**". Travel Behaviour and Society Journal, 6, 90-99. DOI: 10.1016/j.tbs.2016.08.002.

https://www.sciencedirect.com/science/article/abs/pii/S2214367X15300132

3-Energy Economics (Elsevier Editorial System, EES), **Published**
Country: Netherlands, Western Europe
SCimago Journal Rank Indicator (**Q1**), Economics, Econometrics and Finance; Energy (Category), **Impact Factor 9.252.**

2016 Perdomo Calvo, Jorge Andrés and Jaramillo Ana "**Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal**

Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study". Energy Economics, 59, 159-166. DOI: 10.1016/j.eneco.2016.07.016.

https://www.sciencedirect.com/science/article/pii/S0140988316301888

4-Applied Economics Letters (Taylor & Francis Online), **Published**
Country: United Kingdom, Western Europe
SCimago Journal Rank Indicator (**Q3**), Economics, Econometrics and Finance (Category), **Impact Factor 2.000.**

2011 Perdomo Calvo, Jorge Andrés "**A methodological proposal to estimate changes of residential property value: case study developed in Bogotá**". Applied Economics Letters, 18 (16), 1577-1581. DOI: 10.1080/13504851.2011.554360.

https://www.tandfonline.com/doi/abs/10.1080/13504851.2011.554360

5-Journal of Cost Analysis and Parametrics (Taylor & Francis Online), **Published**
Country: United Kingdom, Western Europe

2015 Perdomo Calvo, Jorge Andrés "**An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation**". Journal of Cost Analysis and Parametrics, 8 (1), 23-33. DOI: 10.1080/1941658X.2015.1016586.

https://www.tandfonline.com/doi/citedby/10.1080/1941658X.2015.1016586?scroll=top&needAccess=true&role=tab

Quantitative methods applied to agricultural, environmental, and transport economics in Colombia

by

Jorge Andrés Perdomo Calvo

Thesis by Compendium of Publications

Dissertation submitted to the Faculty of Economics and Business of the University of the Basque Country, Bilbao (Spain), about the mandatory requirements of the thesis by compendium of publications (Chapter XI, Articles 41, 42, 43, and 44) in partial fulfillment of the requirements for the degree of Doctor of Philosophy
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Advisors:

Professor Josu Arteche
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Dedication

To my wife Carol Torres Ospina and my daughter Silvana Perdomo Torres, professor and friend Darrell Lee Hueth, to my friends Juan Pablo Barrera de la Peña, Yaimi Gustavo Ruge Padilla, Jesus Antonio Castro Gonzalez, Jorge Ricardo Suarez Suarez, Jose Francisco Barrera de la Peña, Julian Barrera de la Peña, Harold Cornado, Juan Carlos Trujillo and Juan Carlos Mendieta Lopez, and to my mothers, Ana Celinda Padilla, Martha Amador, Lucia de la Peña and Myriam Suarez.

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Resumen

Colombia es un país que ha logrado crecer económicamente, cuyos ingresos han evolucionado de bajos a medios altos en los últimos 20 años, favoreciendo la reducción de sus niveles de pobreza para sus habitantes, pero persistiendo los retos sociales (equidad, seguridad, corrupción, microtráfico, solución del conflicto armado y problemas de orden público), ambientales (sostenibilidad, minería ilegal, contaminación ambiental, desforestación y tráfico ilegal de flora y fauna), urbanos (transporte y movilidad), agrícolas (tecnificación e industrialización, infraestructura vial, crecimiento, erradicación de cultivos ilícitos), entre otros, propios del crecimiento de su población y por su senda de progreso (Banco Mundial, 2022).

En este sentido, diferentes entidades estatales con el apoyo de la banca multilateral han realizado inversiones importantes en infraestructura vial y medios de transporte para las principales ciudades (Bogotá, Medellín, Cali y Barranquilla), con el fin de mejorar las condiciones de los ciudadanos en materia de movilidad y conexión espacial entre las zonas origen y destino más concurridas (Perdomo, 2017).

También la inversión extranjera en el país se ha incrementado, impulsando la llegada de empresas multinacionales dedicadas a la extracción de recursos naturales no renovables como petróleo, carbón y metales preciosos. Todo esto ha implicado esfuerzos importantes en el diseño de políticas para el sector ambiental y social de Colombia, con el fin de obtener un desarrollo sostenible (BTI, 2022).

Como vocación primordial y propia del territorio, el sector agrícola en Colombia no ha sido ajeno al progreso económico del país. Este sector está conformado fundamentalmente por pequeños agricultores o minifundistas (OECD, 2015). La caficultura se mantuvo como el principal representante de la actividad, relegada a un segundo plano por el cultivo de flores ante la disminución de los precios internacionales del café y reducción del tamaño de la tierra para producirlo. No obstante, otros factores como la presencia de grupos armados ilegales (guerrilla, paramilitares y bandas criminales) han desfavorecido al sector por las distintas formas de violencia e irregularidad ejercida por estos (desplazamientos forzosos de población, secuestros de dueños de las fincas agrícolas,reclutamiento infantil, pagos de cuotas para poder trabajar la tierra, cultivos ilícitos -hoja de coca y amapola-) (BTI, 2022; OECD, 2015).

Ante estas premisas y en busca de aportar soluciones con resultados empíricos, a partir de información secundaria y primaria objetiva, que permitan evidenciar diferentes efectos con incidencia en la toma de decisiones para los sectores agrícola, ambiental y de transporte en Colombia. En este sentido, el propósito del presente trabajo consiste en aplicar técnicas cuantitativas para demostrar resultados encaminados a contribuir al diseño de políticas que ayuden a avanzar en materia agrícola, ambiental y urbana para aportar a la senda de crecimiento económico en Colombia.

Como resultado de este alcance fue posible concebir la publicación de cinco artículos técnicos en revistas indexadas (arbitradas), entre 2011 y 2022, dada la contribución del trabajo al estado del arte sobre aplicación de técnicas cuantitativas avanzadas. Transcendiendo los métodos convencionales, cuyos resultados implican una posible

mejora en la toma de decisiones en materia ambiental, urbana y agrícola en Colombia y ámbito internacional. El primer artículo destaca la implementación y estimación del enfoque de fronteras estocásticas de producción en dos etapas para corregir problemas de endogeneidad con el fin de determinar rendimientos a escala y eficiencia técnica para la actividad cafetera en Colombia. Sus resultados muestran las directrices que deben considerarse en este sector para mejorar la producción (Perdomo *et al.*, 2022).

En el segundo y tercer artículo, se efectúan la estimación de la interacción de técnicas combinadas con sistemas de información geográfica, econometría espacial, datos agrupados, funciones no lineales (transformaciones Box-Cox) y cambio estructural a través del tiempo para demostrar la implicación de externalidades positivas derivadas de las inversiones realizadas en infraestructura de transporte público masivo en las ciudades de Bogotá y Barranquilla (Perdomo, 2017 y 2011).

Otro avance relevante exhibido en el cuarto artículo publicado se refiere a la simulación del comportamiento de la extracción de carbón a cielo abierto una vez los costos de las externalidades negativas (ambientales, económicas y sociales) ocasionadas por la actividad, son internalizadas en las funciones de costos de las empresas multinacionales dedicadas a esta explotación. Esta evidencia se obtiene a partir de ecuaciones de Bellman (programación dinámica) con el fin de establecer una dinámica sostenible sin afectar el modelo de negocio (Perdomo y Jaramillo, 2016).

La última novedad destacada entre las publicaciones se encuentra en el quinto artículo, y consiste en establecer el precio techo para regular la tarifa del servicio formal de parqueaderos públicos en Bogotá a través de técnicas econométricas avanzadas (método de los momentos generalizado en datos panel dinámicos) y precios Ramsey, cuyo valor deberían pagar los usuarios de este servicio sin perjudicar la rentabilidad de la actividad con el fin de mejorar la movilidad en laciudad (Perdomo, 2015).

Todo lo anterior confluye en la presente disertación doctoral por compendio de publicaciones denominada "*Métodos cuantitativos aplicados a economía agrícola, ambiental y de transporte en Colombia"* para mejorar la toma de decisiones que permitan continuar el avance económico del país de la mano de progresos sociales, ambientales y urbanos que permitan mejorar el nivel de bienestar de su población.

Así, el primer estudio denominado "*Rendimientos a escala y eficiencia técnica en la producción de café en Colombia: implicaciones de política en tierra y agricultura colombiana*" (Perdomo *et al.*, 2022), determinó la función de producción cafetera, las economías a escala y la eficiencia técnica por tipo de productor (pequeño, mediano y grande). En síntesis, plantea que los pequeños y medianos caficultores del estudio presentan rendimientos crecientes a escala y son ineficientes técnicamente, mientras los grandes exhiben rendimientos a escala decrecientes y son cuasi eficientes técnicamente (ET).

Perdomo *et al.* (2022) evidenciaron que los pequeños caficultores exhiben rendimientos crecientes a escala. En particular, un aumento del 1% en el conjunto de sus insumos (tierra, trabajo, agroquímicos y maquinaria) conlleva a un incremento de su producción de café en 2,95% (valor estadísticamente significativo). El insumo más destacado para estos es la cantidad de tierra empleada en la actividad, acorde con su representatividad estadística y valor de la elasticidad insumo producto del 1,59%, proseguido por los agroquímicos (0,89%) y el trabajo (0,67%). Por otra parte, su eficiencia técnica es de 0,75 lo que indica ineficiencia en la producción cafetera de este grupo de caficultores.

En el caso de los medianos cafeteros, los resultados son semejantes a los pequeños, presentan rendimientos crecientes a escala debido a que un aumento del 1% en el conjunto de sus insumos (tierra, trabajo, agroquímicos y maquinaria) conlleva a un incremento de la producción de café en 2,2% (valor estadísticamente significativo). El insumo más destacado para esto es la cantidad de tierra empleada en la actividad, acorde con su representatividad estadística y valor de la elasticidad insumo producto del 1,78%, proseguido por la maquinaria (0,59%) y los agroquímicos (-0,28%). Por otra parte, su eficiencia técnica es de 0,75 lo que indica ineficiencia en la producción cafetera de este grupo de caficultores.

Finalmente, los grandes cafeteros, contrario a los pequeños y medianos, tienen rendimientos decrecientes a escala debido a que un aumento del 1% en el conjunto de sus insumos (tierra, trabajo, agroquímicos y maquinaria) conlleva a un incremento de la producción de café en 0,90% (valor estadísticamente significativo). El insumo más destacado para esto es la cantidad de tierra empleado en la actividad, acorde con su representatividad estadística y valor de la elasticidad insumo producto del 0,62%. Por otra parte, su eficiencia técnica es de 0,99 lo que indica cuasi eficiencia en la producción cafetera de este grupo de caficultores.

Lo anterior evidencia la necesidad de diseñar políticas públicas focalizadas al fortalecimiento de los pequeños y mediano caficultores, que les permita aprovechar la senda de rendimientos a escala crecientes. Las mismas deben ser direccionadas al crecimiento de la cantidad de hectáreas dedicadas al cultivo que les permita trascender sus tamaños de unidades productivas a grandes, sacando el máximo provecho a los rendimientos a escala en esta transición de pequeños y medianos a grandes cafeteros.

Ahora bien, la ineficiencia técnica indica que estas unidades productivas no están asignando y empleando de manera adecuada la cantidad de los principales insumos área productiva en café, mano de obra, agroquímicos y maquinaria requerida en la producción y que fácilmente los caficultores pueden controlar, conduciendo a una baja productividad y competitividad del sector e implicando mayores costos de producción.

Este trabajo evidencia la necesidad de direccionar políticas públicas que ayuden al alivio de la ineficiencia técnica y al incremento de la cuasi eficiencia de los grandes cafeteros, con el fin de aumentar la productividad y competitividad en la producción de café en la región cafetera de Colombia. De esta forma, las instituciones encargadas de prestar asesoría de eficiencia técnica a los productores de café en Colombia deben fortalecerse y apoyar principalmente a los pequeños y medianos productores, para facilitar su acceso a más tierra y tecnología de punta (maquinaria de los beneficiaderos de café y automatización de la recolección de la cosecha).

Es importante mencionar que estos grupos son la mayor parte de caficultores del país y son los sectores más vulnerables a cambios estructurales del mercado internacional por su ineficiencia técnica. Igualmente, los trabajadores del sector cafetero como del agrícola en general no gozan de garantías laborales, dada la cultural de la informalidad en su contratación. Por consiguiente, es relevante implementar mecanismos de política que permitan reducir la informalidad laboral presentada en la actividad agrícola del país.

La segunda y tercera publicación, tituladas "*El efecto de la infraestructura del Bus de Tránsito Rápido sobre el valor de las propiedades en Colombia*" (Perdomo, 2017) y "*Una propuesta metodológica para estimar los cambios de los valores de las propiedades: estudio de caso desarrollado para Bogotá*" (Perdomo, 2011) presentan evidencias cuantitativas de los efectos positivos ocasionados por el diseño, construcción e implementación de la infraestructura de transporte masivo de pasajeros en ciudades principales de Colombia (Bogotá y Barranquilla), debido a la ubicación privilegiada de los inmuebles aledaños a la infraestructura, que les permite contar con fácil y rápido acceso a los sistemas de transporte, favoreciendo la reducción de tiempos de caminata y viaje.

Los estudios se diferencian por las metodologías cuantitativas implementadas para presentar la evidencia empírica de la valorización para los predios observados. Los dos enfoques utilizados confirman el impacto positivo y cumplimiento de los propósitos planteados, aunque en Perdomo (2017) la técnica es mejorada dada la mayor disponibilidad de información discriminada por ciudades (Bogotá y Barranquilla) a través de tres periodos anuales de tiempo (2006, 2008 y 2011).

Ambos enfoques cuantitativos demostraron un impacto estadísticamente significativo, de la infraestructura de transporte sobre el precio de los inmuebles, determinado por la distancia entre los inmuebles residenciales y el acceso al sistema de transporte masivo del bus de tránsito rápido (BTR). A mayor lejanía entre la vivienda y el punto de acceso a la infraestructura del BTR, menor es el precio por metro cuadrado (P/M2) de la propiedad, una vez controlado la dinámica espacial contenida en el término del error (autocorrelación residual espacial), ocasionada por la naturaleza propia de las variables distancias Euclidiana al acceso al sistema BTR, supermercados, colegios, universidades, estaciones de policía, entre otras distancias medidas y empleadas en los modelos.

Estos estudios permiten a las entidades del Estado en Colombia encargadas de ejecutar impuestos por valorización, evidenciar algunos de los beneficios privados derivados de las inversiones públicas en infraestructura. Igualmente, proporcionan información adicional para estimar objetivamente la cuantía de su recaudación y así ser retribuidos nuevamente al Gobierno por los dueños de los inmuebles beneficiados.

De esta manera, el Estado colombiano puede nuevamente reinvertir estos recursos para generar nuevos proyectos de infraestructura y compensar a los agentes perjudicados. Con esto, las actuales tributaciones de valorización, recaudadas e impuestas desde el punto de vista legal pueden avalarse y compararse desde el ámbito económico. Asimismo, este trabajo contribuye a entender y conocer los verdaderos valores que debería pagar cada propietario reconociendo elbeneficio que le generó el Estado.

La cuarta publicación denominada "*Estimación de la senda óptima de extracción para un recurso natural no renovable: caso de estudio para la actividad carbonífera a cielo abierto en el centro del departamento del Cesar, Colombia*" (Perdomo y Jaramillo, 2016), presentó evidencias cuantitativas del efecto de internalizar los costos de las externalidadesnegativas sobre el comportamiento de las empresas mineras dedicadas a la explotación de carbón a cielo abierto en el centro del departamento del Cesar en Colombia.

A partir del examen inicial del estado del arte se determinó que la mayor parte de la literatura hasta ese momento se enfocaba en los impactos generados por la demanda de carbón y no por su producción. Razón por la cual, esta investigación implementó simulaciones de largo plazo, a partir de modelos de decisión de Markov y técnicas de programación dinámica (ecuaciones de Bellman), para realizar la simulación de la producción de carbón a cielo abierto objeto del estudio. Este enfoque, contribuyó al acervo documental técnico revisado, generando valor agregado al conocimiento en el tema de producción energética y economía de los recursos naturales.

Así, la simulación obtenida en la programación dinámica, sin considerar los costos de las externalidades, muestra que la amplia cantidad de reservas de carbón conlleva a bajos costos de extracción. Si, además, hay precios favorables en el mercado, la mejor decisión que pueden tomar las firmas es extraer todas las reservas disponibles del recurso en el menor tiempo posible, antes de culminar el tiempo otorgado por el Estado para la explotación del recurso.

Este comportamiento es normal en cualquier agente privado, cuyo objetivo es maximizar sus ganancias. No obstante, esta conducta puede conducir a una reducción en la oferta de bienes y servicios ambientales, otras actividades económicas (agrícola y ganadera), estatus de salud humana y presiones sociales, porque la explotación de carbón a cielo abierto incide y genera directa e indirectamente las externalidades señaladas. Este escenario cambia una vez son asumidos los valores de las externalidades negativas en la función de costos totales de las empresas.

La quinta y última publicación denominada "*Una aproximación económica para fijar la tarifa del servicio de parqueo en Bogotá usando la regulación de precios techo*" (Perdomo, 2015), muestra la estimación económica de la tarifa máxima por minuto que deben cobrar los establecimientos que prestan el servicio de parqueadero a sus usuarios en la ciudad de Bogotá, una vez se consideran los costos totales para poder suministrarlo, con el fin de recaudar los ingresos suficientes que permitan cubrir los gastos y obtener beneficios económicos por ejercer esta actividad sin ocasionar pérdidas para las empresas dedicas a este negocio.

Para cumplir el objetivo del estudio se implementó un modelo de datos panel dinámico, estimado mediante método de los momentos generalizado (para determinar el modelo y forma funcional del comportamiento del costo total de prestación del servicio), también optimización matemática (estática comparativa) y precios Ramsey. Esto combinado con el análisis del criterio de fijación de precios, a partir de los planteamientos teóricos de la economía del transporte y axiomas de la microeconomía sobre análisis de costos (fijos, totales, variables, marginales y medios) se convirtieron en las contribuciones a la literatura existente sobre la regulación de precios en economía del transporte.

Ante lo expuesto y según el artículo 43 de la normativa de tesis doctorales por compendio de publicaciones de la Universidad del País Vasco, el documento se encuentra organizado de la siguiente forma: marco teórico, herramientas metodológicas utilizadas, hipótesis, objetivos generales y específicos, resumen, discusión de los resultados obtenidos de las temáticas en las publicaciones en las siguientes cuatro subsecciones, junto con las fuentes referenciadas. Mientras las conclusiones están contenidas en la segunda sección. Los anexos con los artículos publicados se encuentran en la tercera y última sección.

Structure of the Thesis by Compendium of Publications

1- Initial Overview

1.1- Introduction

Colombia is a country whose income has evolved from low to medium-high in the past two decades, favouring the reduction of poverty levels for its inhabitants, but with persistent social, environmental, urban, agricultural and other challenges due to its population growth and development path (World Bank, 2022). In this sense, different state entities with the support of multilateral banks have made significant investments in road infrastructure and means of transport for the main cities (Bogotá, Medellín, Cali and Barranquilla), in order to improve the conditions of citizens in terms of mobility and spatial connection between the busiest origin and destination areas (Perdomo, 2017). Also, foreign investment in the country has increased, driving the arrival of multinational companies dedicated to the extraction of non-renewable natural resources such as oil, coal and precious metals. All of this requires important efforts in the design of policies for the environmental and social sector in Colombia, in order to obtain sustainable development (BTI, 2022).

As a primary vocation of the territory, the agricultural sector in Colombia, mainly made up of small farmers or smallholders (OECD, 2015), has not been oblivious to its economic progress. Coffee growing is the main representative of agricultural activity, relegated to the background due to the decrease in international coffee prices and the reduction in the size of the land needed to produce it. However, other factors such as the presence of illegal armed groups (guerrillas, paramilitaries and criminal gangs) have disadvantaged the sector due to the different forms of violence and irregularity exercised by these groups (forced displacement of the population, kidnapping of farm owners, child recruitment, payment of fees to work the land) (BTI, 2022).

Given the above premises and in search of providing solutions with empirical results based on objective secondary and primary information, the purpose of this doctoral thesis is to apply quantitative techniques to demonstrate results aimed at showing different effects with an impact on decision-making for the agricultural, environmental and transport sectors in Colombia and to contribute to the design of policies that help to advance the path of sustainable economic growth in Colombia.

The development of this objective has entailed the publication of five technical articles in indexed (refereed) journals between 2011 and 2022, the results of which imply a possible improvement in decision-making in environmental, urban and agricultural matters in Colombia and internationally.

The methodological tools used include the implementation and estimation of the two-stage Stochastic Production Frontier (SPF) approach to correct endogeneity problems in order to determine returns to scale and technical efficiency for coffee production in Colombia, the results of which demonstrate the guidelines that should be considered in this sector to improve production (Perdomo et al., 2022). To these are added the estimation of the interaction of techniques combined with geographic information systems, spatial econometrics, clustered data, non-linear functions (Box-Cox transformations) and structural change over time to demonstrate the implication of positive externalities derived from investments made in mass public transport infrastructure in the cities of Bogotá and Barranquilla (Perdomo, 2017 and 2011).

Other relevant advances exhibited in one of these published articles refer to the simulation of the behaviour of open-pit coal mining once the costs of the negative externalities (environmental, economic and social) caused by the activity are internalised in the cost functions of the multinational companies dedicated to this exploitation. Based on Bellman equations (dynamic programming), a sustainable dynamic is established without affecting the business model (Perdomo and Jaramillo, 2016).

The last novelty highlighted among the publications is to establish ceiling prices to regulate the tariff of the formal public parking service in Bogotá through advanced econometric techniques (generalised method of moments in dynamic panel data) and Ramsey prices, whose value should be paid by the users of this service without harming the profitability of the activity in order to improve mobility in the city (Perdomo, 2015).

All of the above converge in the present doctoral dissertation by compendium of publications entitled "Quantitative methods applied to agricultural, environmental and transport economics in Colombia", whose contribution serves to improve decision-making that will allow the country's economic progress to continue hand in hand with social, environmental and urban progress that will improve the level of well-being of its population.

In this sense, according to article 43 of the regulations for doctoral theses by compendium of publications of the University of the Basque Country (UPV/EHU), this first chapter is organised as follows: after this brief introduction, section 2 provides the theoretical framework of the thesis topic and methodological tools used. The hypotheses and general and specific aims of each of the publications are contained in section 3 and the main results obtained in the thesis are discussed in section 4. Finally, referenced sources are included in section 5. The second chapter contains the conclusions. The third chapter is an Appendix containing the published works.

1.2- Theoretical framework and methodological tools

Having justified the thematic unit of the thesis in the preceding section, this section contains the theoretical framework and methodologies used in the five published articles that make up the thesis titled "Quantitative methods applied to agricultural, environmental and transport economics in Colombia". As its name indicates, the theoretical bases and methodologies used are of a mathematical, statistical and econometric nature, based on theoretical and conceptual frameworks of agricultural, environmental, natural resources and transport economics, whose main pillar are the microeconomic postulates on returns to scale and efficiency in production, externalities, production costs and profit maximisation.

Thus, the theoretical framework of the thesis has these four pillars of microeconomic principles, where the first article of the thesis, "Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies" (Perdomo et al., 2022), is based on the microeconomic axioms on returns to scale and production efficiency.

The theory seeks to show whether coffee production in Colombia shows increasing, constant or decreasing returns to scale by type of producer (small, medium or large). Likewise, by group of coffee growers, measures are offered of their level of technical efficiency (or inefficiency) in carrying out their activity, in order to highlight guidelines that help them to improve their activity and condition to minimise their costs and allow them to confront the different volatilities faced by the price of this product in the international market.

Under the microeconomic premises described above, the research implemented the quantitative methodology of SPF to estimate coffee production functions under conventional (Cobb-Douglas) and flexible (Translogarithmic) functional forms, controlling the effects of input prices (land, labour, agrochemicals, machinery and equipment) on the quantity demanded. In other words, the SPF is estimated using a two-stage methodology that allows correcting the biases of the estimators obtained in a traditional SPF caused by the possible endogeneity of the factors.

With the results obtained it is possible to calculate the input-output elasticities and by extension to show the returns to scale exhibited by type of coffee grower in Colombia (small, medium and large). On the other hand, the results of the two-stage SPF allow us to derive the degree of technical efficiency or inefficiency of each productivity unit, from which improvements in the management of their inputs can be determined to increase their efficiency and, by default, their production. Once all the results of the quantitative implementation (statistics, econometrics and mathematics) are obtained, possible public policies affecting this key sector of the Colombian economy are considered.

On the other hand, the second and fourth articles of the thesis, "The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia" (Perdomo, 2017) and “A methodological proposal to estimate changes of residential property value: case study developed in Bogotá” (Perdomo, 2011), are based on the microeconomic axioms on positive externalities caused by public investment in mass transit infrastructure in the main cities of Colombia from loans from multilateral banks (World Bank and Inter-American Development Bank). The theory seeks to show whether the effects of the investments have transcended their main objective, which is to improve mobility and reduce walking distance, waiting and travel times for users. In other words, what private benefits were generated with the public investment made, which is not being traded in the market.

Thus, using quantitative techniques of spatial econometrics through the combination of geographic information systems, non-linear functions (Box-Cox type), structural change analysis, clustered data over time and matching methods in impact assessment, measures of elasticity and marginal effects were obtained to assess the effects of the investments on the price of real estate (residential and commercial) near the built transport infrastructure. It is concluded that such infrastructure represents a positive externality derived from public finances in Colombia. This helps to put forward proposals for value capture mechanisms or capital gains that should be paid back to the State by the owners of the benefited properties in order to generate more resources to implement more projects with social benefits or to alleviate the burden of international debts to free resources that allow the public sector to continue managing and generating more programmes of social interest.

The third article of the thesis, "Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study" (Perdomo and Jaramillo, 2016), is based on microeconomic axioms on negative externalities caused by private investment in the exploitation of non-renewable natural resources, production costs and internalisation of externalities and profit maximisation. It also discusses postulates of environmental and natural resource economics on sustainability over time.

The quantitative methodology applied in this case is based on Bellman equations (dynamic programming), estimating cost functions using panel data with and without the internalisation of the economic valuation of the externalities produced by private investment in order to demonstrate through quantitative (mathematical and econometric) methodologies whether the negative (environmental, social and economic) impacts caused by open-pit coal mining can be mitigated if their costs are internalised in the cost functions of multinational companies engaged in the activity. In this way, optimal extraction paths are determined without affecting the business model, seeking to ensure environmental and non-renewable resource sustainability over time in Colombia.

Finally, the fifth article of the thesis, "An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation" (Perdomo, 2015), is based on the microeconomic axioms on cost functions, ceiling prices (Ramsey type), profit maximisation and analysis of the behaviour of marginal and variable costs of companies that provide parking services for private vehicles in Bogotá. To obtain the results of the study, advanced econometric techniques (generalised method of moments in dynamic panel data) and Ramsey prices are used, by means of which it is possible to establish the proposal of regulated tariffs for the service without affecting the profitability of the activity and improving mobility in Bogotá.

1.3- Hypotheses and objectives

Continuing with the structure of the thesis by compendium of publications titled "Quantitative methods applied to agricultural, environmental and transport economics in Colombia", this section describes the hypotheses and objectives achieved in the five articles produced, considering what is stated in each one of them, according to the premises used for their approaches.

1.3.1 Hypothesis and general and specific objectives achieved in the publication entitled "*Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies*"

Several studies on coffee production have been carried out in Colombia. However, they start from the premise that this activity and the agricultural sector in general exhibit constant returns to scale per unit of productivity, ignoring the fact that these may vary according to the size of the coffee producer or farmer and the size of the land dedicated to coffee growing or agriculture.

The hypothesis of this research is to demonstrate that coffee farmers in the Colombian coffee-growing region exhibit different returns to scale (increasing, decreasing or constant) according to their productive size. To test this, the following purposes are considered:

Main objective: to estimate the returns to scale and measures of technical efficiency of coffee farmers, according to their production size.

The following **specific objectives** are determined for its scope:

1. To collect from different sources, information on inputs with their prices and coffee production.
2. To carry out an exhaustive literature review on returns to scale in agricultural economics, technical efficiency and conventional stochastic production frontiers and with endogeneity treatment.
3. To estimate econometrically the two-stage SPF approach.
4. To determine the best fit of the estimated models and functional forms of production.

5. To calculate the input-output elasticities and establish the economics of scale exhibited by type of farmer (small, medium and large).
6. To estimate the measures of technical efficiency by type of producer.
7. To interpret the results obtained on returns to scale and technical efficiency to put forward policies to help improve coffee and agricultural production in Colombia.

1.3.2 Hypothesis and general and specific objectives achieved in the publications entitled "*The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia*" and "*A methodological proposal to estimate changes of residential property value: case study developed in Bogotá*"

Internationally, several studies have been carried out on the positive effects of the construction of mass transit infrastructure (Bus Rapid Transit (BRT) and metro) on the reduction of travel times for users, environmental pollution and insecurity, as well as improvements in urban landscaping and in the prices (increases) of real estate (residential and commercial) near the accesses to the infrastructure of the means of transport created.

In this sense, the hypothesis of this research is to demonstrate that the value of properties (residential and commercial) near the mass transit system in Bogotá and Barranquilla has suffered a significant increase due to public investment in these works, once the main characteristics of the properties and their surroundings have been controlled for. In order to verify this, the following purposes are considered:

Main objective: to estimate the valuation of commercial and residential properties near the accesses of the BTR transport systems (Transmilenio and Transmetro) in Bogotá and Barranquilla.

The following **specific objectives** are determined for its scope:

1. To collect from different sources, information on property prices, characteristics and environment of the properties under study.
2. To carry out georeferencing of the properties under study.
3. To carry out an exhaustive literature review on the impacts of the construction of urban passenger transport and its methodological scope in order to demonstrate them.
4. To determine Euclidean and non-linear distances between two geographical points.
5. To estimate the spatial approaches determined, using non-linear Box-Cox functions, clustered data over time, structural change analysis and propensity score matching.
6. To statistically determine the impact of the studies.
7. To calculate the price-distance elasticity and establish the percentage of the valuations of the case by type of property (residential and commercial) in the cities of Bogota and Barranquilla.

8. To calculate the marginal price-distance effect and establish the valuations of the case by type of property (residential and commercial) in the cities of Bogotá and Barranquilla.
9. To interpret the results obtained on the valuations in order to propose value capture instruments.

It is important to clarify that the hypothesis and objectives of these two publications are the same, but they are distinguished by the quantitative approach adopted to validate their fulfilment and scope of the purposes of both articles.

1.3.3 Hypothesis and general and specific objectives achieved in the publication entitled "*Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study*"

Although several studies in Colombia and other international contexts have shown the environmental, social and economic impacts caused by the exploitation of non-renewable natural resources (oil, gas, precious metals, coal, iron and nickel), whose investments come from multinational companies, these studies have not focused on compensation (in addition to the royalties generated) to mitigate these consequences of the activity.

The hypothesis of this research is to demonstrate that open-pit coal mining can become sustainable if the costs of the negative externalities generated are internalised in the cost functions of the companies that carry out the activity in the coal mining area in the centre of the department of Cesar. In order to test this, the following objectives are considered:

Main objective: to simulate a long-term coal extraction path that maximises the profits of the companies dedicated to open-pit coal mining, with and without the internalisation of the value of the negative externalities generated by a sustainable activity over time.

The following **specific objectives** are determined for its scope:

1. To collect from different sources information on prices, discount rate, costs and production of opencast coal and economic valuation of negative externalities.
2. To carry out an exhaustive literature review on the exploitation of non-renewable natural resources, environmental degradation and methodologies to demonstrate it.
3. To estimate the relevant cost functions using panel data.
4. To determine the simulation of sustainable extraction using dynamic programming (Bellman equations).
5. To interpret the results obtained on the optimal extraction paths over time to design guidelines to help find a sustainable solution without affecting the business model in Colombia.

1.3.4 Hypothesis and general and specific objectives achieved in the publication entitled "*An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation*"

On different occasions, regulatory measures have been taken in Colombia that affect the tariffs of goods or services without first carrying out economic studies to support the legal decisions taken. These measures have been affecting or favouring some of the key actors in the different regularised markets, leaving the viability of the implementation to the value judgement of the legal authorities without considering the consequences of these decisions.

The hypothesis of this research is to demonstrate that the maximum fee imposed by legal decree for the payment of car parking services in Bogotá does not cover the total costs of the companies that provide the service to users and therefore are affecting the dynamics and proliferating the informality of the business, avoiding the reduction of congestion and the improvement of mobility in the city. To test this, the following purposes are considered:

Main objective: to estimate the ceiling prices for charging per minute for car parking in formal establishments that provide the service in Bogotá, based on the analysis of the fixed, variable and marginal costs incurred by the firms that offer it.

The following **specific objectives** are determined for its scope:

1. To collect from different sources information on production costs and amount of parking time sold in different establishments in Bogotá.
2. To carry out an exhaustive review of the literature on regulated tariffs and the economic techniques used to determine them.
3. To establish the appropriate functional form of the estimated cost function.
4. To estimate a cost model with dynamic panel data using the generalised method of moments.
5. To establish the marginal cost and average variable cost curves.
6. To determine the minimum number of minutes to be sold by the service providers that will allow them to cover their fixed and variable costs and obtain positive profits from the activity.
7. To calculate with Ramsey prices the maximum tariffs to be paid by the users of the service according to the minimum amount of minutes to be sold by the service providers.
8. To interpret the results obtained in order to impose pertinent legal regulatory measures that do not affect the financial equilibrium of the business and thus control any market power that may be formed by the service providers to charge excessive tariffs.

1.4- Discussion of the main results

Once the synthesis section has been completed, this subsection includes the summary and discussion of the results obtained in each publication included in the thesis, considering the theoretical frameworks and methodologies implemented, as well as the verifications of the hypotheses and achievements of the objectives described in the preceding sections.

1.4.1 Summary and discussion of the results obtained in the publication entitled "*Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies*"

This study determines the coffee production function, from which economies of scale and technical efficiency are analysed by type of producer (small, medium and large). In summary, it suggests that the small and medium coffee farmers in the study exhibit increasing returns to scale and are technically inefficient, while the large ones exhibit decreasing returns to scale and are quasi-technically efficient (TE).

However, in Colombia there is a lack of microeconomic statistical information on the activity at different points in time, which limits the elaboration of a reliable microeconomic diagnosis and analysis of the sector and Colombian coffee farmers. However, the results of this study shed some light on the debate about the assumption that the agricultural sector in Colombia exhibits constant returns to scale, regardless of the size of the farmer (small, medium or large). This widely accepted assertion has been supported with little detailed information at the microeconomic level and without quantitative techniques of analysis such as those provided in this article.

The quantitative methodology implemented in this article evidences the biases in the results when the endogeneity problem in the agricultural production functions originated by the relationship between the prices-quantities of the inputs used (land, labour, machinery and agrochemicals) to obtain the cultivated products and the external factors not controllable by the farmers (climate, pest control in neighbouring farms, institutional measures by the government, the National Federation of Coffee Growers in Colombia and international coffee organisations, uncertainty of international coffee production and volatility of external prices of coffee beans and inputs), which also influence the demand for raw materials in the activity, is not accounted for.

Omitting the endogeneity treatment leads to underestimated returns to scale for small and medium coffee farmers and overestimated returns to scale for large farmers. However, the effects with and without endogeneity maintain the evidence of increasing yields for the first two and decreasing yields for the latter, while the consequence on measures of inefficiency and technical efficiency is weak, i.e. there are no important variations in TE associated with the endogeneity treatment.

Previously, an exhaustive literature review iss carried out to determine the state of the art on the problem, consequences and treatment of endogeneity in the SPF, allowing to determine the process to be carried out in the study in order to establish consistent results and by extension an improvement in decision making from the adjustment of the effect caused by the endogeneity of the SPF.

The paper contributed to the related literature so far on SPF and TE in agricultural production, focusing on the choice of the best-fitting functional form (Translog minflex Laurent and Cobb-Douglas), in order to correct for biases in the results caused by an incorrect functional form, in addition to those caused by the endogeneity of the SPF.

The results of this paper were made possible thanks to primary data collected in 2004 by the universities of Maryland (United States) and Los Andes (Colombia), through surveys of small, medium and large Colombian coffee growers in the departments of Quindío, Risaralda and Caldas.

This survey provided information on the amounts used and obtained in 2003 related to agricultural activity (production and inputs - prices and quantities) and social and economic conditions of 850 coffee farmers, where 556 are small (with less than two hectares of land), 200 medium (between 2 and 7 hectares of land) and 94 large (with more than 7 hectares of land). The annual unit of measurement for coffee production was established in arrobas (approximately 12.5 kilograms).

Inputs for the activity are obtained in the following units of measurement: land (number of hectares cultivated), labour (number of coffee workers and pickers, including owners and their families), agrochemicals (kilograms of fertilisers and pesticides) and machinery (number of equipment such as coffee drying sheds, pulpers, dismucillating machines, motor pumps, engines, silos, fumigators, scythes and chainsaws, etc.). The latter is unified by means of a synthetic index using the principal components methodology.

Once the variables of analysis with their units of measurement are determined, a two-stage procedure is used to define the objective function through the SPF approach. In the first stage, the technique of Seemingly Unrelated Regressions (SUR) estimated with generalised least squares iss used in order to generate unbiased, consistent and efficient estimators (see details in Rosales et al., 2013). In a second stage, the residuals from the SUR estimation are used as control variables in an operational version of the SPF, thus correcting for the possible endogeneity of the inputs used (following Kutlu, 2010 and Amsler et al., 2016) under Translog minflex Laurent and Cobb Douglas functions according to the lowest value of the Akaike criterion used.

In this sense, this article follows the work of Perdomo and Hueth (2011) and Giannakas et al. (2003), who showed the sensitivity of the SPF and TE results to the previously established functional form, recommending the use of non-linear, flexible functions such as Translog and conventional Cobb-Douglas type, choosing the best fit according to the lowest value obtained from the Akaike criterion.

Also, Perdomo and Hueth (2011) warned about the caution of directly interpreting the result of the coefficients in Translog functions, as well as their partial statistical significance. Instead, elasticities and returns to scale should be evaluated in average values of the inputs. The partial and overall statistical representativeness of the results was assessed using Bootstrap standard deviations proposed by Kutlu (2010) in the two-stage SPF.

The results in Perdomo et al. (2022) obtained using the techniques described above show that small coffee farmers exhibit increasing returns to scale. More precisely, it is estimated that a 1% increase in all inputs (land, labour, agrochemicals and machinery) leads to an increase in their coffee production by 2.95% (statistically significant value). The most prominent input for these is the amount of land used in the activity, in line with its statistical representativeness and input-output elasticity value of 1.59%, followed by agrochemicals (0.89%) and labour (0.67%). On the other hand, their technical efficiency is 0.75, which indicates inefficiency in coffee production for this group of farmers.

In the case of medium coffee farmers, the results are similar to those of small farmers, both exhibiting increasing returns to scale. In the case of medium-sized farmers, a 1% increase in their total inputs (land, labour, agrochemicals and machinery) leads to an estimated increase in coffee production of 2.2% (statistically significant). The most prominent input for these is the amount of land used in the activity, with an input-output elasticity of 1.78%, followed by machinery (0.59%) and agrochemicals (-0.28%). Their technical efficiency is 0.75, which again indicates inefficiency in production.

Finally, large farmers, contrary to small and medium ones, exhibit decreasing returns to scale as a 1% increase in their total inputs (land, labour, agrochemicals and machinery) leads to an estimated increase in coffee production of 0.90% (statistically significant). The most prominent input is the amount of land used in the activity, with an estimated elasticity of 0.62%. In this case, its technical efficiency is 0.99, which indicates quasi-efficiency in coffee production for this group of farmers.

The results described above show the need to design public policies focused on strengthening small and medium coffee growers, which will allow them to take advantage of the path of increasing yields at scale. These policies should be directed towards increasing the number of hectares dedicated to the crop, allowing them to increase the size of production units, making the most of the yields at scale in this transition from small and medium to large coffee growers.

However, technical inefficiency indicates that these production units are not allocating and using adequately the amount of the main inputs such as the productive area in coffee, labour, agrochemicals and machinery required in production and that coffee growers can easily control, leading to low productivity and competitiveness of the sector and implying higher production costs.

All this demonstrates the need to address public policies that help to alleviate this technical inefficiency and increase the quasi-efficiency of large coffee growers, in order to increase productivity and competitiveness in coffee production in the coffee-growing region of Colombia. In this way, the institutions in charge of providing technical efficiency advice to coffee producers in Colombia should be strengthened and support mainly small and medium producers, promoting their access to more land and state-of-the-art technology (machinery for coffee processing and automation of harvesting).

It should also be borne in mind that these groups make up the majority of coffee growers in the country and are the sectors most vulnerable to structural changes in the international market due to their technical inefficiency. Likewise, workers in the coffee sector, as in the agricultural sector in general, do not enjoy labour guarantees, given the cultural informality of their contracts. Therefore, it is important to implement policy mechanisms to reduce labour informality in the country's agricultural activity.

Another noteworthy observation is the current lack of detailed microeconomic information such as that available in this study. For a continuous improvement in decision making in the agricultural sector in Colombia, it is necessary to maintain an information system that allows obtaining and accumulating figures of productive units at different moments in time (every five years), in order to implement methodologies and approaches such as those carried out through panel data techniques to capture price volatilities, intensity of inputs used and coffee production.

This would provide more and better information to mitigate the fragmentation of productive soils in Colombia that threatens yields and economies of scale in the agricultural sector and by extension the efficiency and productivity of all primary activity, a situation probably caused by violence and forced displacement, the expansion of illicit crops or the division of land among the heirs of the owners of large farmers, among others. Better information would also make it possible to carry out studies on the effects of the public policies that are designed or implemented as a result of the results in accordance with the established objectives, and to make the guidelines more dynamic in order to strengthen improvements or solve difficulties that promote the sustainable growth of the sector and the level of economic wellbeing of farmers in Colombia.

1.4.2 Summary and discussion of the results obtained in the publications entitled "*The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia*" and "*A methodological proposal to estimate changes of residential property value: case study developed in Bogotá*"

These articles present quantitative evidence of the positive effects caused by the design, construction and implementation of mass passenger transport infrastructure in two major cities in Colombia (Bogotá and Barranquilla) on the properties surrounding the infrastructure, which allows their owners to have easy and quick access to transport systems, favouring the reduction of walking and travel times.

Once the main characteristics of the properties (number of bathrooms, bedrooms, kitchen, living rooms, garages, floors, storage rooms, swimming pool, age, among others) and their surroundings (supermarkets, schools, universities, parks, among others) as well as the presence of other determinants such as pollution, insecurity or flooding areas have been controlled for, the results of the studies support the hypothesis of a higher added value of the properties (residential and commercial) near the accesses of the infrastructure of the mass transport systems in Bogotá and Barranquilla.

Even though the two studies differ in the quantitative methodologies implemented to analyse the empirical evidence of the valuation of the observed properties, both approaches find evidence of a positive impact and fulfilment of the stated purposes and hypotheses. However, in Perdomo (2017) the technique is improved given the greater availability of information disaggregated by cities (Bogotá and Barranquilla) across three time periods (2006, 2008 and 2011).

Both quantitative approaches demonstrated a statistically significant impact of the distance between residential properties and access to the BRT system. The greater the distance between the house and the point of access to the BRT infrastructure, the lower the price per square metre of the property, once the spatial dynamics contained in the error term (spatial residual autocorrelation), caused by the nature of the Euclidean distance variables to access the BTR system, supermarkets, schools, universities, police stations, among other distances measured and used in the models, are controlled for.

The empirical evidence found in these articles can be used in the design of instruments, policies and regulations on planning and construction of infrastructure projects (transport, communications, pedestrian and vehicular bridges, road networks, bicycle paths, pavements and avenues) in Colombia and elsewhere, providing the public institutions involved with more tools for decision-making.

In this direction, both publications are available for consultation by officials of the entities in charge of executing valorisation taxes, who can analyse and implement this type of quantitative methodologies in order to objectively measure the private benefit (through property prices) generated by the State when making investments in infrastructure.
In terms of the state of the art, according to the exhaustive literature review carried out, these articles include the treatment of spatial residual correlation in Perdomo (2011) in the hedonic models generally used to measure this impact and the comparison of results with the matching approach applied in social impact assessment. In the literature review it was found that there are very few works on urban economics applying the Propensity Score Matching (PSM) approach and until then there were no publications that simultaneously compared PSM techniques (combined with spatial econometrics) and spatial hedonic models.

A further advance was proposed in Perdomo (2017), improving the quantitative techniques proposed in Perdomo (2011), considering the interaction of geographic information systems, non-linear functions (Box-Cox type), structural change analysis and time-clustered data, with a new proposal for a value capture mechanism, according to the literature review considered up to that period. It should be noted that not applying the spatial treatment in the hedonic models implies biased results in the impact assessed.

Both papers also incorporated the non-linear specification of hedonic models and considered more explanatory control variables, avoiding biased estimates due to incorrect functional form and omitted variables. Box-Cox (non-linear) functions were proposed for the specification of the implemented hedonic models.

The data in Perdomo (2011) were obtained in 2008 from a survey of 304 residential homeowners in Bogotá, where they were inquired about the value and characteristics of the property, capturing the geographic coordinates of these to calculate Euclidean distances to the nearest access of the BRT system and to places that generate amenities around the properties under study.

The spatial weights matrix was devised with a distance threshold between properties of 623 metres. This matrix was used to transform the estimated errors and the dependent variable of the study (price per square metre), showing statistical relevance that indicates the need to adjust the hedonic model with the spatial treatment that supports the result of the expected impact.

The variable defined as the distance between the property and the access point to the BRT system was statistically significant with a negative coefficient sign, revealing the impact of the project on the price per square metre of the residential property, since the greater the distance between the property and the access point to the transport system, the lower the price. Specifically, for each metre of distance, the price per square metre decreases by US$0.02. In terms of elasticity, a 1% increase between the distances of the evaluated points leads to a reduction of the price per square metre by 0.05%. Using the matching approach, the added value for the effect under study is approximately US$59 per square metre, and the contrasted pleasant impact conceived from the hedonic model is US$50 per square metre. Both results are similar, demonstrating the impact and hypothesis put forward in Perdomo (2011).
The data in Perdomo (2017) are obtained in 2006, 2008 and 2011, from surveys of 1,125 residential homeowners and 305 commercial property owners in Bogotá and Barranquilla, where they are inquired about the value and characteristics of the property, capturing the geographical coordinates of these to calculate the Euclidean distances to the nearest access of the BRT system and to places that generate amenities around the properties under study (supermarkets, schools, universities, parks, among others).

Descriptive statistics of the available data show that the average the price per square metre for residential properties in Bogotá are US$600 and US$585 (at constant 2011 prices), ranging between a minimum and maximum of US$145 and US$1,019 for the year

2006 and US$42 and US$4,736 for the year 2008. For Barranquilla the price per square metre is US$222 (at constant 2011 prices) with a range between US$53 and US$479.

For commercial properties in Bogotá, average prices in 2006 and 2008 are US$1,363 and US$2,158 (at constant 2011 prices), ranging from a minimum and maximum of US$53 and US$7,037 (2006) and US$52 and US$21,351 (2008). The price per square metre in Barranquilla is US$262 (at constant 2011 prices) with a range between US$53 and US$605. The average minimum distances between residential dwellings and the access zone to the BRT system are: Bogotá (2006 and 2008) 1,070 and 1,144 metres, Barranquilla (2011) 1,274 metres (with minimums and maximums of 44 and 1,995 metres; 57 and 3,753 metres; 100 and 3,600 metres). The average for commercial real estate is: Bogotá (2006 and 2008) 304 and 286 metres, Barranquilla (2011) 937 metres (with ranges between 324 and 615 metres; 0 and 2,019 metres; 247 and 1,721 metres).

The variable defined as the distance between residential and commercial properties to the point of access to the BRT system s statisitically significant with negative signs of the coefficients. Specifically, it is estimated that if properties are located at a greater distance from the access point to the transport system, their price decreases so that for each metre of distance their price per square metre decreases by US$0.04.

In terms of elasticity, a 1% increase between the distances of the evaluated points leads to a reduction of the price per square metre by 0.1%. These results show the underestimation of the effect in Perdomo (2011), a consequence of the improved data, the quantitative methodology implemented, the treatments of the spatial residual autocorrelation and the adjusted specification of the functional form of the estimated hedonic model. However, the results found for the change in the price per square metre under each methodology are not contradictory, due to the inverse relationship presented between this variable and the distance to the BRT system access (negative sign of the coefficient of interest).

These studies allow state entities in charge of executing valorisation taxes to quantify some of the private benefits derived from public investments in infrastructure, which can be used to objectively estimate the amount of their collection and thus be repaid back to the government by the owners of the benefited properties. In this way, the State can again reinvest these resources to generate new infrastructure projects and to compensate the damaged agents. With this, the current valuation taxes, collected and imposed from a legal point of view, can be endorsed and compared from an economic point of view.

Other additional benefits offered by these two articles are the estimation of the marginal effects and elasticities of the other control variables (own and environmental characteristics of the properties) which, although not highlighted in the publications, serve to complement previous work or originate new lines of research on the attributes that favour or disfavour property prices in a city. One example is the presence of air pollution (measured as particulate matter, PM10) in the neighbourhood of the property, whose negative coefficient shows an inverse relationship with the price per square metre. In other words, a higher presence of PM10 near the property leads to a reduction in its price per square metre. The same sign is observed for the effects caused by the age of the property and the presence of flooding areas (Perdomo, 2017).

Perdomo (2011) establishes the statistical representativeness for the distances between the properties under study and the access to shopping centres or parks, where the negative signs of their coefficients are also highlighted, whose marginal effects (0.01 and 0.02) and elasticities (0.06% and 0.01%) are equivalent to those obtained for the distance to the access of the mass public transport system in Bogotá.

Although several previous studies recognise the favourable changes in property market prices caused by the development of mass transport projects and infrastructure (such as metro, commuter rail and BRT), their results probably suffer from possible biases in conventional estimations (usually linear or log-log models regressed by ordinary least squares). These problems have been corrected with the techniques used in these two articles, thus providing more reliable results.

1.4.3 Summary and discussion of the results obtained in the publication entitled " *Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study*"

The rising prices of non-renewable natural resources (oil, gas, precious metals, coal, iron and nickel) on international markets have generated pressure for their exploitation in countries with significant reserves. However, several studies have shown that this exploitation has significant negative impacts on the environment (fauna, flora, landscapes, pollution of water bodies), human health, as well as other social and economic aspects (Perdomo and Jaramillo, 2016).

Although the companies dedicated to the extraction of these resources pay royalties to the state in accordance with the profits obtained according to the behaviour of their international prices, they are not compensating for the negative impacts caused. The environmental degradation and increased levels of poverty caused to the population by the unsustainable way in which private and public companies exploit renewable and non-renewable resources can exceed the amount of royalties received.

Given the large level of reserves, which leads to low extraction costs and thanks to the favourable market prices faced by the industry at the time, the multinational companies established in the area decide to extract all the available reserves of the resource in the shortest possible time, before the end of the concession, without paying any attention to the negative effects that this way of acting causes.

Nor is there an economic valuation of the negative externalities generated in order to account for them in their variable operating costs and internalise them in order to invest in reducing the damage caused and achieve economic, social and environmental sustainability, once the impacts caused have been compensated. In this sense, this article presents quantitative evidence of the effect of internalising the costs of negative externalities on the behaviour of open-pit coal mining companies in the centre of the department of Cesar in Colombia.

The results obtained show how firms can carry out sustainable open-pit coal production when the monetary value of the externalities generated by the activity in the study area are previously included, which can be used for the design of a sustainable exploitation once the costs of the impacts caused by the companies have been assumed without affecting their business model.

Based on the state of the art analysed, the research implements long-term simulations using Markov decision models and dynamic programming techniques (Bellman equations). The results of this article were possible thanks to the secondary information provided by Benchmark (database associated with the Faculty of Business Administration of the Universidad de los Andes) where from the results of profit and loss for each company, the total costs per year of production between 2004 and 2008 were obtained, taken as the sum of the cost of sales, operating expenses (composed of administrative and sales expenses, non-operating expenses and depreciation at constant 2008 prices) of the seven most important coal companies (including Drummond, Norcarbon, Consorcio Minero Unido, Prodeco Carboandes, Carbones la Jagua and Compañía de Carbones del Cesar) in the study area. Descriptive statistics show that the average annual cost incurred by a coal company is US$70,500, fluctuating between a minimum and maximum of US$985 and US$369,000 respectively.

Data on the level of production per company (4.7 million tonnes per year) and coal reserves (338 million tonnes) are taken from the report "Distritos Mineros: Exportaciones e infraestructura de transporte" prepared by the Unidad de Planeación Minero-Energética (UPME). The average market price (US$110, with minimum and maximum between US$99 and US$131) for the resource is taken from the statistical bulletin of mines and energy 2003-2008, prepared by the UPME.

The costs of negative externalities (social, economic and environmental generated), caused by coal activity in central Cesar, were estimated by the Ministry of Environment, Housing and Territorial Development and described in Perdomo et al. (2010), whose average annual value was US$111,000 for all mining companies (at constant 2008 prices), ranging between US$1,2589 and US$745,000.

With this information, the total cost functions without and with internalisation of the value of impacts, used in dynamic programming, are determined. Without considering the costs of externalities, a 1% increase in reserve levels in central Cesar leads to a 0.69% decrease in production costs, while a 1% increase in resource extraction increases firms' total costs by 1.7%. This allows for a representative increase in the economic benefits derived from the activity for the companies established in the region.

Thus, the simulation obtained in dynamic programming, without considering the costs of externalities, shows that the large amount of coal reserves entails low extraction costs and with its favourable market prices, the best decision that firms can take is to extract all the available reserves of the resource in the shortest possible time, before the end of the period granted by the State for the exploitation of the resource, which is usually 40 years.

This behaviour is normal for any private actor whose objective is to maximise profits. However, this behaviour can lead to a reduction in the supply of environmental goods and services and other negative effects on other economic activities (agriculture and livestock), human health status and social pressures.

This scenario changes once the values of negative externalities are assumed in the firms' total cost function. A 1% increase in reserve levels in central Cesar leads to a 1.29% decrease in production costs, while a 1% increase in resource extraction increases firms' total costs by 2.27%. This means that economic losses are incurred when mineral inventory is below 100 tonnes, while above this value and up to 2,500 tonnes, profits start to become positive as coal reserves increase. Consequently, there is an increase in ore reserves and an increase in the useful life of the concession to more than 40 years.

The above shows that in Colombia the impact studies and environmental management plans must be reinforced with an economic analysis that helps to previously determine the viability of the extraction activities, in order to obtain the true economic values of the negative externalities originated by them, which allow for compensation, mitigation and restoration measures of the environmental goods and services, economic activities and social degradation potentially affected by a coal project in a certain area of the country.
The results obtained with the Bellman equations can be used to look for mechanisms that include all the production costs in order to correct unsustainable behaviour by the companies in charge of carrying out the activities.

1.4.4 Summary and discussion of the results obtained in the publication entitled " *An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation* "

This article shows the economic estimate of the maximum rate per minute to be charged by the establishments that provide parking services to their users in the city of Bogotá, once the total costs to be able to provide it are considered, in order to collect sufficient revenue to cover expenses and obtain economic benefits for carrying out this activity.

In Colombia there are regulatory measures to control the prices of goods and services that have been imposed without previously conducting economic studies to support the legal decisions taken (Decrees 1504 of 1998 and 268 of 2009), affecting or favouring some of the key players in the various regularised markets, leaving the feasibility of implementation to the judgement of legal professionals without considering the economic consequences of these decisions.

Thus, the economic analysis and quantitative techniques implemented in Perdomo (2015) show that the maximum rate imposed by legal decree for the payment per minute of car parking service in Bogotá does not cover the total costs of the companies that provide the service to users.

In the face of regulatory impositions, which seek to control market power, the informality of the business has expanded because the decreed rate is profitable for those informal businesses that incur lower insurance, administrative, tax and adaptation costs that other firms must incur in order to provide the service in an adequate and safe manner.

To meet the objective of the study, a dynamic panel data model is used to determine the behaviour of the total costs of providing the service. This model is estimated by means of the generalised method of moments, also using mathematical optimisation (comparative statics) and Ramsey prices, all combined with the analysis of the pricing criteria, based on the theoretical guidelines of transport economics and axioms of microeconomics on cost analysis (fixed, total, variable, marginal and average).

According to the exhaustive literature review carried out up to that time, empirical works with case studies such as the one presented in Perdomo (2015) have not been considered. Several research studies on parking service regulation have been carried out on the demand side (users) using the stated preference technique (estimating willingness to pay, WTP), without considering supply, as it is done in this article. This aspect constitutes another added value to the knowledge on the subject because the use of Ramsey prices has generally been implemented to control market power in the telecommunications sector and not in the transport sector.

The results of the article are obtained thanks to confidential secondary information, granted with the necessary permissions by the City Parking company, given that no official state entity keeps this type of detailed information at the microeconomic level. A total of 360 data are obtained on the number of minutes sold and costs (fixed and variable - rent, commissions, interest, taxes, payroll, insurance, incident payments, adaptations, technology), based on a 36-month record (January to December between 2010 and 2012), of 10 of its car parks located in Bogotá. This allows the dynamic panel data structure used to implement the quantitative methodologies of the case to be formed.

Descriptive statistics of the available data show that the average monthly total cost per parking facility is US$13,579 -at constant June 2011 prices- (US$453 daily), with a minimum and maximum variation of US$3,605 and US$44,526. The arithmetic mean of the amount of time purchased monthly by users of the service is 295,879 minutes (approximately 9,863 minutes per day), with a range between 64,576 and 640,166 minutes (around 2,153 and 21,339 minutes per day).

With this information, the linear, quadratic and cubic functional forms of the relationship between total cost (TC) and quantities (Q, minutes of service sold) are formulated, which are estimated using the generalised method of moments to obtain the marginal cost (MC) and average total cost (ATC) curves, at whose crossing point the minimum optimal value of minutes to sell (Q*) is obtained so that the firms offering the service manage to cover at least their variable costs.

The results show that the cubic function satisfies the conditions for determining the crossover between MC and ATC, according to the consistency of the expected signs on its coefficients (positive, negative, positive) and the statistical representativeness (partial and joint) of the variable Q (in its linear, quadratic and cubic specification), while the estimation of the linear and quadratic form does not meet the expected theoretical conditions.

From the calculation of the first order conditions (comparative statics) of the cubic function and equating it with its ATC, the Q* is obtained, whose value corresponds to a minimum of 438,132 minutes per year that a parking establishment should sell to cover its variable costs. Applying the Ramsey pricing approach with Q*, it is obtained that the per-minute rate to be charged to users was US$0.27 per minute consumed, which is higher than the regulatory imposition of US$0.05 per minute. This leads to the conclusion that the price imposed by the authorities does not cover the variable and fixed costs of the companies offering this service.

These results can be used to redirect and strengthen the methods of economic regulation designed by public entities in Colombia to control market power, since subjective regulations established without a rigorous ex-ante analysis could possibly lead to the closure of formal companies and the spread of informal agents to satisfy market needs.

1.5- References

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2- Conclusions

The doctoral thesis presented here comprises five articles published in different scientific journals (see annexes in section 3) between 2011 and 2022. In them, different quantitative techniques are used to obtain empirical results that can be used by different governmental institutions in their decision making, seeking to strengthen the design of public policies in environmental, urban and agricultural matters in Colombia.

2.1- Returns to Scale and Technical Efficiency in Colombian Coffee Farms

The article "Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies" uses the techniques proposed by Kutlu (2010) and Amsler et al. (2016) for the treatment of endogeneity in the estimation of the stochastic production frontier (SPF). The results obtained are of particular importance for the design of agricultural policies in Colombia that allow considering lines of action that seek to improve the welfare level of small and medium farmers with low incomes, according to their technical inefficiency and increasing returns to scale evidenced.

Improving the efficiency of small and medium-sized coffee farms in Colombia would require a multifaceted approach involving a combination of policies that target different areas of the coffee farming industry. Some potential policies that could be implemented include:

- Providing access to credit and financial resources: Small and medium-sized coffee farms often face challenges in accessing credit and other financial resources that could help them to invest in modern equipment and technologies. Policymakers could increase access to credit and other financial resources by establishing loan programs, providing grants for equipment upgrades, and offering tax incentives to encourage investment.

- Encouraging sustainable farming practices: Sustainable farming practices can help to improve the efficiency of coffee farms by reducing waste, conserving resources, and enhancing soil quality. Policymakers could provide incentives for farmers to adopt sustainable practices, such as offering training programs, subsidies for organic farming, and certification programs for sustainably produced coffee.

- Improving infrastructure: Poor infrastructure can be a significant barrier to efficiency in the coffee farming industry. Roads and transportation networks may be inadequate, making it difficult for farmers to transport their coffee to market. Policymakers could invest in infrastructure improvements, such as road repairs and upgrades, to help farmers access markets more easily.

- Promoting technological innovation: Technological innovations can help to increase the efficiency of coffee farming by reducing labor costs and improving yields.

Policymakers could invest in research and development to support the progress of new technologies and encourage the adoption of existing technologies, such as precision agriculture tools, that can help to improve efficiency.

- Supporting cooperative farming models: Cooperative farming models can help small and medium-sized farmers to improve their bargaining power and gain access to new markets. Policymakers could support the development of cooperatives by providing funding for infrastructure and training programs, and by creating policies that encourage cooperative farming.

By implementing these and other policies, it may be possible to help small and medium-sized coffee farms in Colombia to become more efficient, competitive, and sustainable in the long term.

2.2- Investment in Transport Infrastructure and Property Values

The publications "The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia" and "A methodological proposal to estimate changes of residential property value: case study developed in Bogotá" use non-linear models with spatial autocorrelation treatment to measure the positive effect of investments made in mass public transport infrastructure on property prices in the cities of Bogotá and Barranquilla. The results obtained contain relevant information for the design of value capture mechanisms to generate returns to private benefits from public investments in different urban projects in Colombia.

The usefulness of value capture mechanisms depends on several factors, including the type of project, the level of private investment, and the local legal and regulatory framework. In some cases, value capture mechanisms may not be appropriate or feasible, such as in areas with low property values or where private investment is limited.

However, in many urban projects, value capture mechanisms can provide a means of financing public investments while also creating a more equitable distribution of the costs and benefits of the project. By capturing the increased property values resulting from public investment, value capture mechanisms can generate returns to private stakeholders and incentivize further private investment in the area.

2.3- Internalisation of Opencast Coal Extraction Externalities

The article "Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study" uses Markov decision models and dynamic programming techniques (Bellman equations) to obtain simulations of optimal opencast coal extraction when the costs of environmental, social and economic externalities generated by the activity are internalised by the firms that carry it out. The results obtained can be used to design mechanisms that significantly affect production costs in order to move towards sustainable development, avoiding environmental liabilities and total depletion of non-renewable resources exploited in Colombia.

If the costs of environmental, social, and economic externalities generated by opencast coal extraction are internalized, several conclusions can be drawn:

- Optimal opencast coal extraction would be more sustainable: By internalizing the costs of externalities, firms would have to take into account the negative impact of their activities on the environment, society, and the economy. This would provide a financial incentive for firms to reduce the negative impact of their activities, which would lead to more sustainable opencast coal extraction.

- The true cost of coal extraction would be reflected: When externalities are not internalized, the costs of coal extraction are often borne by the environment, society, and the economy, rather than the firms that extract the coal. Internalizing these costs would ensure that the true cost of coal extraction is reflected in the market, which would encourage firms to explore alternatives to coal extraction that may be less damaging to the environment and society.

- Firms would need to innovate: Internalizing the costs of externalities would encourage firms to innovate and find ways to extract coal with minimal environmental and social impact. This would promote the development of new technologies and practices that are more efficient and sustainable, and ultimately lead to better outcomes for the environment, society, and the economy.

- Communities would benefit: When firms internalize the costs of externalities, they may be required to compensate communities for any negative impact that their activities have on local people. This would ensure that the communities affected by opencast coal extraction are fairly compensated for any harm caused, which would promote social justice and reduce inequalities.

2.4- Price Cap Regulation in Parking Services

Finally, the publication "An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation" uses the generalised method of moments in dynamic panel data and Ramsey prices to obtain the value that users of the car park service should pay without harming the profitability of the activity in order to improve mobility in the city of Bogotá.

The rationale behind using price caps in public services is to ensure that prices remain affordable and accessible to all members of society, while also incentivizing providers to improve efficiency and quality of service.

Price caps are often used in industries such as utilities, transportation, and healthcare where there is limited competition and the providers have a natural monopoly. In such industries, providers can charge high prices for their services because customers have no other option but to use their services.

To prevent these providers from charging excessive prices, regulators often set a cap on the maximum price they can charge. The cap is usually set at a level that allows providers to cover their costs and make a reasonable profit, while also ensuring that prices are affordable and accessible to all customers.

In addition to protecting customers from high prices, price caps also provide an incentive for providers to improve efficiency and quality of service. If providers are able to deliver the same service at a lower cost, they can increase their profits by charging lower prices while still earning a reasonable profit.

Overall, the use of price caps in public services aims to strike a balance between protecting customers from high prices and incentivizing providers to improve efficiency and quality of service.

2.5- Concluding Remarks

Finally, it should be mentioned that the techniques implemented and the results obtained in the five publications presented can be used by public institutions to design and implement policies aimed at improving the agricultural, environmental and urban performance that determine the well-being of Colombians.

3- Annexes (Published Works)

1- **Studies in Agricultural Economics** (Institute of Agricultural Economics Nonprofit Kft. (AKI)), **Published**
Country: Hungary
SCimago Journal Rank Indicator (**Q2**), Agricultural and Biological Sciences (Category), **Impact Factor 2.000.**

2022 Perdomo Calvo, Jorge Andrés; Arteche, Josu and Ansuategi, Alberto "**Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies**". Studies in Agricultural Economics, 144 (3), 104-1112. DOI: 10.7896/j.2370

https://studies.hu/returns-to-scale-and-technical-efficiency-in-colombian-coffee-production-implications-for-colombias-agricultural-and-land-policies/

2-Travel Behaviour and Society (Elsevier Editorial System, EES), **Published**
Country: Netherlands, Western Europe
SCimago Journal Rank Indicator (**Q1**), Social Sciences; Transportation (Subject Area and Category), **Impact Factor 5.85.**

2017 Perdomo Calvo, Jorge Andrés "**The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia**". Travel Behaviour and Society Journal, 6, 90-99. DOI: 10.1016/j.tbs.2016.08.002.

https://www.sciencedirect.com/science/article/abs/pii/S2214367X15300132

3-Energy Economics (Elsevier Editorial System, EES), **Published**
Country: Netherlands, Western Europe
SCimago Journal Rank Indicator (**Q1**), Economics, Econometrics and Finance; Energy (Category), **Impact Factor 9.252.**

2016 Perdomo Calvo, Jorge Andrés and Jaramillo Ana "**Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study**". Energy Economics, 59, 159-166. DOI: 10.1016/j.eneco.2016.07.016.

https://www.sciencedirect.com/science/article/pii/S0140988316301888

4-Applied Economics Letters (Taylor & Francis Online), **Published**
Country: United Kingdom, Western Europe
SCimago Journal Rank Indicator (**Q3**), Economics, Econometrics and Finance (Category), **Impact Factor 2.000.**

2011 Perdomo Calvo, Jorge Andrés "**A methodological proposal to estimate changes of residential property value: case study developed in Bogotá**". Applied Economics Letters, 18 (16), 1577-1581. DOI: 10.1080/13504851.2011.554360.

https://www.tandfonline.com/doi/abs/10.1080/13504851.2011.554360

5-Journal of Cost Analysis and Parametrics (Taylor & Francis Online), **Published**
Country: United Kingdom, Western Europe

2015 Perdomo Calvo, Jorge Andrés "**An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation**". Journal of Cost Analysis and Parametrics, 8 (1), 23-33. DOI: 10.1080/1941658X.2015.1016586.

https://www.tandfonline.com/doi/citedby/10.1080/1941658X.2015.1016586?scroll=top&needAccess=true&role=tab

Article “Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia’s Agricultural and Land Policies”

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Returns to Scale and Technical Efficiency in Colombian Coffee Production: Implications for Colombia's Agricultural and Land Policies

This paper applies a parametric approach to estimate technical and scale (in)efficiencies using input and output data at the level of 850 individual Colombian coffee-farms. Different Stochastic Production Frontier functions are estimated using a two-step procedure that corrects the endogeneity that has been ignored in previous works, leading to more reliable (i.e. unbiased and consistent) results. We conclude that small and medium coffee farmers are technically inefficient and exhibit increasing returns to scale, whereas large coffee farmers are close to being quasi-technically efficient and exhibit decreasing returns to scale. The corrected-for-endogeneity estimation also indicates that small and medium-sized units must prioritise primarily the land factor, whereas large farms should concentrate their efforts on increasing the labour factor. Based on these results, several agricultural and land policy recommendations are made.

Keywords: coffee production, stochastic production frontier, endogeneity, technical efficiency, returns to scale

JEL classification: Q12

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Introduction

Colombia is the World's third largest producer of coffee after Brazil and Vietnam and the highest in terms of the Arabica bean (Giovanucci *et al.*, 2002; ICO, 2021). From the time the commercial production of coffee first began in 1870, coffee has traditionally played an important role in the economic growth of Colombia. Today, it plays a smaller economic role, but it is still a primary source of income for nearly half a million rural families.

A great deal of Colombian coffee is produced on small and medium-sized family farms. This may be the consequence of the existence at the beginning of the twentieth century of large quantities of unclaimed land on the slopes of (particularly) the central cordillera, the relative scarcity of large accumulations of capital, and the country's inability to attract foreign immigrants. Whatever the precise reason for the growth of small and medium-sized coffee farms in Colombia, currently units of small size comprise the great bulk of coffee farms of the nation. Thus, the National Federation of Coffee Growers of Colombia estimates that there are 560,000 coffee growing families, where small farmers with less than 5 hectares of land are responsible for approximately 69 percent of coffee production in Colombia. This feature can in the future be exacerbated by virtue of the peace deal signed by the Government of Colombia with the Revolutionary Armed Forces of Colombia (FARC) at the end of 2016, that pledges to address unequal land ownership and foster development in neglected rural areas hit hard by violence.

Some reports indicate that agricultural productivity in general, and the productivity of coffee plantations in particular, are relatively low in Colombia (OECD, 2015). Hence, it is essential to assess what possibilities exist for improving the efficiency of coffee production. It is particularly interesting to analyse if providing land to a wider share of the rural population has a positive effect in terms of improving the productivity of coffee plantations. For that analysis, it is important to focus on the relationship between land size and productivity in Colombian coffee production.

This study aims to shed some light in this direction by examining the technical efficiency of small, medium- and large-sized coffee farms as well as testing for economies of scale in each of these groups. For that purpose, we apply a parametric approach to estimate technical and scale (in) efficiencies using input and output data at the level of 850 individual farms (556 small, 200 medium and 94 large-sized) in the Departments of Risaralda, Caldas, and Quindío in Colombia in year 2003. As far as we know, this database is the most recent to have been applied to coffee farms and, although a more current database may be desirable, no updated database exists with the same level of detail.

This study draws on the extensive literature on technical efficiency and returns to scale in agricultural production in developing countries following the seminal finding by Sen (1962) that yields per acre and farm size were inversely related for small Indian farms. This inverse relationship has been confirmed by studies in Africa (Barrett, 1996; Kimhi, 2006), Asia (Carter, 1984; Heltberg, 1998; Akram-Lodhi, 2005; Besley and Burgess, 2000), Europe (Alvarez and Arias, 2004) and Latin America (Berry and Cline, 1979) and contested by others, such as Bhalla and Roy (1988), who have shown that when differences in land quality are taken into consideration this phenomenon disappears. Lamb (2003) has additionally attributed these findings to labour market imperfections and measurement errors. More recent studies have imposed greater theoretical structure on the empirical work and have found that large farms are more efficient and more productive than small farms (Adamopoulos and Restuccia, 2014).

A subset of the literature on technical efficiency and returns to scale has focused on coffee production. Thus, Data Envelopment Analysis (DEA) techniques have been used to compute farm-level technical efficiency measures in Costa

Rica by Mosheim (2002), in Côte d'Ivore by Binam *et al*. (2003), in Colombia by Perdomo and Mendieta (2007), and in Vietnam by Rios and Shively (2006) and Garcia and Shively (2011). Vedenov *et al*. (2007), Nchare (2007) and Perdomo and Hueth (2011), instead of using non-parametric mathematical programming, have made use of Stochastic Frontier Analysis (SFA) to estimate an input distance function and evaluate production efficiency in Mexico, Cameroon, and Colombia, respectively.

Perdomo and Hueth (2011) and Perdomo and Mendieta (2007) constitute two preliminary attempts to study the production function, returns to scale and technical efficiency of Colombian coffee farms using SFA and DEA. They found that small- and medium-sized coffee farms presented technical inefficiency and increasing returns to scale, whereas the larger coffee farms presented technical efficiency and decreasing returns to scale. Nevertheless, some authors have raised concerns about endogeneity in production function estimation (Kutlu, 2010; Tran and Tsionas, 2013). Stochastic production frontier models usually assume that input choices are independent of the efficiency and productivity terms. However, if a producer observes some factors – unobservable by the econometrician – that affect a farm's efficiency and/or its productivity, the input choices may also be influenced by this knowledge, resulting in an endogeneity problem in the stochastic production frontier estimation (Shee and Stefanou, 2015). This situation may therefore lead to a biased inference on input elasticities, economies of scale and technical efficiency. In this paper we follow Kutlu (2010) (see also Amsler *et al.*, 2016) to deal with endogeneity when estimating the SFA to assess the technical and scale (in)efficiencies of Colombian coffee farms.

The rest of the paper is organised as follows: the empirical model for the estimation of technical and scale efficiency is presented in the next section. The data set is described in the third section and the empirical results are discussed in the fourth section. Some recommendations for agricultural and land policies and concluding remarks follow in the fifth and sixth sections, respectively.

Empirical Model

Consider the following general form of the stochastic production frontier (SPF) function:

$$q_i = f(x_{i1}, \cdots, x_{im}, \beta) e^{\mu_i - \omega_i} \qquad i = 1, \cdots, n \tag{1}$$

where q_i is the observed output produced by the i-th farm, x_{ij} is the quantity of the j-th input used by the i-th farm ($j=1,\cdots,m$), β is a vector of parameters to be estimated, and $\mu_i - \omega_i$ is a composite error term. The μ_i term corresponds to the statistical noise (assumed to be independently and identically distributed) and ω_i is a non-negative random variable associated with technical inefficiency. Regarding $f(\cdot)$, the Transcendental and Cobb-Douglas functions are the two most commonly used functional forms in empirical studies of production, which include frontier analyses (Battese and Broca, 1997). The Cobb-Douglas stochastic frontier model takes the form:

$$q_i = A \prod_{j=1}^{m} x_{ij}^{\beta_j} e^{\mu_i - \omega_i} \tag{2}$$

which can be estimated as a linear relationship using the following expression:

$$ln\, q_i = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln\, x_{ij} + \mu_i - \omega_i \tag{3}$$

Similarly, the logarithmic transformation of the Transcendental SPF model takes the following form:

$$\begin{aligned} ln\, q_i = \beta_0 + \sum_{j=1}^{m} \beta_j \, ln\, x_{ij} + \tfrac{1}{2} \sum_{j=1}^{m} \beta_{jj} (ln\, x_{ij})^2 + \\ + \sum_{j=1}^{m} \sum_{k>j}^{m} \beta_{jk} \, ln\, x_{ij} \, ln\, x_{ik} + \mu_i - \omega_i \end{aligned} \tag{4}$$

Note that the usual procedures for estimating SPF models depend on the assumption that the inputs are exogenous. However, in many situations this assumption is difficult to maintain because some inputs can be influenced by unobserved factors such as expected rainfall in the farm's location, managerial ability of the farmer etc. that obviously have an impact also on the produced output. To overcome this endogeneity problem, we follow Kutlu (2010) and Amsler *et al*. (2016) and estimate the SPF in a two-step procedure. In the first step, we estimate the reduced form of the inputs demand function system, where the endogenous variables ($x_{i1}, \cdots, x_{im}$) are log- linear functions of their prices ($p_{x_{i1}}, \cdots, p_{x_{im}}$) and a set of unobserved factors, which have the characteristics of providing good instruments for the log inputs. Note that the error terms of such regressions, denoted as $\varepsilon_{i1}, \cdots, \varepsilon_{im}$, are possibly contemporaneously correlated, and consequently the system requires an estimation by means of seemingly unrelated regression (SUR) using iterative generalised least squares to obtain unbiased, consistent, and efficient estimators (Rosales *et al.*, 2013). In the second step the residuals from the SUR estimation, denoted as $\hat{\varepsilon}_{i1}, \cdots, \hat{\varepsilon}_{im}$, are used as controls in an operational version of equation (1):

$$q_i = f(x_{i1}, \cdots, x_{im}, \hat{\varepsilon}_{i1}, \cdots, \hat{\varepsilon}_{im}; \beta^*) e^{\mu_i - \omega_i} \tag{5}$$

Following Battese and Coelli (1992), the specification of the technical efficiency of production for the i-th farm (TE_i) is defined by:

$$TE_i = \frac{f(x_{i1},\cdots,x_{im},\hat{\varepsilon}_{i1},\cdots,\hat{\varepsilon}_{im};\beta^*) e^{\mu_i - \omega_i}}{f(x_{i1},\cdots,x_{im},\hat{\varepsilon}_{i1},\cdots,\hat{\varepsilon}_{im};\beta^*) e^{\mu_i}} = e^{-\omega_i} \tag{6}$$

$TE_i \in [0,1]$ provides a measure of the shortfall of observed output from maximum feasible output in an environment that allows for variation across farms.

The elasticity of output[1] of the i-th farm with respect to the j-th input ($e_{q_i x_{ij}}$) is defined by:

$$e_{q_i x_{ij}} = \frac{\partial\, ln\, q_i}{\partial\, ln\, x_{ij}} \tag{7}$$

[1] Whereas the elasticity is constant for the Coob-Douglas specification, the form of the translog in equation (4) implies that the elasticity depends on the level of the inputs. Following general conventions (see Greene, 2012) the elasticity is here calculated at the average inputs as $\frac{\partial\, ln\, \hat{q}_i}{\partial\, ln\, x_{ij}} = \hat{\beta}_j + \sum_{k=1}^{m} \hat{\beta}_{jk}\, ln\bar{x}_{ik}$ where, $ln\, \bar{x}_{ij}$ and $ln\bar{x}_{ik}$ are the averages log-inputs.

As a result, the returns to scale (RTS) are expressed by:

$$RTS_i = \sum_{j=1}^{m} e_{q_i x_{ij}} \quad (8)$$

It measures the proportional change in output resulting from a unit proportional increase in all inputs. Then $RTS > 1$ shows the presence of increasing returns to scale, $RTS < 1$ indicates the existence of decreasing returns to scale and $RTS = 1$ implies constant returns to scale.

Data Description

The data used in the present study are from a survey undertaken by the Department of Agricultural and Resource Economics (AREC) of the University of Maryland[2] (United States) during the year 2004 in the Departments of Risaralda, Caldas, and Quindío in Colombia. It contains information obtained from 850 coffee farms of which 556 are small-sized (below 2 hectares), 200 are medium-sized (between 2 and 7 hectares) and 94 are large-sized (above 7 hectares). The information collected corresponds to the 2003 crop year[3].

For the purposes of the present study, output is measured in annual arrobas[4] produced. Four inputs are included in the production frontier function, namely land measured in hectares, labour (including family, hired workers and coffee pickers) measured in full time equivalents, intermediate inputs (fertiliser and pesticides) measured in kilograms, and capital stock (machinery) measured through a synthetic index of capital intensity. We use this index because the information in the survey only includes the number of machines used by each farm, without discriminating between different types of machines. This index, called Index of Machinery Intensity (IMI), is constructed by means of Principal Component Analysis (PCA) and feature scaling or minmax scaler process as follows (see details in Johnson, 1998, Ch. 5 and Perdomo *et al*. 2016, p. 42-44). The relative weights across different factors of machinery used in coffee growing (total number of coffee pulper machines, water pump machines, coffee demucilager machines, motors, coffee silo machines, fumigation machines, scythes machines and chainsaws) were estimated with PCA, because their units of measurement are heterogeneous, so their direct aggregation or sum is unsuitable for determining machinery intensity (MI). Once MI is calculated, values are normalised (between zero and one) using feature scaling or minmax scaler (see details in Perdomo *et al*., 2016, p. 42) as

$$IMI_i = \frac{MI_i - MI_{min}}{MI_{max} - MI_{min}} \quad (9)$$

where MI_i are obtained from PCA, MI_{min} and MI_{max} are their minimum and maximum values and $IMI_i \rightarrow 1$ indicates more intensity of machinery.

Several additional variables have been included in the regression in the first step to obtain the residuals used as controls in the second step. First, the number of people per household is used as a proxy of rural population density. Second, three dummy variables have been used to indicate (i) if the farm obtains income from activities other than coffee production, (ii) if the main source of income comes from coffee activity, and (iii) if the farm has road access to the municipal centre. The sample mean of these, and the rest of variables are given in Table 1.

Empirical Results

Table A1 in the Appendix shows the SUR estimates (first stage) of the input demand functions. The residuals in this regression are incorporated in the SPF function in the second step. Tables 2, 3 and 4 show the maximum likelihood

Table 1: Sample mean values of model variables.

Variable	Small-sized farms	Medium-sized farms	Large-sized farms
Output (arrobas year)	160.31	481.97	2726.11
Land (hectares)	1.44	3.53	14.33
Labour (workers, full time equiv.)	9.09	21.87	99.02
Chemicals (Kgs)	3.48	23.59	102.33
Machinery (capital intensity index-IMI-)	0.13	0.23	0.18
Price of Land (US$ per hectare)	22,184.28	41,378.20	52,852.84
Price of Labour (US$ weekly per worker)	100.44	179.76	188.55
Price of Chemicals (US$ per Kg)	7.22	7.66	8.82
Price of Machinery (index)	0.87	0.93	0.83
Family size (persons)	4.00	3.92	3.24
Diversification (dummy variable)	0.28	0.42	0.50
Specialisation (dummy variable)	0.87	0.80	0.74
Road Access (dummy variable)	0.66	0.79	0.98
Sample size	556	200	94

Source: Own composition

2 The survey strategy was conducted by Prof. Darrell Hueth.

3 Unfortunately, similar surveys have not been conducted since then.

4 Arroba is a Portuguese and Spanish unit of weight, mass, or volume, representing a weight of around 25 pounds or 12.5 kilograms.

estimates of the different specifications for the SPF function for small-, medium- and large-sized farms, respectively. The standard errors from the two-stage method employed here are inconsistent because the estimates are conditional on estimated standardised error terms from the first stage. Hence, we only present bootstrap standard deviations as proposed by Kutlu (2010). The tables also include values of the Hausman test indicating that endogeneity exists in equation (3) in the three groups of farms. The general significance of the control functions reinforces the hypothesis of endogeneity of the inputs. The results of the Sargan test evidence as well the validity of the instruments used in the first step to control for the endogeneity of the input variables. For the sake of comparison, the estimation of the SPF function with and without correction of endogeneity are included. Even though not all the inputs are individually significant, we keep them in all the functional specifications for comparative purposes.

Table 2: Stochastic Production Frontier estimates (Second Stage) for small-sized farms.

Dependent Variable: (Coffee Production)	Translog without endogeneity corrected	Translog with endogeneity corrected	Cobb Douglas without endogeneity corrected	Cobb Douglas with endogeneity corrected
Explanatory Variables	**Coefficients (β)**	**Coefficients (β*)**	**Coefficients (β)**	**Coefficients (β*)**
Intercept	6.0258***	3.0936	3.5793***	2.2199**
Land	1.3551	1.5594	0.6171***	1.7572***
Labour	0.3007	0.8253	0.6322***	0.5204**
Chemicals	-0.2040	0.5583	0.1770***	0.7259***
Machinery	1.6073**	0.5774	-0.0076	-0.3369
Land^2	-0.4230	-0.3396	-	-
Labour ^2	-0.3609***	-0.4252***	-	-
Chemicals^2	-0.0750	-0.1472**	-	-
Machinery^2	0.1415	0.0448	-	-
Land*Labour	-0.0884	0.0654	-	-
Land*Chemicals	-0.2521**	-0.1670*	-	-
Land*Machinery	0.0431	-0.0833	-	-
Labour*Chemicals	0.1450**	0.1366***	-	-
Labour*Machinery	-0.4579*	-0.2568	-	-
Chemicals*Machinery	-0.1355	-0.1059	-	-
Residual first stage land	-	-1.0262*	-	-1.2548**
Residual first stage labour	-	-0.0145	-	0.1328
Residual first stage chemicals	-	-0.7090***	-	-0.6492***
Residual first stage machinery	-	0.2310	-	0.3001
Natural logarithm of v_i	-1.9760***	-2.1502***	-1.868013***	-2.0444***
Natural logarithm of u_i	-1.6106***	-1.7686***	-1.56359***	-1.7063***
AIC	950.76	860.62	974.04	886.66
Wald test (chi-square)	792.46***	1,690.14***	569.20***	1,562.62***
LR test of sigma_u=0 (chi-square)	55.25***	78.62***	47.97***	66.59***
Hausman test for endogeneity (chi-square)	-	62.97***	-	56.42***
Sargan test (F statistic)	-	0.01	-	0.06
RTS	2.15	3.17	1.42	2.67
TE (50th percentile)	0.75	0.75	0.74	0.75
Observations	555	550	555	550

Note: *, ** and *** Significant at 0.10, 0.05 and 0.01 levels, respectively
Source: Own composition

Table 3: Stochastic Production Frontier estimates (Second Stage) for medium-sized farms.

Dependent Variable: (Coffee Production)	Translog without endogeneity corrected	Translog with endogeneity corrected	Cobb Douglas without endogeneity corrected	Cobb Douglas with endogeneity corrected
Explanatory Variables	**Coefficients (β)**	**Coefficients (β*)**	**Coefficients (β)**	**Coefficients (β*)**
Intercept	6.1810***	7.0956***	4.1913***	5.5284***
Land	0.7045	2.1543**	0.5397***	1.7836***
Labour	-0.0810	-0.3845	0.5087***	0.1133
Chemicals	-0.6445***	-1.1043***	0.0655*	-0.2826**
Machinery	0.4215**	0.7649*	0.0551	0.5864***
Land^2	0.3019	0.2633	-	-
Labour ^2	-0.0544	-0.0969	-	-
Chemicals^2	0.0173	0.0493	-	-
Machinery^2	0.0692***	0.0336	-	-
Land*Labour	-0.0292	0.0360	-	-

Dependent Variable: (Coffee Production)	Translog without endogeneity corrected	Translog with endogeneity corrected	Cobb Douglas without endogeneity corrected	Cobb Douglas with endogeneity corrected
Explanatory Variables	**Coefficients (β)**	**Coefficients (β*)**	**Coefficients (β)**	**Coefficients (β*)**
Land*Chemicals	-0.1599	-0.1309	-	-
Land*Machinery	0.0165	0.0352	-	-
Labour*Chemicals	0.2848*	0.2533**	-	-
Labour*Machinery	-0.0410	-0.0501	-	-
Chemicals*Machinery	-0.0237	-0.0151	-	-
Residual first stage land	-	-1.6827***	-	-1.3040***
Residual first stage labour	-	0.4826**	-	0.4709***
Residual first stage chemicals	-	0.4527***	-	0.3273***
Residual first stage machinery	-	-0.5292***	-	-0.5967***
Natural logarithm of v_i	-2.0833***	-2.2288	-1.820015***	-1.8495***
Natural logarithm of u_i	-1.1813***	-1.2933	-1.294065**	-1.6848
AIC	307.72	289.64	310.17	288.78
Wald test (chi-square)	295.25***	570.08***	243.33***	215.98***
LR test of sigma_u=0 (chi-square)	5.66***	5.59***	3.05***	1.52
Hausman test for endogeneity (chi-square)	-	15.09***	-	26.82***
Sargan test (F statistic)	-	1.45	-	1.14
RTS	1.26	2.44	1.17	2.20
TE (50th percentile)	0.70	0.71	0.71	0.75
Observations	199	199	199	199

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively
Source: Own composition

Table 4: Stochastic Production Frontier estimates (Second Stage) for large-sized farms.

Dependent Variable: (Coffee Production)	Translog without endogeneity corrected	Translog with endogeneity corrected	Cobb Douglas without endogeneity corrected	Cobb Douglas with endogeneity corrected
Explanatory Variables	**Coefficients (β)**	**Coefficients (β*)**	**Coefficients (β)**	**Coefficients (β*)**
Intercept	7.3622***	8.5448***	4.2502***	5.7954***
Land	0.2053	0.0035	0.2628***	0.7685***
Labour	-0.4440	-0.5065	0.6300***	0.2026**
Chemicals	-0.1954	-0.2082	0.0799**	-0.0210
Machinery	0.4661	0.3550	-0.0068	0.2878**
Land^2	-0.3158	-0.2698	-	-
Labour ^2	0.0611	0.0280	-	-
Chemicals^2	-0.0594	-0.1003	-	-
Machinery^2	-0.0118	-0.0611	-	-
Land*Labour	0.2351*	0.2633	-	-
Land*Chemicals	0.0560	0.0325	-	-
Land*Machinery	0.1685	-0.0305	-	-
Labour*Chemicals	0.0122	0.0431	-	-
Labour*Machinery	-0.1023	0.0773	-	-
Chemicals*Machinery	-0.1184**	-0.1313**	-	-
Residual first stage land	-	-0.4821	-	-0.6583***
Residual first stage labour	-	0.6750***	-	0.6954***
Residual first stage chemicals	-	0.0624	-	0.0797
Residual first stage machinery	-	-0.3359**	-	-0.3273***
Natural logarithm of v_i	-2.1385***	-3.0192	-2.412315***	-3.6032
Natural logarithm of u_i	-9.1123	-3.2178	-1.858953***	-1.7887
AIC	99.77	49.26	99.12	54.97
Wald test (chi-square)	519.94***	953.60***	409.40***	537.59***
LR test of sigma_u=0 (chi-square)	0	0.12	1.24	3.34***
Hausman test for endogeneity (chi-square)	-	35.37***	-	71.76***
Sargan test (F statistic)	-	0.27	-	1.79
RTS	0.90	0.99	0.97	1.24
TE (50th percentile)	0.99	0.86	0.77	0.77
Observations	94	94	94	94

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.
Source: Own composition

Table 5 contains the estimated elasticities and RTS defined in equations (7) and (8), for small-, medium- and large-sized farms. The RTS obtained from the SPF without endogeneity correction is underestimated in every situation. Focusing on the estimates with endogeneity correction, Table 5 shows that small- and medium-sized farms are subject to increasing RTS. It is also noteworthy that land is by far the most important input, especially in small- and medium-sized farms, whereas labour is especially important in large farms.

Implications for Colombia's Agricultural and Land Policies

In general, agricultural policies in post-conflict situations prioritise improvements in productivity and competitiveness with the aim of increasing the incomes of households whose livelihoods come from agriculture and guaranteeing food production (Adam-Bradford *et al.*, 2020; Jimenez *et al.*, 2021). This is precisely why it is pertinent to analyse in detail what effect the land distribution measures proposed in the 2016 peace accord in Colombia could have on the strategic sector of coffee production in terms of productivity. The results shown in the previous section suggest that small and medium coffee farmers in Colombia are technically inefficient in their production process and moreover, these production units exhibit increasing returns to scale. The challenge for agricultural and land policies is therefore to increase the scale of these farms in a way that does not conflict with another major objective of the proposed reform, which is to establish a more equitable distribution of land in rural areas (Faguet *et al.*, 2017).

It is beyond the scope of this article to carry out a detailed study of the direct and indirect effects of the different ways in which land reform can be implemented in Colombia. However, it does seem pertinent to comment that some concrete proposals in the literature and in the peace agreement itself, such as the formalisation of communal property regimes in rural settings, can make it possible to reconcile the objective of expanding access to land ownership with ensuring that the scale of farms is not sub-optimal.

Another important challenge is to enable the largest farms to improve their productivity through better access to labour. In fact, some reports attribute a reduction in factor endowments to the decline in coffee output that the country has suffered in the past decades (Saenz *et al.*, 2021). With a large mass of potential workers fleeing conflict zones, the wages of the remaining rural workers rose, leading to higher costs for coffee producers (World Bank, 2002). In addition, rural labour shortages have complicated the control of crop pests and the harvesting of the crop at the optimal time (Ocampo-Lopez and Alvarez-Herrera, 2017).

The resolution of the armed conflict may alleviate to some degree the depopulation of these rural areas and reduce some labour supply tensions. However, there are many more issues that need to be resolved in order to improve labour productivity indicators, which is the way in which the economic performance of every farm, but primarily the large plantations, can be improved. There are several studies promoted by companies and associations in the coffee

Table 5: Production elasticities and RTS.

SMALL-SIZED FARMS	**Translog with endogeneity corrected**	**Translog without endogeneity corrected**	**Cobb Douglas with endogeneity corrected**	**Cobb Douglas without endogeneity corrected**
Output elasticity of land	1.59***	0.758	1.76***	0.62***
Output elasticity of labour	0.67***	0.64***	0.52***	0.63**
Output elasticity of chemicals	0.85***	0.20	0.73***	0.18***
Output elasticity of machinery	-0.15	0.313	-0.34	-0.01
RTS	2.95***	1.90**	2.67***	1.42***
MEDIUM-SIZED FARMS	**Translog with endogeneity corrected**	**Translog without endogeneity corrected**	**Cobb-Douglas with endogeneity corrected**	**Cobb-Douglas without endogeneity corrected**
Output elasticity of land	2.20***-	0.58-	1.78***	0.54***
Output elasticity of labour	0.06-	0.46**	0.11	0.51***
Output elasticity of chemicals	-0.40-	0.05	-0.28**	0.07*
Output elasticity of machinery	0.57**-	0.15	0.59***	0.06
RTS	2.43***-	1.24***-	2.20***	1.17***
LARGE-SIZED FARMS	**Translog with endogeneity corrected**	**Translog without endogeneity corrected**	**Cobb-Douglas with endogeneity corrected**	**Cobb-Douglas without endogeneity corrected**
Output elasticity of land	0.62**	0.27	0.26***	0.77***
Output elasticity of labour	0.24	0.63***	0.63***	0.20**
Output elasticity of chemicals	-0.05	0.02	0.08**	-0.02
Output elasticity of machinery	0.24	0.04	-0.01	0.29**
RTS	1.05**	0.95**	0.97***	1.24***

Source: Own composition

sector that point to another series of factors as determinants to address the shortage and low productivity of labour in the Colombian coffee sector (Rocha, 2014).

In order to increase labour productivity on all types of plantations, but especially the larger ones, it is necessary to implement the following actions: (1) accompanying policies to hire more salaried workers with the formalisation of contracts that are more in line with labour regulations, (2) develop strategies to improve competitiveness in international markets that allow for wage improvements, and (3) offer training programmes to encourage specialisation among workers in the sector and prevent them from having to combine their activity with other complementary activities[5], without any signs of considering coffee growing as a long-term activity.

Conclusions

Two main contributions have been made in this work. On the one hand, the analysis of returns to scale, elasticities and technical efficiency previously carried out by other authors has been refined, correcting for endogeneity biases through a two-stage process to estimate the stochastic production frontier, in line with the proposal of Kutlu (2010) and Amsler *et al*. (2016). The correction for endogeneity is crucial, as it substantially conditions the conclusions of the analysis. We show that small and medium coffee farmers in Colombia are technically inefficient in their production process. In addition, these production units exhibit increasing returns to scale. Besides, large coffee farmers are close to being technically efficient and exhibit decreasing returns to scale. The corrected-for-endogeneity results also indicate that the input intensity that small and medium-sized units must prioritise in their agricultural activity is primarily the land factor, whereas large farms should concentrate their efforts on increasing the labour factor.

On the other hand, in this paper we try to translate these empirical results into agricultural and land policy recommendations in a context as special as the current one, where peace talks revolve around proposals to facilitate access to agricultural land for the poorest peasants in violence-affected areas.

We are aware that there are many aspects and challenges affecting the coffee sector in Colombia that are not addressed in this analysis and that could be analysed in future extensions of this paper. To the productivity analysis in this article should be added an analysis of competitiveness in international markets, as some of the aforementioned challenges relate to the need to attract investment from international suppliers, to accommodate the rapid expansion of coffee farms in low-income areas that have largely remained remote and isolated from international markets, as well as to cope with coffee's high dependence on foreign exchange rates.

[5] It should be borne in mind that many small farmers are in fact usually part farmers, part workers. The income of small farmers is based partly on the sale of crops and livestock, and partly on wage employment, whether on a farm or plantation or in some other rural occupation. Therefore, a sustainable development strategy for the coffee sector must also take into account, as a component, the wages of workers in coffee plantations.

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Appendix

Appendix 1: SUR model first stage results.

Dependent variable: LN(chemicals)	**Farm size**			**Dependent variable: LN(machinery)**	**Farm size**		
	Small	**Medium**	**Large**		**Small**	**Medium**	**Large**
Explanatory Variables	**Coefficients**	**Coefficients**	**Coefficients**	**Explanatory Variables**	**Coefficients**	**Coefficients**	**Coefficients**
Intercept	-2.6856***	2.4852	11.4980**	Intercept	-1.8679***	-5.0786**	-7.2970*
LN (price land)	0.0816***	0.2327***	0.3093**	LN (price land)	0.0059	0.1334*	0.2799**
LN(price labour)	0.1029	0.0512	-0.4464*	LN(price labour)	0.0054	0.1107	-0.0729
LN(price chemicals)	0.0734	-0.5258***	-0.5917**	LN(price chemicals)	-0.0335	-0.1401	-0.0310
LN(price machinery)	-0.1247	-0.0618	-0.0409	LN(price machinery)	-0.3825***	-0.1098	-0.3022**
Specialisation (dummy variable, yes=1 and no=0)	0.1606**	0.0270	-0.1620	Specialisation (dummy variable, yes=1 and no=0)	-0.0687**	0.3221*	0.3203
Road access (dummy variable, yes=1 and no=0)	0.1759***	0.0132	-1.4296*	Road access (dummy variable, yes=1 and no=0)	0.0130	0.4808***	0.6713
Diversification (dummy variable, yes=1 and no=0)	0.0315	0.2114	0.1909	Diversification (dummy variable, yes=1 and no=0)	-0.0689**	0.3780**	0.1635
LN(family size)	-	-	-0.3102	LN(family size)	-	-	0.2463
Global fit (chi-square)	68.09***	36.91***	20.15***	Global fit (chi-square)	126.29***	35.94***	14.90*
Observations	551	200	94	Observations	551	200	94

Dependent variable: LN(land)	**Farm size**			**Dependent variable : LN(labour)**	**Farm size**		
	Small	**Medium**	**Large**		**Small**	**Medium**	**Large**
Explanatory Variables	**Coefficients**	**Coefficients**	**Coefficients**	**Explanatory Variables**	**Coefficients**	**Coefficients**	**Coefficients**
Intercept	-0.4910	0.7622	2.0774	Intercept	2.0310**	5.0348	12.6031
LN (price land)	0.0380*	0.0401	0.1838**	LN (price land)	0.1366***	0.0748	0.2808***
LN(price labour)	0.0579***	-0.0188	-0.1025	LN(price labour)	-0.0167	-0.3373***	-0.9355***
LN(price chemicals)	-0.0602	-0.0022	-0.1047	LN(price chemicals)	-0.2160***	0.0561	-0.1737
LN(price machinery)	-0.0558	0.0221	-0.1557*	LN(price machinery)	-0.1147	-0.0185	-0.1501
Specialisation (dummy variable, yes=1 and no=0)	-0.0160	-0.0633	0.2205	Specialisation (dummy variable, yes=1 and no=0)	-0.1649*	-0.1929	0.6042***
Road access (dummy variable, yes=1 and no=0)	0.0282	-0.0539	-0.7360*	Road access (dummy variable, yes=1 and no=0)	0.0664	0.3056**	-0.1615
Diversification (dummy variable, yes=1 and no=0)	-0.0574	0.1249*	0.2022	Diversification (dummy variable, yes=1 and no=0)	-0.1237*	0.2988**	0.4497**
LN(family size)	-	-	-0.2391**	LN(family size)	-	-	-0.2370
Global fit (chi-square)	26.41***	9.27	21.81***	Global fit (chi-square)	32.78***	47.64***	66.36***
Observations	551	200	94	Observations	551	200	94

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.
Source: Own composition

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The effects of the bus rapid transit infrastructure on the property values in Colombia

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A B S T R A C T

Several articles have theoretically and empirically verified favorable changes in the value (per square meter) of properties near urban mass transit infrastructure. The main purpose of this study was to demonstrate this effect under an unbiased specification using Geographical Information Systems (GIS) and advanced econometric techniques (Pooled Cross Sections, Spatial Econometrics, Box-Cox Transformation and Structural Change). Particularly, if the construction of the bus rapid transit (BRT) infrastructure impacted the price market (per square meter or asking price) of the residential and commercial properties in Bogota and Barranquilla (Colombia) with access to the BRT. Results indicated the true private monetary or higher valuation of such properties, caused by public investment over several years (1999–2011). This effect is conceived as a positive economic externality of the BRT projects.

The Effects of the Bus Rapid Transit Infrastructure on the Property Values in Colombia

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ABSTRACT

Several articles have theoretically and empirically verified favorable changes in the value (per square meter) of properties near urban mass transit infrastructure. The main purpose of this study was to demonstrate this effect under an unbiased specification using Geographical Information Systems (GIS) and advanced econometric techniques (Pooled Cross Sections, Spatial Econometrics, Box-Cox Transformation and Structural Change). Particularly, if the construction of the bus rapid transit (BRT) infrastructure impacted the price market (per square meter or asking price) of the residential and commercial properties in Bogota and Barranquilla (Colombia) with access to the BRT. Results indicated the true private monetary or higher valuation of such properties, caused by public investment over several years (1999-2011). This effect is conceived as a positive economic externality of the BRT projects.

Keywords: Property value; BRT infrastructure; Colombia; advanced econometric techniques; unbiased specification.

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1. Introduction

The main anticipated impacts of the Bus Rapid Transit (BRT) systems, in the cities (of the developing countries) with more than 600,000 citizens, are: improved mobility through reduction of travel time and, increased quality of life, and improved transport model operations to adjust for its ineffectiveness (World Bank, 2004). Also, the BRT systems are a major determinant for organizing economic activity in cities' geography (Redding and Turner, 2014).

The government, by means of public investment over the last 18 years (1999-2016) financed BRT projects in several Colombian cities (Bogotá, Cali, Pereira, Cartagena, Barranquilla, Bucaramanga and Medellin). This building strategy has become popular in other worldwide locations including Mexico, Hong Kong, Seoul, Curitiba, Chicago, Quito, India and Turkey (World Bank, 2004; Hidalgo and Gutierrez, 2013; Hidalgo and Huizenga, 2013).

Various economic and social studies have estimated the monetary values of the positive and negative externalities derived from BRT projects. They have also conducted numerous ex-post evaluations through cost-benefits analyses (CBA) to demonstrate the substantial social benefits of public investment in infrastructure (National Department of Planning, NDP, 2012). Likewise, their results have helped to draw fiscal instruments to continue financing new BRT projects in Colombia (World Bank, 2004).

As a result, several research projects have theoretically and empirically verified the economic benefits (land-use strategy, improving accessibility and reduction in air pollution) of constructing or expanding transport innovation infrastructure (Urban rail and BRT systems or Integrated Mass Transit Systems –IMTS–). Bocarejo et al. (2012), Geetam and Deepty (2012), Perdomo and Arzuza (2015), Moreno (2004), Perdomo et al. (2010), Sandoval and Hidalgo (2004), Lleras (2003), Herbert et al. (2002), Vinha

(2005) and Bajic (1983) have analyzed the positive impact of BRT and urban rail systems on road safety, reductions in traffic accidents and crime rates, saving travel time, economic growth and the positives changes on land-value and higher valorization, respectively, using indicators, statistics and econometrics approaches.

Specifically, these studies confirm the favorable changes regarding the value (per square meter) of the properties near to urban mass transit infrastructure, using methods such as: Hedonic Pricing Models (conventional and –HPM– spatial –SHP–), *Difference in Differences* (*DD*), Propensity Score Matching (*PSM*) and other quantitative approaches (e.g., Rodriguez and Vergel, 2013; Perdomo, 2011 and 2010; Rodriguez and Mojica, 2008; Perdomo et al., 2007; Mendieta and Perdomo, 2007; Ardila, 2004; Rodriguez and Targa, 2004; McMillen and McDonald, 2000 and 2002).

Nevertheless, there are possible biases in the results due to inconsistencies in research methods (Ordinary Least Square –OLS–) or as a consequence of model specification errors, it is caused by omitted relevant variables (Suparman et al., 2014), incorrect functional form, errors of measurement and incorrect specification of the stochastic error term or spatial autocorrelation –endogeneity– (see Greene, 2002 and Pace and LeSage, 2009, for a review). These inconsistencies, possibly, directly affect the accuracy of results when determining the impact of the BRT infrastructure on residential and commercial property values (based on Rosales et al., 2013, 2013, Ch. 1 and 2 and Hill, 2013).

Owing to these factors, this study means to demonstrate this impact but (unlike many past studies) under an unbiased specification through the interaction of Geographical Information Systems (GIS) and advanced econometric techniques (Pooled Cross Sections, Spatial Econometrics, Box-Cox Transformation and Structural Change over time –2006, 2008 and 2011–). In this manner, Box-Cox is a technique that transforms a set of functions to stabilize variance and its regression produces the most accurate estimates of marginal attribute price (Cropper et al., 1988).

Structural Change Analysis, was used, because in Bogotá phase I of the BRT infrastructure (Transmilenio) was completed in 2000 and its expansion began in 2002 (phase II and phase III –partially– were finalized in 2008 at Bogotá) while for Barranquilla its phase I (Transmetro) was finished in 2010 (World Bank, 2004).

The main avenue for this analysis will be through determining the impact of the construction of the bus rapid transit (BRT) infrastructure on the market price (per square meter or asking price –willing to accept, WTA–) of nearby residential and commercial properties in Bogota and Barranquilla (Colombia).This paper organizes itself around several sections: Section 2 covers a literature review while Section 3 defines the interaction of analytical methodology (Pooling Cross Sections across Time, Hedonic Pricing Models, Box-Cox Transformation, Spatial Econometrics and Structural Change). Section 4 holds research microdata and empirical evidence, with a final conclusion taking place in Section 5.

2. Literature Review

Previous studies conducted by many scholars of various disciplines (economics, geography, urban planning and design, business, finance and statistics) have shown favorable changes of values of the properties near urban mass transit infrastructure (e.g., Rodriguez and Vergel, 2013; Perdomo, 2011 and 2010; Rodriguez and Mojica, 2008; Perdomo et al., 2007; Rodriguez and Targa, 2004; McMillen and McDonald, 2000 and 2002), being profitable to their landowners. This has led to lively academic discussion, within which it is worth highlighting several aspects.

Krause and Bitter (2012) reviewed the association between spatial econometrics, land values, and sustainability, listing a series of articles. They focused their study on the expansion of spatial econometrics, the recognition of the differences between land values and improvement values, and acknowledgment of value premiums stemming from more sustainable forms of development.

Krause and Bitter extensively reviewed literature on spatial methods in valuation (spatial dependence and spatial heterogeneity), emergence of land values as a research interest (land values indices, real estate value decomposition, price volatility, and values leverage) and sustainability and property values (green building premiums and the value of compact development). They concluded that implementing and interpreting these topics is complex.

In spite of this, the empirical review to estimate changes in property values located close to IMTS infrastructure in a city, using quantitative techniques (HPM, SHP, PSM, *DD*, OLS, GIS and statistical comparisons –only with cross sections database–), is extensive (see Geng et al., 2015; Seya et al., 2013; Yokoi and Asao, 2012; Liu and Zheng, 2012; Perdomo 2011 and 2010; Mendieta and Perdomo, 2007; Perdomo et al., 2007 and Rodriguez and Mojica, 2008; Rodriguez and Targa, 2004; McMillen and McDonald, 2002).

In addition, Kiel and McClain (1995) and Gibbons and Machin (2005) were the pioneers using HPM, pooling cross sections across time and *DD* to calculate declines (or favorable changes) in residential property values near an incinerator or located close to the IMTS system, respectively. Particularly, Gibbons and Machin, textually argued that this "*…less common approach uses cross section time series data to implement a quasiexperimental or difference-in-difference methodology to look at before-and after outcomes in areas affected and unaffected by a transport infrastructure change*" (Gibbons and Machin, 2005, 150).

Although, the article of Gibbons and Machin is the only previous study accommodating the interaction between pooling cross sections across time and *DD* to calculate the goal impact in this study, there are no previous researches in which simultaneously using GIS and advanced econometric methods to obtain the unbiased effects in this paper.

Therefore, and unlike the literature review in this paper, interaction among several quantitative methods (GIS and advanced econometric) were used to improve the estimation of the unbiased effects of the BRT infrastructure (Transmilenio and Transmetro) on the value of nearby residential and commercial properties in Bogota and Barranquilla. The following section therefore contains the conceptual framework of this paper's analytical methodology.

3. Interaction of the Analytical Methodology

In accordance with the main purpose of this study and microdata available on property values (price per square meter), their physical characteristics (total number of bedrooms, bathrooms, garage, living rooms, living-dining rooms, kitchens, age, numbers of floors and architectural finish), location in relation to private and public equipment (minimum distance between the observed property and the closest BRT station or its terminal, banks, university, supermarkets, police station and fire station) and presence of externalities (proximity to farmers' markets, flood-prone areas, air pollution and crime rates).

Furthermore is relevant to note that recent studies (Perdomo et al., 2016) about economic segregation have used hedonic price model to define implicit prices of the public goods amount (police, fire station, parks and so on). Also in developing country (even Colombia, Bogota and Barranquilla) is very important the police station and fire station, due to the lack the public investment, poor and insecurity, that is different to industrialized country, it is the reason that these control variables are not typically seen in hedonic price models. In addition, these variables are important because they are similar to the effect of the BRT Infrastructure on property price, when public investment has been to provide public goods (police, fire station, parks and so on).

So, this work implemented the interaction of the following methods: pooling cross sections across time (under structural change over time –2006, 2008 and 2011–), hedonic price model (based on Rosen, 1974), Box-Cox transformation and spatial econometrics (by implementation of GIS –using the XY coordinates of the properties–, based on Haab and McConnell, 2002) defined as

$$P_{it}^{\theta} = \delta_0 D_{City-06-08} + \delta_1 D_{2008} + \rho \mathbf{W} P_{it}^{\theta} - \beta_1 x_{1,it}^{\lambda} - \alpha_1 \mathbf{W} x_{1,it}^{\lambda} + \gamma_1 D_{City-06-08} x_{1,it} + \cdots + \beta_k x_{k,it}^{\lambda} + \cdots + \alpha_k \mathbf{W} x_{k,it}^{\lambda} + U_{it} \qquad (1)$$

Where P_{it} is the dependent variable or the price per square meter (price/m^2, WTA) of a property (*i* indicates the indexes individual, *i=property 1, property 2, property n*; *n* is a random sample size –*n*=1,125 and *n*=305, residential or commercial, respectively, see Section 4–) observed in the time period (indices time, *t= 2006, 2008 and 2011*).

$\beta_1,\ldots, \beta_k$, $\alpha_1,\ldots, \alpha_k$, δ_0 and δ_1 are the parameters; $x_{1,it},\ldots, x_{k,it}$ are control variables (explanatory variables) or the property's physical characteristics, its location (Euclidean minimum distances calculated with GIS coordinates; Chiang, 1984) and presence of externalities, observed in *t*. $x_{1,it}$ is the effect variable as the minimum distance between the observed property and the closest Transmilenio or Transmetro station or terminal (Fig. 1 and Fig. 2). So, $x_{1,it}$ is considered more relevant in Eq. (1) to this paper.

θ and λ are the transformation coefficients of the Box Cox form ($P_{it}^{\theta} = \frac{P_{it}^{\theta}-1}{\theta}$, $\mathbf{W}P_{it}^{\theta} = \frac{\mathbf{W}P_{it}^{\theta}-1}{\theta}$, $x_{1,it}^{\lambda} = \frac{x_{1,it}^{\lambda}-1}{\lambda}, \ldots, x_{k,it}^{\lambda} = \frac{x_{k,it}^{\lambda}-1}{\lambda}$, $\mathbf{W}x_{k,it}^{\lambda} = \frac{\mathbf{W}x_{k,it}^{\lambda}-1}{\lambda}$), the Theta ($\theta$) and Lambda ($\lambda$) values are between -5 and +5, $-5 \leq \theta \leq 5$ and $-5 \leq \lambda \leq 5$. Thus, according to their results, the functional forms can be estimated by OLS (linear to $\theta = \lambda = 1$; double logarithmic to $\theta = \lambda = 0$; semi-log to $\theta = 1$ =1 and $\lambda = 0$ =0; log-linear to $\theta = 0$ =0 and $\lambda = 1$; double reciprocal to $\theta = -1$ and $\lambda = -1$) to avoid incorrect functional form as they were, possibly, estimated in the research of the literature review section (Hill, 2013).

This is because, generally, their functional forms have been double logarithmic, without and real test. However, the values of θ and λ can be unknown parameters, so the regression in Eq. (1) is nonlinear in variables and parameters or Box-Cox form; therefore θ and λ are estimated by means of maximum likelihood method (see details, about Box-Cox form, in Rosales et al., 2013, 171; Perdomo and Hueth, 2011; Mendieta and Perdomo, 2008, 184-191 Greene, 2002, 173 and 174, for a review).

W is an inverse distance spatial weight matrix based on a 500 meter cut-off –Euclidean minimum distances– (LeSage and Pace, 2010). It is an *nxn* positive symmetric matrix and contains information on the neighborhood structure for each location of the Bogota and Barranquilla properties. ρ denotes the spatial autoregressive coefficient, $\mathbf{W}P_{it}^{\theta}$ represents the endogenous interactions effects among dependent variables. $\mathbf{W}x_{k,it}^{\lambda} = \frac{\mathbf{W}x_{k,it}^{\lambda}-1}{\lambda}$ signifies the exogenous interaction effects among the independent variables and U_{it} indicates the error term (identically and independently distributed, *iid*) with mean zero and unknown variance –$U_{it} \sim N(0, \sigma_{U_{it}}^2)$– (see details in Anselin, 1988; Anselin et al., 1998; Perdomo, 2011 and 2010; Elhorst, 2010; Seya et al., 2013; Pace et al., 1998, for a review).

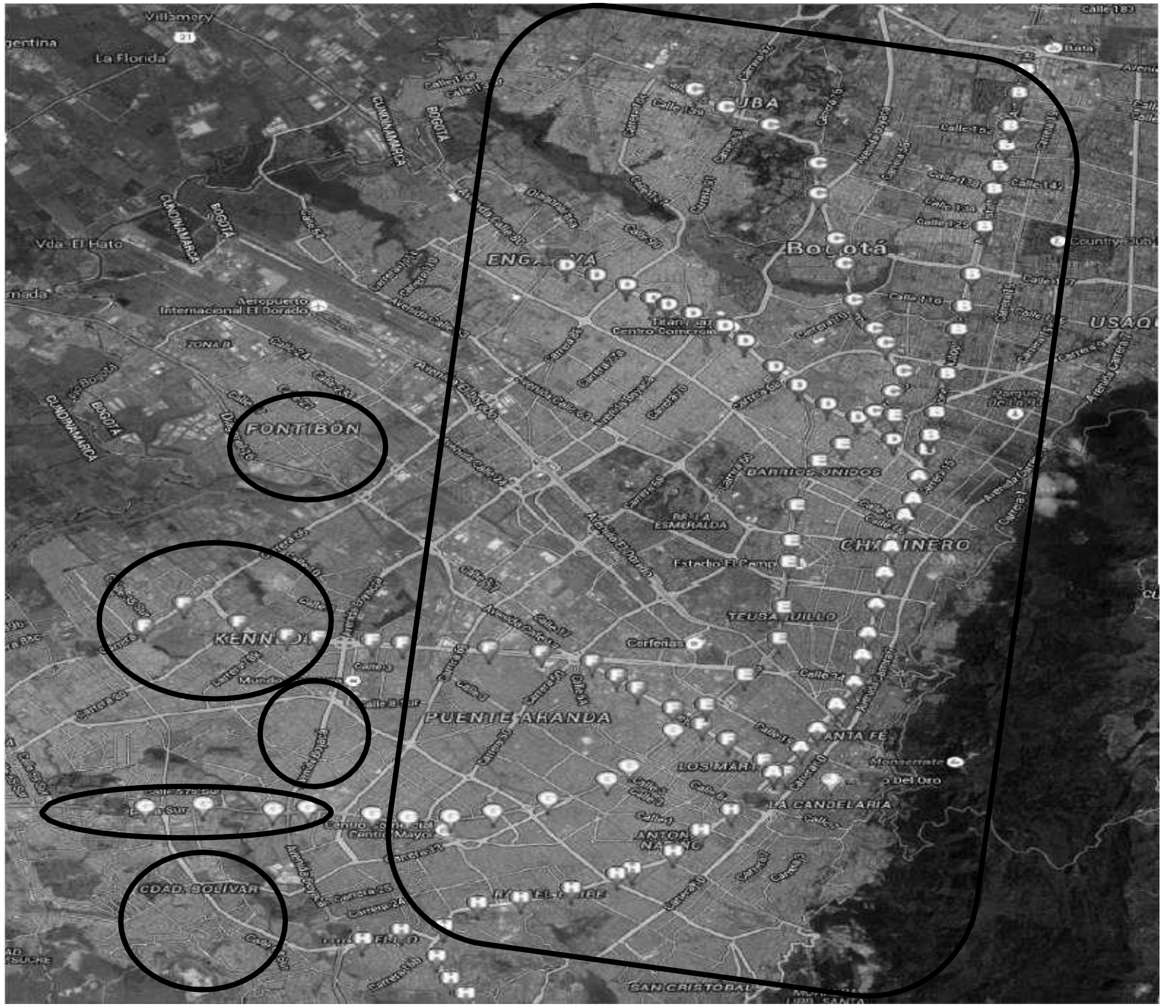
Dummy variables $D_{City-06-08}$ and D_{2008} consider the structural changes over time, capturing the differences in the dynamics of the property market in Bogota and Barranquilla during phases I and II of Transmilenio and phase I of Transmetro, respectively (World Bank, 2004; Hidalgo and Gutierrez, 2013; Hidalgo and Huizenga, 2013). Therefore, $D_{City-06-08}$ and D_{2008} distinguish differences in the intercept terms, the slope coefficients, or both.

Gamma (γ_1) and delta (δ_1) are the differentials slope[1] (β_1) values or the unbiased effect of the BRT (Transmilenio and Transmetro) infrastructure on properties in Bogota and Barranquilla (Colombia) in 2006, 2008 and 2011 (see details, about pooling cross sections across time –under structural change over time–, in Rosales et al., 2013, Ch. 7; Perdomo and Ramirez, 2011; Bernal and Peña, 2011; Cameron and Trivedi, 2009; Wooldridge, 2006 and 2007, Ch. 13, for a review).

4. Research Microdata and Empirical Evidence

Microdata used in the empirical evidence, by means of the interaction of the methods described above, was based on GIS (geographical coordinates). Moreover, three surveys during the years of 2006, 2008 (Bogota) and 2012 (Barranquilla) compiled the microdata. Fig. 1 and Fig. 2 exhibit circles that show the extent of the simple random samples at several zones for Bogota and Barranquilla.

[1] $\frac{\partial P}{\partial x_{1,it}} = \frac{-\beta_1 x_1^{\lambda-1} + \gamma_1 D_{Bogota-06-08}}{P^{\theta-1}}$, from the definition in Eq. (1).



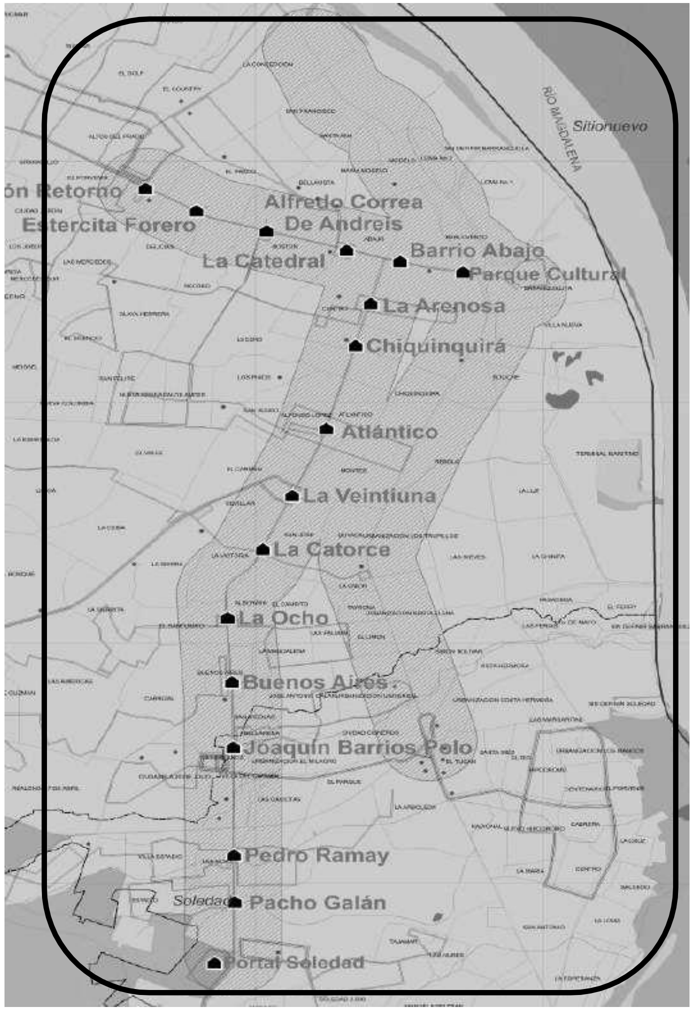


Fig. 1. The geographical extent of the simple random sample for Bogota zones (2006 and 2008). Fig. 2. The geographical extent of the simple random sample for Barranquilla zones (2012).
Source: http://www.colombiamania.com/transmilenio/ and National Department of Planning (NDP, 2012), respectively.

The two Figures also indicate the dimension of the BRT infrastructure, the estates of which are in the samples according to affected and unaffected areas (less or more than 500 meters away, respectively; CONPES 3185, 2002, 9). So, in Figs. 1 and 2, the whites and blacks points, respectively, are the paths of the BRT infrastructure (trunks, stations and terminals). In this manner, 1,125 landowners of the residential properties and 305 landowners of the commercial properties provided information (price market or asking price –willing to accept, WTA–, physical characteristics, location in relation to private and public equipment and presence of externalities).

This data set in Bogota was used by Perdomo et al. (2007) in the vicinity of the Transmilenio Portal in Suba and intersection of Boyaca Avenue and 1 de Mayo Avenue[2]. During 2008, zones were located in Usaquén, Chapinero, Santafé, San Cristóbal, Usme, Tunjuelito, Bosa, Kennedy, Fontibón, Engativá, Barrios Unidos, Teusaquillo, Mártires, Antonio Nariño, Puente Aranda, La Candelaria, Rafael Uribe, Ciudad Bolívar and Suba[3] (Fig. 1).

While data set in Barranquilla, during 2011, was compiled in the study areas of the zones adjacent to the Via 40 Avenue (area unaffected by Transmetro system), Murillo Avenue and Olaya Herrera Avenue (zones with access to Transmetro system). These trunks were opened in April 2010 (Fig. 2). Additionally, the data on air pollution and crime rates come from Environmental Entities (IDEAM) and National Policy, respectively, for Bogota and Barranquilla zones (average per zone) in Figs. 1 and 2, during 2006, 2008 and 2011. Table 1 and Table 2 detail their descriptive statistics (mean, standard deviation, random sample size, minimum and maximum values).

[2] The Lincoln Institute of Land Policy (LILP) provided project funding and published its findings in 2007.

[3] Project funding by the IDU (Instituto de Desarrollo Urbano, is the government entity responsible for public infrastructure development and maintenance in Bogota).

Table

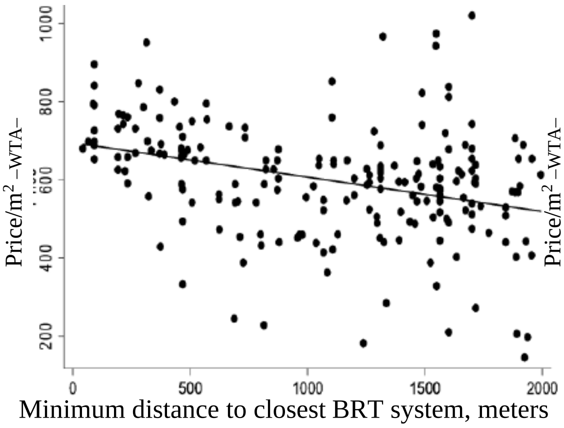
Descriptive statistics of the microdata set for residential properties

Variable	Year	BRT-IMTS	City	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2006	Transmilenio	Bogota	206	600.38	147.76	144.53	1,019.18
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2006	Transmilenio	Bogota	206	1,070.80	568.87	43.53	1,995.26
Total number of bedrooms	2006	Transmilenio	Bogota	206	3.04	1.22	1	15
Total number of bathrooms	2006	Transmilenio	Bogota	206	1.86	0.74	1	7
Total number of garages	2006	Transmilenio	Bogota	206	0.76	0.58	0	3
Total number of living-dining rooms	2006	Transmilenio	Bogota	206	1	0	1	1
Total number of living rooms	2006	Transmilenio	Bogota	206	1	0	1	1
Air Pollution-particulate matter (PM10)	2006	Transmilenio	Bogota	206	81.11	6.87	69	85
Age (constructed years)	2006	Transmilenio	Bogota	206	9.15	8.8	0	45
Land area (square meters, m^2)	2006	Transmilenio	Bogota	206	78.39	71.6	35	800
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2008	Transmilenio	Bogota	488	584.53	593.27	41.63	4,735.70
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2008	Transmilenio	Bogota	488	1,144.17	825.71	57.17	3,753.16
Total number of bedrooms	2008	Transmilenio	Bogota	488	4.3	2.75	0	23
Total number of bathrooms	2008	Transmilenio	Bogota	488	2.21	1.64	0	25
Total number of garages	2008	Transmilenio	Bogota	488	0.37	0.5	0	2
Total number of living-dining rooms	2008	Transmilenio	Bogota	488	0.9	0.92	0	6
Total number of living rooms	2008	Transmilenio	Bogota	488	0.36	0.67	0	5
Air Pollution-particulate matter (PM10)	2008	Transmilenio	Bogota	488	77.21	6.79	75	98
Age (constructed years)	2008	Transmilenio	Bogota	488	22.09	12.04	1	114
Land area (square meters, m^2)	2008	Transmilenio	Bogota	488	114	84.33	13	743
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2011	Transmetro	Barranquilla	431	222.26	93.28	52.73	478.96
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2011	Transmetro	Barranquilla	431	1,274.30	900.13	100.44	3,599.51
Total number of bedrooms	2011	Transmetro	Barranquilla	431	3.06	0.85	1	6
Total number of bathrooms	2011	Transmetro	Barranquilla	431	1.31	0.53	1	4
Total number of garages	2011	Transmetro	Barranquilla	431	0.11	0.31	0	1
Total number of living-dining rooms	2011	Transmetro	Barranquilla	431	0.81	0.43	0	3
Total number of living rooms	2011	Transmetro	Barranquilla	431	1.02	0.21	0	4
Air Pollution-particulate matter (PM10)	2011	Transmetro	Barranquilla	431	17.56	2.69	14.6	20
Age (constructed years)	2011	Transmetro	Barranquilla	431	35.45	12.51	10	90
Land area (square meters, m^2)	2011	Transmetro	Barranquilla	431	89.66	20.66	10	450
Total number of observations (*n*)	1,125							

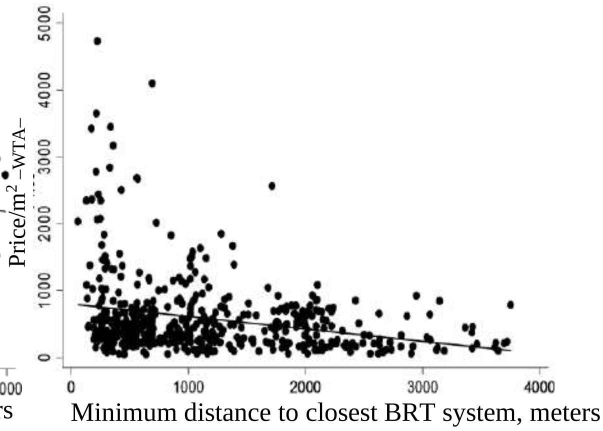
Table
Descriptive statistics of the microdata set for commercial properties

Variable	Year	BRT-IMTS	City	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2006	Transmilenio	Bogota	33	1,362.78	1,443.90	52,66	7,037.00
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2006	Transmilenio	Bogota	33	304.45	188.31	323.95	615.32
Total number of bathrooms	2006	Transmilenio	Bogota	33	1.84	2.08	0	9
Total number of garages	2006	Transmilenio	Bogota	33	18.51	2.9	13	20
Age (constructed years)	2006	Transmilenio	Bogota	33	15.24	13.27	0	42
Crime rates-total number of robberies	2006	Transmilenio	Bogota	33	269.3	17.02	237	278
Air Pollution-particulate matter (PM10)	2006	Transmilenio	Bogota	33	81.6	6.64	69	85
Land area (square meters, m^2)	2006	Transmilenio	Bogota	33	156	240.53	9	1300
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2008	Transmilenio	Bogota	261	2,158.39	3,185.82	51.34	21,351.12
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2008	Transmilenio	Bogota	261	285.84	272.07	0	2,019.03
Total number of bathrooms	2008	Transmilenio	Bogota	261	2.43	6.69	0	81
Total number of garages	2008	Transmilenio	Bogota	261	8.87	8.16	0	27
Age (constructed years)	2008	Transmilenio	Bogota	261	16.06	5.94	1	57
Crime rates-total number of robberies	2008	Transmilenio	Bogota	261	114.26	90.46	1	282
Air Pollution-particulate matter (PM10)	2008	Transmilenio	Bogota	261	75.52	3.45	75	98
Land area (square meters, m^2)	2008	Transmilenio	Bogota	261	138	218.2	2.3	1752
Price per square meter, WTA, - in constant (2011) prices, US Dollars	2011	Transmetro	Barranquilla	11	261.75	166.08	53.26	615.18
Minimum distance between the observed property and the closest IMTS station or its terminal, meters	2011	Transmetro	Barranquilla	11	937.10	513.63	247.33	1,720.56
Total number of bathrooms	2011	Transmetro	Barranquilla	11	1.09	0.54	0	2
Total number of garages	2011	Transmetro	Barranquilla	11	1.81	2.18	0	6
Age (constructed years)	2011	Transmetro	Barranquilla	11	32.85	7.9	18	42
Crime rates-total number of robberies	2011	Transmetro	Barranquilla	11	154	303.12	0	1042
Air Pollution-particulate matter (PM10)	2011	Transmetro	Barranquilla	11	19.02	2.19	14.6	20
Land area (square meters, m^2)	2011	Transmetro	Barranquilla	11	102	8.04	84	120
Number of observations (n)	305							

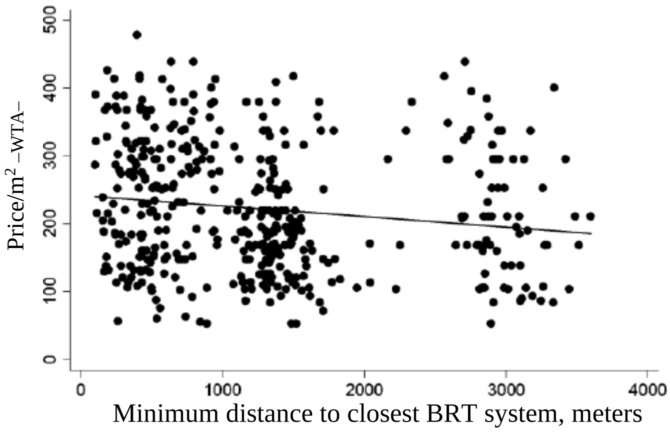
Results in Table 1 and 2 show a wide variation in the main variables due to dissimilar sizes of random samples over time (2006, 2008 and 2011). Variation also happens because of the differences in the dynamics of the property market between Bogota and Barranquilla. In the interaction model –Eq. (1)– dummy variables ($D_{City-06-08}$ and D_{2008}) therefore consider the structural changes (intercepts and slopes coefficients) to capture these differences of the property market.



Bogota (2006)

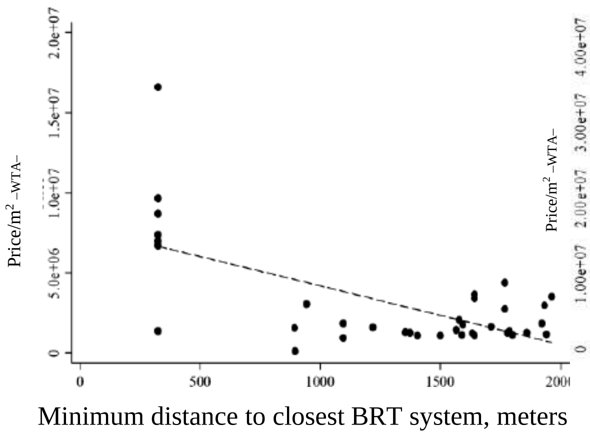


Bogota (2008)

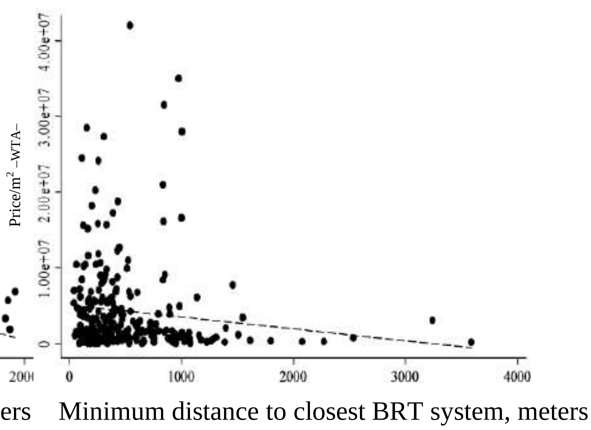


Barranquilla (2011).

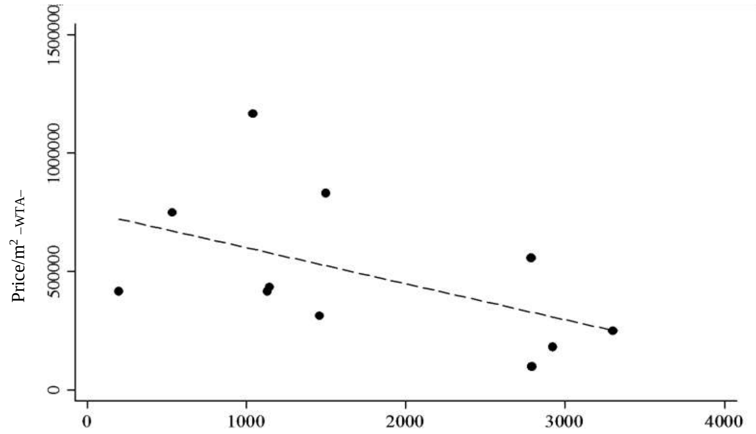
Fig. 3. Correlation analysis of residential property microdata set in Bogotá and Barranquilla.



Bogota (2006)



Bogota (2008)



Barranquilla (2011).

Fig. 4. Correlation analysis of commercial property microdata set in Bogotá and Barranquilla.

The trends lines (Fig. 3 and Fig. 4) clearly indicate an inverse relationship (linear association) between price per-square meter (price/m^2, WTA, in constant –2011– price, Y-axis), the minimum distance of a property (residential or commercial), and the closest BRT station or terminal (X-axis) in Bogota and Barranquilla over three years (2006, 2008 and 2011).

Similarly, as shown in Table 3, the difference in mean price/m^2 (WTA) among treatment and control properties (less and more than 500 meters of the BRT system, respectively) is statistically distinguishable. So, according to the data in Table 1, Figs. 3-4 and Table 3, preliminary results were not theoretically expected. In this way, the information represented by the main variables is reliable for estimating the interaction model in Eq. (1), whereby the estimations tend to improve the impact of the BRT system on the price/m^2 in Bogota and Barranquilla (Colombia).

Table 4 presents the regression estimates[4] of the interaction model in Eq. (1), the results of which use 25 explanatory variables pertaining to residential properties. This study used such variables as controls to describe the physical characteristics of each property, its location and presence of externalities to reduce biased estimators by the omitted variables problem (Hill, 2013; Rosales et al., 2013).

[4] Geoda (spatial econometrics) obtained the spatial weight matrix (**W**), defined as the threshold distance (500 meters, Euclidean Distance) between each residential property and its location in relation to private and public equipment. Stata 11 estimated the Box–Cox form in Eq. (1), using maximum likelihood method and robust SEs process to obtain efficient estimators.

Table 3
Two samples mean comparison tests to compare the average price per square meter

Two group mean comparison test	Variable	Sample	Treatment Group Mean (properties have access to the IMTS)	Control Group Mean (properties without access to the IMTS)	Difference (price/m^2)
Residential properties microdata set in Bogota (2006), sample size is 206 observations, 156 for control group and 80 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$694	US$570	US$124***
Residential properties microdata set in Bogota (2008), sample size is 488 observations, 364 for control group and 124 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$838	US$498	US$340***
Residential properties microdata set in Barranquilla (2012), sample size is 431 observations, 329 for control group and 102 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$250	US$214	US$36***
Commercial properties microdata set in Bogota (2006), sample size is 33 observations, 6 for control group and 27 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$1560	US$471	US$1,089**
Commercial properties microdata set in Bogota (2008), sample size is 261 observations, 43 for control group and 218 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$2,399	US$937	US$1462***
Commercial properties microdata set in Barranquilla (2011), sample size is 11 observations, 9 for control group and 2 for treatment group.	Price per square meter – in constant (2011) prices, US Dollars -WTA-	Non-Matched	US$192	US$277	US - $85

Note: *** and *Significant at 0.01 and 0.1 levels, respectively.

Table 4
Spatial hedonic price model (Box-Cox Transformation) of residential properties microdata set (2006, 2008 and 2011)

Explanatory variables	Dependent variable (price per square meter, constant -2011- prices, US Dollars, –WTA–) of residential properties at Bogota and Barranquilla		
	Coefficient	Marginal Effect (US$)	Elasticity
Intercept	7.56	-	-
W*(price per square meter –WTA–)	0.000001***	-	-
Minimum distance between the observed property and the closest IMTS station or its terminal (IMTSD)	-0.40***	-0.04	-0.10
Minimum distance between the observed property and the closest university (UNID)	-0.31***	-	-
Minimum distance between the observed property and the closest supermarket (SMARKD)	0.17***	-	-
Minimum distance between the observed property and the closest bank (BANKD)	-0.029		

W*(UNID)	0.000070*		
W*(BANKD)	-0.00042***		
Air Pollution-particulate matter (PM10)	-0.09		
Total number of bathrooms (nbatr)	0.01		
Total number of bedrooms (bebr)	0.18***		
Total number of living rooms (nliv)	0.07		
Total number of living-dining rooms (nlivd)	0.04		
Total number of garages (ngar)	0.06		
Age (constructed years)	-0.004**		
Total number of floors (nfloors)	-0.015		
Apartment (dummy variable, yes=1 and no=0)	0.24***	-	-
2008 (dummy variable, yes=1 and no=0, D_{2008})	0.86***	-	-
City over the years 2006 and 2008 (dummy variable, Bogota=1 and Barranquilla=0, $D_{City-06-08}$)	-	-	-
$D_{City-06-08}$*IMTSD	0.000092*	0.001	0.004
$D_{City-06-08}$*bebr	-0.25***	-	-
$D_{City-06-08}$*nfloors	0.11*	-	-
$D_{City-06-08}$* BANKD	-0.0002	-	-
Near to Farmers' Markets (dummy variable, yes=1 and no=0)	-0.12**		
Near to Flood Places (dummy variable, yes=1 and no=0)	-0.30**		
Architectural finish (dummy variable, yes=1 and no=0)	0.17**		
Lambda (λ)	-0.18	-	-
Theta (ϴ)	0.015	-	-
Number of observations (n)		1,125	

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.

Table 5
Spatial hedonic price model (Box-Cox Transformation) of commercial properties microdata set (2006, 2008 and 2011)

Explanatory variables	**Dependent variable (price per square meter, constant -2011- prices, US Dollars, –WTA–) of commercial properties at Bogota and Barranquilla**		
	Coefficient	**Marginal Effect (US$)**	**Elasticity**
Intercept	11.57	-	-
W*(price per square meter –WTA–)	0.027**	-	-
Minimum distance between the observed property and the closest IMTS station or its terminal (IMTSD)	-0.160***	-0.39	-0.13
Minimum distance between the observed property and the closest university (UNID)	-0.082	-	-
Minimum distance between the observed property and the closest fire station (FIRED)	-0.150**	-	-
Minimum distance between the observed property and the closest bank (BANKD)	-0.052		
Minimum distance between the observed property and the closest police station (POLD)	0.004		
Air Pollution-particulate matter (PM10)	-0.86		

Total number of bathrooms (nbatr)	0.02		
Total number of garages (ngar)	0.03*		
Age (constructed years)	-0.03**		
2008 (dummy variable, yes=1 and no=0, D_{2008})	1.59	-	-
City over the years 2006 and 2008 (dummy variable, Bogota=1 and Barranquilla=0, $D_{City-06-08}$)	-	-	-
$D_{City-06-08}$*IMTSD	0.0005	-	-
$D_{City-06-08}$*BANKD	0.0013	-	-
Near to Farmers' Markets (dummy variable, yes=1 and no=0)	-0.80***		
Near to Flood Places (dummy variable, yes=1 and no=0)	-0.34**		
Architectural finish (dummy variable, yes=1 and no=0, af)	6.18***		
$D_{City-06-08}$*af	0.06		
$D_{City-06-08}$*PM10	-5.58*		
Near to mall (dummy variable, yes=1 and no=0)	0.93***		
Near to park (dummy variable, yes=1 and no=0)	0.30		
Near to Inter-Municipal Bus Station (dummy variable, yes=1 and no=0)	-1.99*		
Crime rates-total number of robberies	-0.0001		
Lambda (λ)	0.20	-	-
Theta (Θ)	0.05	-	-
Number of observations (n)		305	

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.

Although 11 explanatory variables were not statistically significant to explain price/m^2 behavior in Table 4, they maintained the expected sign with respect to the relationship between them. However, the estimator of the main exogenous variable (IMTSD) was statistically significant and presented the expected negative sign. This accurately demonstrates the impact of the BRT system on market price (price/m^2, WTA) of residential properties in Bogota and Barranquilla.

The inverse relationship between IMTSD and price/m^2 imply that the price/m^2 therefore decreases according to increasing distance from the BRT system. Specifically, if the IMTSD goes up by 1% (or by 1 meter), on average, the price/m^2 of the housing goes down by about 0.10% (or by about US$0.04) in Bogota and Barranquilla. Indeed, the higher valuation per square meter associated with easy access to the BRT system in Bogota corresponds to approximately US$20.5 [(US$0.04+

US$0.001)*501[5]=US$20.54; US$20.54-US$0.041=US$20.5], while for Barranquilla it is approximately US$20 (US$0.04*501=US$20.04; US$20.04-US$0.04=US$20).

Thus, each household located in Bogota receives an average benefit of US$1,965 [US$20.5*96[6]] whereas those in Barranquilla receive approximately US$1,800 [US$20*90[7]]. On the other hand, Table 5 presents the regression estimates[8] of the interaction model in Eq. (1), which uses 21 explanatory and control variables to reduce biased estimators by the omitted variables problem. These results represent commercial properties.

Likewise, 11 explanatory variables were not statistically significant enough for explaining price/m^2 behavior in Table 5. Even so, they maintained the expected sign in the relationship between them. However, the estimator of the main exogenous variable (IMTSD) was statistically significant, presenting the expected negative sign. Particularly, this result accurately demonstrates the impact of the BRT system on the market price (price/m^2) of residential properties in Bogota and Barranquilla.

Thus, the inverse relationship between IMTSD and price/m^2 imply that the further away the commercial property is from the BRT system, the more its price/m^2 decreases. In other words, if the IMTSD goes up by 1% (or by 1 meter), the price/m^2 of the commercial property will lower by around 0.19% (or by about US$0.39).

The higher valuation per square meter associated with easy access to the BRT system in Bogota and Barranquilla corresponds to approximately US$195 [US$0.39*501[9]=US$195.39; US$195.39-US$0.39=US$195] per square meter. Thus, each commercial property benefits on average by about US$25,740 [US$195*132[10]]. Therefore, the BRT system has significantly impacted price/m^2 of residential and

[5] It is for a residential property to 501 meters away of the BRT system, using a simulation between two housing (to less and more than 500 meters of the BRT system, respectively).
[6] It is the average of the land area (m^2) in Table 1 for the residential properties in Bogota over years 2006 and 2008 ($\frac{78.39+114}{2}$).
[7] It is the average of the land area (m^2) in Table 1 for the residential properties in Barranquilla in 2011.
[8]Geoda (spatial econometrics) obtained the spatial weight matrix (**W**), defined as the threshold distance (500 meters, Euclidean Distance) between each commercial property and its location to private and public equipment. Stata 11 was a means for estimating the Box–Cox form in Eq. (1), using the maximum likelihood method and robust SEs process to obtain efficient estimators.
[9] It is for a commercial property to 501 meters away from the BRT system, using a simulation between two properties (to less and more than 500 meters of the BRT system, respectively).
[10] It is the average of the land area (m^2) in Table 1 for the commercial properties in Bogota and Barranquilla over years 2006, 2008 and 2011 ($\frac{156+138+102}{3}$).

commercial properties in Colombia. Commercial properties have seen greater impact than residential areas as business owners tend to set up close to BRT stations or terminals.

5. CONCLUSION

Even though several articles have theoretically and empirically verified favorable changes in value (per square meter, WTA) of properties near urban mass transit infrastructure, the main purpose of this study was to also demonstrate this effect. However, this study distinguishes itself by using the interaction of advanced quantitative techniques (pooling cross sections across time, structural change over time –2006, 2008 and 2011–, hedonic price model, Box-Cox transformation and spatial econometrics –by implementation of GIS–) to unbiasedly estimate impact of the BRT system on market price (price/m^2, WTA) of residential and commercial properties in Bogota and Barranquilla.

Toward achieving this goal, was collected a random sample size of 1,125 residential and 305 commercial properties. In this way was established microdata based on property values (price/m^2), their physical characteristics, location in relation to private and public equipment (minimum distance between the observed property and the closest BRT station or its terminal, banks, university, supermarkets, police station and fire station), and presence of externalities in Bogota and Barranquilla. Data pertained to the years 2006, 2008 and 2011.

The results of the regression estimates show the accuracy of favorable impact accorded by the BRT system on the market price (price/m^2) of residential properties in Bogota and Barranquilla in 2006, 2008 and 2011. Its marginal effect (-0.04) infers that each household located in Bogota receives an average benefit of US$1,965 and US$1,800 in Barranquilla. Similarly, each commercial property receives an average benefit of US$25,740. So, the BRT system has had an important impact on residential and commercial property prices/m^2.

Previous studies recognized favorable change of the market price (per square meter) of residential and commercial properties because of the BRT system; however, possibly, the studies overestimated the positive benefit of transit infrastructure on the market prices. There are possible biases in the existing results according to inconsistencies of the methods applied (OLS) or as a consequence of model specification errors.

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Optimal extraction policy when the environmental and social costs of the opencast coal mining activity are internalized: Mining District of the Department of El Cesar (Colombia) case study

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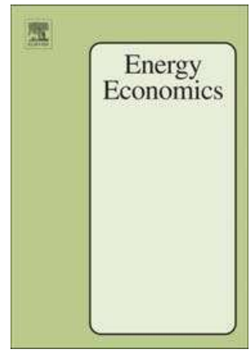
ABSTRACT

Several articles have confirmed the social and environmental consequences of opencast coal mining. The main purpose of this study is to simulate the optimal extraction policy of coal mining with and without the internalization of the environmental and social monetary costs that occur in the Mining District (located in the central part of the Department of El Cesar) using discrete dynamic programming (backward recursion, discrete state Markov decision model and Bellman equation). Results indicate that the private optimal of the overproduction policy for the terminal phase of the resource extraction program can be reduced once the negative externalities produced by mining practices are internalized into the cost function of the mining investment companies in Colombia. This means that if there is an increase in the total cost of extraction to offset the environmental and social impacts generated, the negative externalities would be less than or equal to the current level. Likewise, profits would continue being positive for the mining firms at the Mining District.



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Optimal Extraction Policy when the Environmental and Social Costs of the Opencast Coal Mining Activity are Internalized: Mining District of the Department of El Cesar (Colombia) Case Study

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ABSTRACT

Several articles have confirmed the social and environmental consequences of opencast coal mining. The main purpose of this study is to simulate the optimal extraction policy of coal mining with and without the internalization of the environmental and social monetary costs that occur in the Mining District (located in the central part of the Department of El Cesar) using discrete dynamic programming (backward recursion, discrete state Markov decision model and Bellman equation). Results indicate that the private optimal of the overproduction policy for the terminal phase of the resource extraction program can be reduced once the negative externalities produced by mining practices are internalized into the cost function of the mining investment companies in Colombia. This means that if there is an increase in the total cost of extraction to offset the environmental and social impacts generated, the negative externalities would be less than or equal to the current level. Likewise, profits would continue being positive for the mining firms at the Mining District.

Keywords: Optimal extraction policy, opencast coal mining practices, environmental and social monetary costs, dynamic simulation analysis, Markov decision model, Bellman equation.

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1. Introduction

Opencast coal mining activity began during the early 1980s in Colombia. The country's coal reserves are plentiful (roughly 1,813 million tons) and the coal rents were approximately 1.5% of Colombia's Gross Domestic Product in 2009. Thus, the coal industry is a lucrative business (it creates employment, generates values-added, and improves foreign investment) at the Mining District[1], which is located in the central part of the Department of El Cesar (Colombia). Part of its profits are transferred as royalties to this Department (Viloria, 1998; Bonet, 2007).

Despite the fact that the Department of El Cesar receives the highest royalties, its mining municipalities have high levels of poverty (unmet basic needs –UBN–) and its population has a low standard of living (lack of public health services, poor sanitation and access to clean water) (Bonet, 2007). Also, in this mining area the opencast mining practice is producing negative externalities (environmental and socials impacts[2]).

Owing to these factors, this article compares optimal extraction policy with and without the internalization of the environmental and social monetary costs that are caused by mining investment companies in Colombia[3] in the Mining District (located in the central part of the Department of El Cesar) using discrete dynamic programming (backward recursion, discrete state Markov decision model and Bellman equation). The goal is to find the socially optimal

[1] Conformed by four towns (Becerril, El Paso, Codazzi, La Jagua and Chiriguana).

[2] "*Coal transportation vehicles contribute to road accidents and road damage. These heavy vehicles are also a nuisance to the communities living along the roads because of the dust and noise they create"* (Fatah, 2008). The environmental damages of opencast coal mining activity (extraction, processing, transportation and combustion) are: greenhouse gas, noise, air and water pollution (aquifers, wetlands and rivers), soil degradation, landscape (land erosion), ecosystem (loss of forests area and biodiversity and of nonrenewable resource (coal)), public health problems, land-use conflict (agriculture, livestock and mining) (Yushi et al., 2008; Perdomo et al., 2010).

[3] Drummond Ltd. (a subsidiary of Drummond Inc.), Norcarbon, Consorcio Minero Unido, Prodeco, Carboandes, Carbones La Jagua and Compañía de Carbones del Cesar are the seven most important companies (Tewalt et al., 2006).

quantity of the stock level of coal or its optimal extraction path, which can help to define a sustainable approach over time for the opencast coal mining extraction in the Mining District. Sections organize this paper: Section 2 covers a literature review while Section 3 defines the conceptual framework and analytical methodology. Section 4 contains research data and empirical evidence, and Section 5 has the final conclusion.

2. Literature Review

Previous studies conducted by academics of various disciplines have shown the environmental externalities caused by extraction and consumption of nonrenewable resources (mostly coal and oil). Specifically, these studies confirm the social and environmental consequences of the opencast coal mining practice. This has led to a lively academic discussion, several aspects of which are worth highlighting.

Foster (1980) examined the depletion of the energy resources and the nature of pollution production at a macroeconomic level. From main milestones historical on the mathematical treatments (Ramsey, optimal control and Hotelling's) to confirm the environment problems by extraction and consumption of energy (coal and oil), the author used three basic models with the structures of the problem, which were established by a utility function or from the consumption perspective.

Foster concludes that "*the energy resources should be used more slowly to reduce environmental damage and over plan the rate of use should be increase–a counter-Hotellian result*" Foster (1980, p. 21). Similarly, from the consumption perspective of nonrenewable resources (coal), Chakravorty et al. (2006) characterized the solution of Hotelling model when there is a ceiling on the stock of emission (environmental agreements such as the Kyoto Protocol) using a utility function of energy consumption, for evidence of the transition from consumption of fossil fuels (coal) toward clean energy resources (solar energy). They show that coal is used until the stock of pollution reaches the ceiling. Their "*results provide a point of departure from the standard Hotelling notion of a switch from a cheap nonrenewable to a costly renewable resource"* Chakravorty et al. (2006, p. 2877).

Though Foster (1980) and Chakravorty et al. (2006) studied environmental problems that the consumption of coal causes, this article is different to because coal use is analyzed from the production and supply perspective (greenhouse gas, noise, air and water pollution, soil degradation, land erosion, loss of forest area and biodiversity, public health problems, land-use conflict) whereas they focus on a utility function; or from the consumption viewpoint (burned and carbon emissions related with the wear of the ozone layer).

In other words, this study is a complement to the analysis of the environment problems generated by extraction and consumption of nonrenewable resources, or the results of the first stage in the chain to provide a point of departure toward sustainable extraction outlined in the Hotelling rule (1931), Karp's article (1993) and Conrad's book (1999). Similarly, considering the books of Miranda and Fackler (2002) and Maldonado (2009), who by means of the discrete dynamic programming (enunciated by Bellman (1957)), also substantiated in the Hotelling rule, examined the optimal extraction policy of a nonrenewable resource.

As well, Karp (1993) shows the failure of the Coase Conjecture when the nonrenewable resource extraction (gold) is effected by a monopolist. This analysis is based on a model of competitive equilibria (Hotelling condition) with and without property rights by means of the process of rational expectations Markov equilibrium. As a result, this article is a complement to our paper because it provides a simulation to prove the failure of the Coase Conjecture, which is similar to the simulation to demonstrate optimal extraction policy with and without the internalization of their environmental and social monetary costs that occur through using opencast coal mining practice.

In addition, there are several studies on crude oil extraction analysis and optimal depletion of a nonrenewable resource (see Dasgupta, and Heal, 1974; Pindyck, 1978 and 1980; Chapman 1987; Hashem, 1989; Farzin, 1992; Karp, 1993; Chappell and Dury, 1994; Kunce, 2003; Hung et al., 2006; Gao et al., 2008; Lin, 2009; Leighty and Lin, 2009; Belgodere, 2009). Furthermore, the optimal resource extraction framework was stated by Hotelling (1931), Conrad (1999), Miranda and Fackler (2002) and Maldonado (2009).

On the other hand, the environmental and social impacts (externalities and costs) of opencast coal mining practices have been examined by Yushi et al. (2008) and Fatah (2008). There are several studies on this topic based in the Columbian Mining District (see Viloria, 1998; Sanchez et al., 2005; Gamarra, 2005; Bonet, 2007; the Mining Energetic Planning Unit, 2007; Governor of Cesar's Office, 2008; Perdomo et al., 2010).

In spite of this, there are no previous studies in which optimal extraction of the opencast coal mining activity has been estimated once it has been internalized, the costs of the negative externalities generated, and its policy implications used to define a sustainable approach over time. Nonetheless, the most closely related article to our topic is by Perdomo et al (2010). The methodologies of the aforementioned study are supported by means of descriptive statistics, mathematical treatment (Ramsey, optimal control and Hotelling rule) and conventional econometric techniques to determine results. Nevertheless, and unlike the literature review, in this paper discrete dynamic programming is used (backward recursion, discrete state Markov decision model and Bellman equation approaches) to perform the simulation of the optimal extraction policy (prompted by the Hotelling rule, 1931) from a total cost function, which was estimated through a panel data model.

However, the discrete dynamic programming process is established according to the Principle of Optimality (Hotelling, 1931; Karp, 1993) (enunciated by Bellman (1957)) as follows: "*An optimal policy has the property that, whatever the initial state and decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision*" Miranda and Fackler (2002, p. 162) or Maldonado (2009, p. 40). The following section contains the conceptual framework of this paper's analytical methodology.

3. The Economics of Nonrenewable Resources Framework and Analytical Methodology

In accordance with the main purpose of this study and the data available, this work implements the theoretical framework and methodology from the textbooks of Conrad (1999, p. 77-96 and p. 166-182), Miranda and Fackler (2002, p. 161-191) and Maldonado (2009, p. 90-106 and p. 151-172), which include the Hotelling rule and dynamic programming, respectively. According to the economics of nonrenewable resources theory, each mining investment company is a firm that maximizes (*max*) the value of its equity and has a mining lease during a fixed-period (T)[4]. So, the firms extract coal to sell in the international spot market (competitive), where its price is exogenous, therefore they are price takers (Cherian et al., 1998).

[4] Let T denote the lease expiration date, T=60, the lease expiration is 60 years, into the mining district.

For that reason, multinational corporations choose the extraction policy to maximize the present value of their profits (π) from coal production over the life of the lease. Perfect information should be available, because the initial coal reserves (cr_{it})[5], extraction rate (cp_{it}), total cost (tc_{it})[6], finite time horizon or mining lease fixed-period (T), coal price world market (P_t), discount rate (δ), discount factor (ρ)[7], environmental and social monetary costs (ESC_{it}) are known into the mining district. Following Conrad, Miranda and Fackler and Maldonado step-by-step looks like this:

1- Coal price (P_t)[8] is stochastic (Cherian et al., 1998).

2- The coal extraction cost increases with cumulated coal extracted (i.e., the cost function or total cost (tc_{it}) is decreasing in the amount of remaining coal –cr_{it}–). So, the cost function ,or reserve-dependent costs of the firms (without the internalization of the environmental and social monetary costs), is defined as

$$tc_{it} = f\,(cp_{it},\, cr_{it}) \qquad (1)$$

i = company 1, company 2,..., company 7 and t = 2004, 2005,..., 2008

3- From the equation: (1) its marginal cost (*MC*) or first order condition ($MC = \frac{6tc}{6cp} > 0$) depends on the coal extraction rate (cp_{it}). Thus, their first-order conditions with respect (*cp* and *cr*) are positive ($\frac{6tc}{6cp} > 0$) and negative ($\frac{6tc}{6cr} < 0$), respectively. "*The classic natural resources literature, see Neher (1990) and references therein, assumes that the*

[5] Indexes individual, *i* =1, 2,.., 7 or is each firm (Drummond, Norcarbon, Consorcio Minero Unido, Prodeco, Carboandes, Carbones La Jagua and Compañía de Carbones del Cesar) and indices time, *t*=2004, 2005, 2006, 2007 and 2008.
[6] It is cost function gives the cost of coal extraction per unit time.
[7] $\rho = \frac{1}{1+ð}$.
[8] P_t=110, it is the world coal price in Table 1 (average).

MC is creasing in the coal extraction rate (cp_{it}), and the cost function is decreasing in the level of amount of remaining coal (cr_{it})" (Cherian et al., 1998, 12).

4- The amount of coal available and the lease duration (60 years, $T = 60$) are finite ($t = 1,2,\ldots,T$; $t = 1,2,\ldots,60$).

As a result, our purpose is to find the optimal extraction policy when the environmental and social costs of the opencast coal mining activity are internalized, and to calculate the optimal value of the lease. Nevertheless, considering the sixty-year lease duration, our problem becomes a multi-period or multistate problem, and the solution requires dynamic programming (Backward Recursion, discrete time, discrete state Markov decision model and Bellman equation). The procedure starts from Principle of Optimality, which implies that the value function (V_t) must satisfy:

$$V_t(cr_{it}) = max_{cp_{it} \in \{0,1,2,\ldots,\bar{p}\}}\{P_t cp_{it} - tc_{it} + \rho \sum_0^{\varphi} V_{t+1}(cr_{it} - cp_{it})\},\ cp_{it} \in \bar{p}\ t = 1,2,\ldots,T \qquad (2)$$

Eq. (2) describes the Bellman equation, which captures the essential problem faced by a dynamic, future-regarding optimizing firm: the need to optimally balance an immediate reward $V_t(cr_{it})$ against expected future rewards $\rho E_t V_{t+1}(cp_{it+1})$. In this manner, Backward Recursion is solved using numerical solution algorithms or Newton's iterative method (Miranda and Fackler, 2002, p. 8, see Appendix A for a review of the mathematical processes) and computational economic models (MATLAB programming language).

Thus, "*each recursive step involves a finite number of algebraic operations, implying that the finite horizon value functions are well-defined for every period. Note however, that it may be possible to have more than one sequence of optimal policies if ties occur when performing the* *maximization embedded in the Bellman equation. Since the algorithm requires exactly T iterations, it terminates in finite time with the value functions precisely computed and at least one sequence of optimal policies obtained"* (Miranda and Fackler, 2002, p. 171).

According to Miranda and Fackler (2002, see p. 170-176 for a review of the mathematical processes), in order to initialize the Backward Recursion process in this analysis it is necessary to specify the reward or profit function (π), the state transition function (g), discount factor (ρ), terminal period (T) and terminal value function (V_{T+1}); set $t \rightarrow T$ (1 ➝ 60). Once these elements have been stipulated, the discrete time and the discrete state Markov decision model have the following structure:

- *The state variable* is the amount of remaining coal in the mine at the beginning of the year (cr_{it}, measured in millions of tons), $cr_{it} \in \{0, 1, 2, \ldots, \bar{cr}\}$, which can vary between 0 and the maximum remaining coal in the mine ($\bar{cr}$)[9].
- *The action variable* is the coal extraction rate (the average is 4.7 million tons per year, Table 1) over the year (cp_{it}, measured in tons), $cp_{it} \in \{0, 1, 2, \ldots, \bar{p}\}$, which can vary between 0 and the maximum rate ($\bar{cp}$)[10].
- *The state transition function (g)* is $g(cr_{it}, cp_{it}) = cr_{it} - cp_{it} = 2{,}000 - 4.7$ is the amount of coal extracted over the year, measured in millions of tons.
- *The reward function or profit function* (π) is $\pi(cr_{it}, cp_{it}) = P_t cp_{it} - tc_{it}$. The lease provides the stream of profits at the rate of π.
- *The terminal condition* is $V_{T+1}(cr_{it}) = 0$[11].
- *The value of the opencast coal mine* $[V_t(cr_{it})]$[12] is

[9] $\bar{cr} = 2{,}000$ million tons (largest value in Table 1).
[10] $\bar{p}$= 2,000 million tons (the largest value of *cr* in Table 1).
[11] Indexes *T*+1 is expected future rewards.

$$V_t(cr_{it}) = max_{cp_{it} \in \{0,1,2,\ldots,\bar{q}\}}\{P_t cp_{it} - tc_{it} + \rho V_{t+1}(cr_{it} - cp_{it})\}\ s.t.\ V_{T+1}(cr_{it}) = 0 \quad (3)$$

The value of the opencast coal mine, given that it contains cr_{it} millions of tons of coal at the beginning of year *t*, satisfies the Bellman equation in Eq. (3) subject to (*s.t.*) the terminal condition ($V_{T+1}(cr_{it}) = 0$) (see Cherian et al., 1998; Conrad, 1999; Miranda and Fackler, 2002; and Maldonado, 2009, for a review), where ρ is the annual discount factor[13]. Similarly, the empirical practice of the aforementioned cost function in Eq. (1) is estimated using a balanced panel data model (set seven mining investment companies are observed over five years, from 2004 to 2008), given by

$$tc_{it} = \gamma cp_{it}^{\beta} cr_{it}^{-\alpha} s_{it} \rightarrow lntc_{it} = ln\gamma + \beta lncp_{it} - \alpha lncr_{it} + lns_{it}^{14} \quad (4)$$

Where γ, β and α are the parameters and the error ε_{it} is independent and identically distributed (*iid*), (see Greene (2002), Gujarati (2003), Baltagi (2005), Cameron and Trivedi (2009), Perdomo and Ramirez (2011), Rosales et al. (2013) and Perdomo (2015) for a review). Also, the monetary values of environmental and social externalities (ESC_{it}) are added in Eq. (1), hence Eq. (5) implies a new expression defined as:

$$etc_{it} = \theta cp_{it} cr_{it}^{-\phi} u_{it} \rightarrow lnetc_{it} = ln\theta + \lambda lncp_{it} - \phi lncr_{it} + lnu_{it}^{15} \quad (5)$$

In Eq. (5) the cost function is indicated as (etc_{it}, $etc_{it} = tc_{it} + ESC_{it}$) with the internalization of the environmental and social monetary costs, θ, λ and ϕ are the new parameters and the error u_{it} is *iid*. In addition, these cots were considered from Perdomo et al. (2010, 12), which were

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[12] Indices *t* is the value of the mine over the year.

[13] $\rho = \frac{1}{1+\delta}$, δ is private discount rate (Libor rate), $\delta = 0.0397$ (average in Table 1) and $\rho = 0.96$.

[14] *ln* is natural logarithm.

[15] *ln* is natural logarithm.

compiled from the unpublished study of the Colombian Ministry Environmental (2010). This Entity of the Government affected the estimation of the environmental and social monetary costs that mining investment companies incur in the Mining District located in the central part of the Department of El Cesar (Colombia), and it uses Non-market valuation techniques (Contingent Valuation and Choice Models), hedonic price equations, health (mortality and morbidity), travel costs models, replacement cost and substitute cost methods to establish the monetary value of the damage of greenhouse gas, noise, air and water pollution (aquifers, wetlands and rivers), soil degradation, landscape (land erosion), ecosystem (loss of forest area and biodiversity and of nonrenewable resource (coal)), public health problems and land-use conflicts (agriculture, livestock and mining) (details in Colombia Ministry Environmental, 2010).

$$V_t(cr_{\mathrm{it}}) = max_{cp_{\mathrm{it}} \in \{0,1,2,\ldots,\overline{q}\}}\{P_t cp_{\mathrm{it}} - etc_{\mathrm{it}} + \rho V_{t+1}(cr_{it} - cp_{it})\}\ s.t.\ V_{T+1}(cr_{it}) = 0 \qquad (6)$$

As a result, the Colombian Ministry Environmental determined that the monetary value of the environmental and social externalities (ESC_{it}) is US$8 per extracted ton or US$111,000 per year, approximately, in the Mining District. In this manner, Eq. (6) describes the new Bellman equation subject to the terminal condition ($V_{T+1}(cr_{it}) = 0$) after the internalization of the environmental and social monetary costs in Eq. (5).

4. Research data and Empirical Evidence

The data used in the empirical evidence - by means of the dynamic programming and balanced panel data model described above - on total cost (tc_{it})[16], coal extraction rate (cp_{it}), amount of

[16] Is important to recognize that "*a representative cost function could be based on empirical analysis with cost data form several mines. This, however, is difficult for two reasons. First, mining companies keep cost data a closely guarded secret. Second, whatever cost data are publicly available are in highly aggregated form. They include both the cost mining and the cost of capital replacement"* Cherian et al. (1998, 12).

remaining coal (cr_{it}), world coal price (P_t), Libor rate (δ), monetary values of environmental and social externalities (ESC_{it}) (at the Mining District located at the central part of the Department of El Cesar) come from Benchmark database organization, Mining Energetic Planning Unit, Governor of Cesar's Office, Energy Information Administration and Perdomo et al (2010, 12), respectively. The variables included in the analysis are detailed in Table 1[17].

Table 1
Variables and descriptive statistics

Variables	Unit of Measure	Mean	Standard Deviation	Minimun	Maximun
Coal extraction rate (*cp*)	Tons per Year	4,686,838	7,598,748	77,230	22,900,000
Total Cost (*tc*)	Dollars per Year	70,500	114,500	985	369,000
Monetary values of environmental and social externalities (*etc*	Dollars per Year	111,000	198,500	1,259	745,000
Amount of remaining coal (*cr*)	Tons per Year	338,000,000	586,000,000	7,553,803	2,000,000,000
World Coal Price (*P*)	Dollars per Year	110	12	99	131
Libor Rate (δ)	Per cent (12-month)	3.97	1.22	2.19	5.35
Number of observations (n)	35				

Results in Table 1 present summary statistics and the variation for the main variables of the models in Eq. (1) and Eq. (5) and for the Bellman equations in Eq. (3) and Eq. (6). In general, the standard deviation, minimum and maximum show that the yearly total cost ranges from US$985 to US$369 for a firm and the mean yearly total cost was US$70,500. The yearly total cost (once the environmental and social monetary values are internalized) ranges from US$1,259 to US$745,000 for a firm and its mean yearly total cost was US$111,000.

In this way, the results in Table 1 are reasonable to apply to the econometric techniques and dynamic programming of the aforementioned theoretical framework. In this manner, the total cost function results (without monetary values of environmental and social externalities), in Eq. (1), are reported in Table 2. Thus, the Cobb-Douglas function estimate satisfies first order conditions (MC or $\frac{6tc}{6cp} > 0$ and $\frac{6tc}{6cr} < 0$) (Cherian et al. 1998, 12) and their explanatory variables (*lncr* and *lncp*) were statistically significant and present the expected sign (see positive and negative signs, respectively).

[17] Total cost and monetary values of environmental and social externalities were deflected using the Price Index (2008=100), constant of 2008 prices in US Dollars.

Table 2
Balanced Panel Data Cost Model[18] (without the monetary values of environmental and social externalities)

Dependent Variable (*Natural logarithm of the total cost, lntc*)	
Explanatory Variables	**Coefficient**
Natural logarithm of the constant	6.470598***
Natural logarithm of the coal reserves (*lncr*)	(-0.6995851)***
Natural logarithm of the coal production (*lncp*)	1.698321***
Number observations (*n*)	31

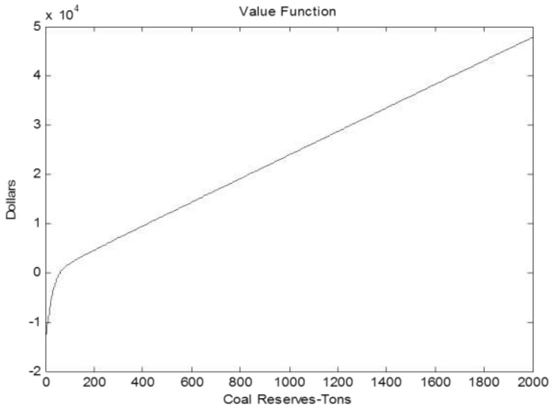
Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.

Given values for γ (6.47), β (-0.7), α (1.7), P_t (110) and cp_{it} (4.6 million, mean yearly, approximately) Eq. (2) are replaced by the following Bellman equation to solve using dynamic programming:

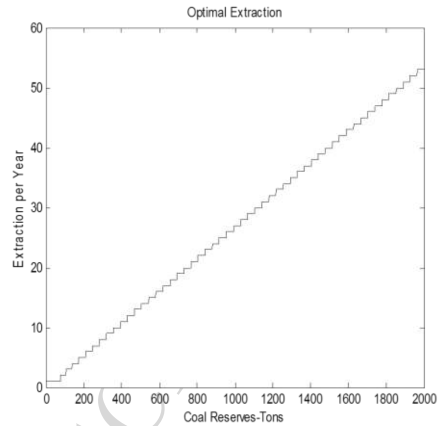
$$V_t(cr_{it}) = max_{cp_{it} \in \{0,1,2,\ldots,2000\}}\{110(4.6) - e^{6.47}cr_{it}^{-0.7}cp_{it}^{1.7} + 0.96V_{t+1}(2{,}000 - 4.6)\}\ s.t.\ V_{61}(cr_{it}) = 0 \quad (7)$$

Through the Backward Recursion, discrete time, discrete state Markov decision model and Bellman equation in Eq. (7), Fig. (1) illustrates the results[19] of the simulation analysis (without internalizing the externalities costs) on the maximization of the present value of the coal lease (Fig. 1(a)) and the private optimal extraction policy (Fig. 1(b)), and coal depletion or optimal stock of remaining coal (Fig. 1(c)). The expected trend line in Fig. (1a) indicates the positive association between the optimal value of the opencast coal mine (present value of benefits or their profits) and the stock level of coal reserves (tons annually). That is, the profits of the firms are increasing according to simultaneously increasing coal reserves (up to US$50,000 million (US$7,143 million per firm; 50.000/7)) at lease expiration date (year 60); however these are negatives when the coal reserves are less than 80 million tons annually.

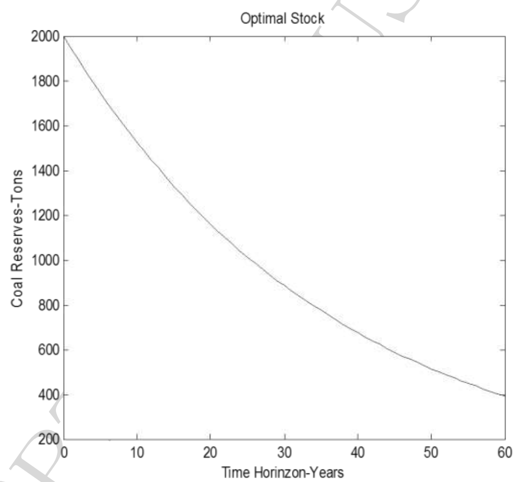
[18] The balanced panel data model (random effects) was carried out using Stata (version 11), through robust standard errors and generalized least squares methods to removed heteroscedasticity. In the random effects model there is no endogeneity, heteroscedasticity and residual autocorrelation, their estimators are unbiased and efficient (blue, best linear unbiased estimator); once they were compared with fixed effects, first difference and ordinary least squares.
[19] Using Matlab and the CompEcom library (getindex).



(a) The present value of coal lease



(b) Coal extraction rate



(c) Coal depletion

Fig. 1. Simulation Analysis Without Internalizing Externalities Costs

The expected trend line in Fig. (1b) shows a positive association between the optimal extraction policy or coal output rate (tons annually) and the stock level of coal reserves (tons annually). Specifically, the extraction policy of the firms is increasing (suggesting an increase to 53 million tons, average, annually) alongside growth in coal reserves; however this occurs when the coal reserves are more than 80 million tons annually up to 2,000 million tons annually to maximize the optimal present value of the opencast coal mine in Fig. (1a). Fig. (1c) describes the depletion trend (monotonically decreasing) of the coal reserves, which suggests a depletion to less than 400 million tons at lease expiration date (year 60).

The social and environmental consequences that occur due to the use of opencast coal mining practices were not considered. That is, the damages derived from the optimal extraction policy in Fig. (1b) which maximize the optimal present value of the opencast coal mine in Fig. (1a) are devastating, according to Yushi et al (2008) and Fatah (2008). As well, a significant reduction in resource stocks and environmental and social liabilities could be a result for future generations.

Therefore, to moderate, avoid or offset long-term negative impacts the environmental and social monetary values should be internalized into the cost functions of the firms. This will lead to finding the socially optimal quantity of the stock level of coal - or its optimal extraction path - which can help to define a sustainable approach in order to reduce environmental and social liabilities for future generations.

Table 3
Balanced Panel Data Cost Model[20] (with the monetary values of environmental and social externalities)

Dependent Variable (*Natural logarithm of the total costs with externalities value, lnetc*)	
Explanatory Variables	**Coefficient**
Natural logarithm of the constant	9.763329***
Natural logarithm of the coal reserves (*Lncr*)	(-1.297522)***
Natural logarithm of the coal production (*Lncp*)	2.273711***
Number observations (*n*)	31

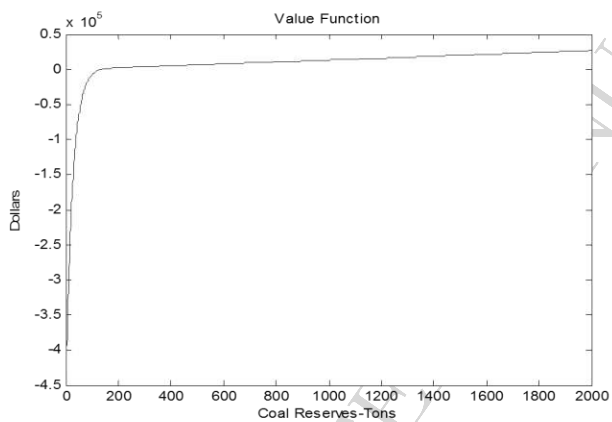
Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.

Given the environmental and social monetary values estimated by the Colombian Ministry Environmental (2010), the total cost function results (once they have been internalized into the environmental and social monetary costs), in Eq. (5), are reported in Table 3. So, the Cobb-Douglas function estimate satisfies first order conditions (MC or $\frac{6tc}{6cp} > 0$ and $\frac{6tc}{6cr} < 0$) (Cherian

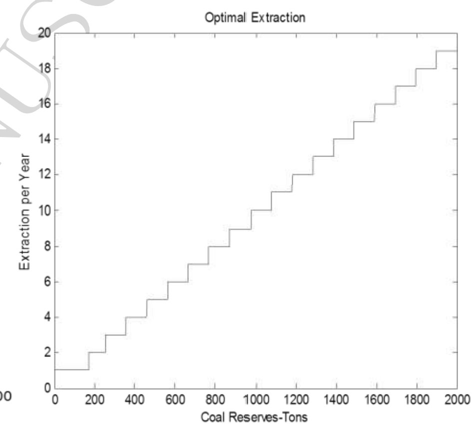
[20] The balanced panel data model (random effects) was carried out using Stata (version 11), through robust standard errors and generalized least squares methods to removed heteroscedasticity. In the random effects model there is no endogeneity, heteroscedasticity and residual autocorrelation, their estimators are unbiased and efficient (blue, best linear unbiased estimator); once were compared with fixed effects, first difference and ordinary least squares.

et al. 1998, 12) and their explanatory variables (*lncr* and *lncp*) were statistically significant and presented the expected sign (see positive and negative signs, respectively). Given values for θ (9.76), λ (-1.3), ϕ (2.3), P_t (110) and cp_{it} (4.6 million, mean yearly, approximately) Eq. (6) is replaced by the following Bellman equation to solve using dynamic programming:

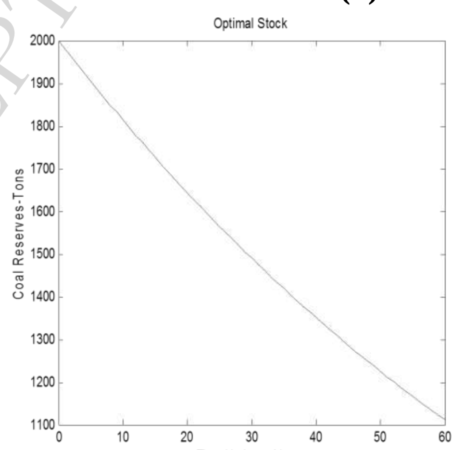
$$V_t(cr_{it}) = max_{cp_{it} \in \{0,1,2,\ldots,2000\}}\{110(4.6) - e^{9.76}cr_{it}^{-1.3}cp_{it}^{2.3} + 0.96V_{t+1}(2{,}000 - 4.6)\}\ s.t.\ V_{61}(cr_{it}) = 0 \quad (8)$$



(a) New present value of coal lease



(b) New coal extraction rate



(c) New coal depletion

Figure 2. Simulation Analysis once the external costs have been internalized

Similarly, through Backward Recursion, discrete time, discrete state Markov decision model and Bellman equation in Eq. (8), shown in Fig. (2) illustrates the results[21] of the simulation analysis (once environmental and social monetary costs have been internalized) on the maximization of

[21] Using Matlab and the CompEcom library (getindex).

the present value of the coal lease (Fig. 2(a)) and the private optimal extraction policy (Fig. 2(b)), and coal depletion, or optimal stock of remaining coal (Fig. 2(c)). The trend line in Fig. (2a) indicates a new shape: the positive association between the optimal value of the opencast coal mine and the stock level of coal reserves (tons annually). That is, the profits of the firms continues increasing according to increasing coal reserves up to less than US$50,000 million, US$30,000 million (US$4,286 million per firm; 30.000/7), approximately, at lease expiration date (year 60); however, once the externalities costs have been internalized, they are negatives when the coal reserves are less than 200 million tons annually.

This result implies, possibly, a change to the private optimal extraction policy (in Fig. 2b) and the stock level of coal reserves (tons annually) –in Fig. (2c)–, up to 19 and 1,100 million tons annually, respectively, in contrast to the results showed in Figs. (1b) and (1c). Also, it indicates a reduction on negative impacts (environmental and social) generated by the activity due to decrease of the coal output (annually), which is a result of the internalization of the monetary values for the externalities occasioned, if these are used to offset or mitigate them.

The socially optimal extraction path and its socially optimal quantity of the stock level of coal are described in Figs. 2(b) and 2 (c), respectively, which would define a possibly sustainable approach to reduce environmental and social liabilities for future generations. This means that if there is an increase in the total cost of extraction to offset the environmental and social impacts generated, the negative externalities would be less than or equal to the current level. Therefore, it is possible to find the socially optimal quantity of the coal stock for future generations.

Likewise, profits continue being positive for the mining firms. This would help to define for the Colombian environmental planners a sustainable approach for the opencast coal mining activity in the Mining District.

5. Conclusions

The opencast coal mining practice has caused serious environmental and social impacts in the Mining District located in the central part of the Department of El Cesar (Colombia). The Colombian environmental planners are trying to strengthen the environmental and social regulations to reduce the negative impacts caused by activity in the mining area and to generate sustainable development for this practice in the country.

In this article the private optimal extraction policy (at this mining area) is used with and without the internalization of the environmental and social monetary costs, for the cost function of the mining investment companies to find the socially optimal quantity of the coal stock, or its socially optimal extraction path. This can help to define a sustainable approach for the opencast coal mining extraction in the Mining District located in the central part of the Department of El Cesar.

These results use a balanced panel data cost model and dynamic simulation analysis (backward recursion, discrete state Markov decision model and Bellman equation). Data was collected on total cost, coal extraction rate, amount of remaining coal, world coal price, Libor rate, monetary values of environmental and social externalities (in the Mining District located in the central part of the Department of El Cesar) from several resources as Benchmark database organization, Mining Energetic Planning Unit, Governor of Cesar's Office, Energy Information Administration and Colombian Environmental Ministry. The simulation analysis shows that the present private optimal overproduction policy for the terminal phase of the resource extraction program can be reduced once the monetary value of negative externalities, produced by mining practices, are internalized at the cost function of the mining investment companies. The resulting estimation suggests a depletion of the coal reserves to less than 1,100 million tons, at the lease expiration date (year 60), once the externalities costs have been internalized. The profits continue to be positive for the mining firms.

Otherwise, the actions of coal extraction policy suggest a rapid increase to 53 million tons, (average, annually) to maximize the present value of the private profits and therefore a depletion of the coal reserves to less than 400 million tons at the lease expiration date. This means reducing available coal resources for future generations and growth of the current environmental and social problems.

However, the Colombian environmental entities that can carry out the implementation of this type of analysis should create a data collection microeconomic system like the one used in this work. They should provide economic mechanisms for the compensation, mitigation and restoration of the environmental and social impacts caused by opencast coal mining extraction. The goal should be to achieve sustainable development in mining and to increase the welfare of future generations.

In other words, if there is an increase in the total cost of extraction to offset the environmental and social impacts generated, the negative externalities will be less than or equal to the current level. It is therefore possible to find the socially optimal quantity of the coal stock for future generations. Finally, the results of this study are a preliminary approach to the implementation of environmental economics and natural resources conservation for a mining project in Colombia.

Therefore, they are meant to open doors to new lines of research in order to deepen the study of the problems mentioned herein.

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We express gratitude particularly to professors Josu Arteche, Marta Escapa Garcia and Alberto Ansuategi of the Doctoral Programme in Economics: Economic Analysis Tools at the University of the Basque Country (UPV/EHU, Spain) for their support to this topic as Doctoral Dissertation of Jorge Andrés Perdomo. Finally, Richard S.J. Tol's (Editor in Chief) critical comments and suggestions and the anonymous referee are also gratefully acknowledged.

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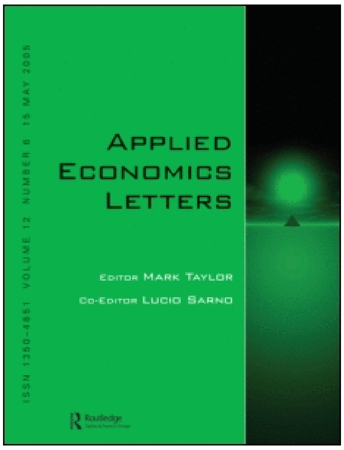
Highlights

- We examine the optimal extraction policy, at the Mining District located at the central part of the Department of El Cesar, with and without environmental and social monetary costs.
- We use a discrete dynamic programming (backward recursion, discrete state Markov decision model and Bellman equation).
- The method can help to the policymakers to define a sustainable approach over time for the opencast coal mining extraction at the Mining District located at the central part of the Department of El Cesar.
- We found the socially optimal quantity of the coal stock or its optimal extraction path.
- Our the simulation analysis showed that the present private optimal overproduction policy for the terminal phase of the resource extraction program can be reduced once the monetary value of negative externalities, produced by mining practice, are internalized at the cost function of the mining investment companies in Colombia.

Article “A methodological proposal to estimate changes of residential property value: case study developed in Bogotá”



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A methodological proposal to estimate changes of residential property value: case study developed in Bogotá

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A methodological proposal to estimate changes of residential property value: case study developed in Bogotá

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This article is an empirical study of residential land values in the vicinity of the TransMilenio system (Bus Rapid Transit, BRT) in Bogotá (Colombia). The results have been established through impact evaluation by means of nonparameteric approaches (Propensity Score Matching, PSM) and econometric approaches (Spatial Hedonic Price, SHP) indicating that access to the BRT system generates benefits on the change of property value.

Keywords: TransMilenio; Bogotá; impact evaluation; propensity score matching; spatial hedonic price; change of property value

JEL Classification: C14; C25; C52; L92; R11

I. Introduction

Transport progress opened in Bogotá in December 2000 with the Bus Rapid Transit (BRT) service (TransMilenio). The project system includes an infrastructure network for its operation (exclusive right-of-way with dedicated station, sidewalk, bridge, mixed traffic lane and so forth) supplied by the Colombian government because the total cost of the investment is significant (Mendieta and Perdomo, 2008). Nevertheless, some profits are perceived through positive externalities[1] (Rodríguez and Targa, 2004).

Therefore, the main objective of this article is to estimate the impact of the TransMilenio infrastructure on the price of residential properties in the vicinity, by means of impact evaluation through Propensity Score Matching (PSM) and Spatial Hedonic Price (SHP), using Geographical Information Systems (GIS) in Bogotá (Colombia). In this way value-capture mechanisms could be developed, which could be used to finance future phases of the BRT project.

Finally, the rest of the article is organized as follows: Section 2 contains empirical analysis on the topic. Section 3 describes analytical methods (SHP and PSM). Section 4 provides data description and presents the results on issues mentioned above. Section 5 concludes the article.

II. Related Literature

To my knowledge, there are only few studies on the topic, and in Colombia the study is in its initial stages of emergence. However, SHP technique has been implemented to estimate changes of property value in Bogotá by Rodríguez and Targa (2004) and Mendieta and Perdomo (2007); likewise, PSM method has been implemented by Perdomo *et al.* (2007) and mean comparison test by Rodríguez and Mojica (2008).

[1] Economic development, land-use strategy, improving accessibility, saving travel time, land-value increases, traffic accident decreases, reductions in crime rates and air pollution (Lleras, 2003; Sandoval and Hidalgo, 2003; Moreno, 2004; Mendieta and Perdomo, 2007; Perdomo *et al.*, 2007; Rodríguez and Mojica, 2008).

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Globally, the studies that are more closely related to the SHP and PSM methods indicate that the introduction of a new ordinance to Chicago in 1923 allowed determining the effects of zoning on relative land-value growth rates, once the authors controlled for initial land use and the endogeneity of zoning decisions with spatial econometrics and PSM (McMillen and McDonald, 2002).

Likewise, Vinha (2005) estimated the impact of the metro infrastructure on the development patterns in Washington, DC, by means of PSM. Empirical research about changes of residential property value with Hedonic Price (HP) and PSM are few (McDonald and Osuji, 1995; McMillen and McDonald, 2000, 2004; Batt, 2001). Besides, there are not many studies simultaneously conducted through both methods, so their results cannot be analysed and compared.

III. Analytical Methodology

To estimate the impact of the TransMilenio infrastructure on the values of residential properties in the vicinity, HP and PSM are used. Notwithstanding, before estimating HP and PSM it is important to have a spatial analysis using GIS to avoid any possible problem about spatial autocorrelation and endogeneity (Anselin, 1980), omitting a relevant variable or incorrect functional form (Rosales *et al.*, 2010).

In this sense, HP is an approach based on the market for heterogeneous goods developed by Rosen (1974). Therefore, residential price ($V(z)$) is a function (f) of property attributes (z) such as total bedrooms and baths, externalities (air pollution, noise, crime rates and so forth) and accessibility ($z_1, \ldots, z_k$). Hence, the equilibrium HP function is

$$V(z) = f(z_1, \ldots, z_k) \qquad (1)$$

where the left-hand side of Equation 1 is the Willingness to Accept (WTA) a house price equal to the right-hand side or Willingness to Pay (WTP) for changes in property attributes. Thus, its empirical evidence is estimated by means of Box–Cox form (see Equation 2)[2] with maximum likelihood method.

$$V_i(z_{ki})^{(\theta)} = \beta_0 + \beta_1 z_{1i}^{(\lambda)} + \beta_2 z_{2i}^{(\lambda)} + \ldots + \beta_k z_{ki}^{(\lambda)} + e_i \qquad (2)$$

where $V_i(z_{ki})^{(\theta)} = \frac{V(z_{ki})^{\theta}-1}{\theta}$, $z_{ki}^{(\lambda)} = \frac{z_{ki}^{\lambda}-1}{\lambda}$, $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ are the parameters; e_i represents the error term, identically and independently distributed (*iid*) with mean zero and unknown variance $e_i \sim N(0; \sigma^2_e)$; θ and λ are the transformation coefficients. Nevertheless, the spatial distribution of houses in an area and their distance attributes (to the city centre, train station, university, river or canal, near TransMileno, on major street and so forth) typically induce a spatial autocorrelation problem (Haab and McConnell, 2002, p. 267).

In this way, spatial econometrics methodology allowed problem solution by constructing a spatial weight matrix (W) that contains information on the neighbourhood structure for each location. Taking account of this adjustment and using Equation 2, the SHP model (Box–Cox form) is

$$V_i(z_{ki})^{(\theta)} = \beta_0 + \rho W V_i(z_{ki})^{(\theta)} + \beta_1 z_{1i}^{(\lambda)} + \beta_2 z_{2i}^{(\lambda)} + \ldots + \beta_k z_{ki}^{(\lambda)} + \varepsilon_i \quad \varepsilon_i = \lambda W \varepsilon_i + e_i;\ e_i \sim N(0; \Lambda) \qquad (3)$$

where ε_i represents error term (*iid*) with mean zero and unknown variance ($\varepsilon_i \sim N(0,\Lambda)$), ρ and λ are parameters on the spatial lag. On the other hand, to estimate the impact of the TransMilenio infrastructure on the value of residential properties in the vicinity, PSM technique is used based on Heckman *et al.* (1997).

Therefore, houses in the vicinity of TransMilenio system accessibility are the treatment group (Y_1) whereas properties without this attribute determined the control group (Y_0), denoted in a binary response variable $D = 1$ and $D = 0$, respectively. The profit from the BRT infrastructure is $\Delta = Y_1 - Y_0$. However, spatial logit model must be used (see Equation 4) to estimate the conditional probability ($0 \leq P_i(D = 1/X) \leq 1$), because Δ is unobservable.

$$P_i(D = 1) = \frac{1}{1 + e^{\rho WD + X\beta + \varepsilon_i}} \qquad (4)$$

where X is a matrix of explanatory variables such as distances (schools, universities, city centres, museums and so forth) and β is a vector of coefficients. Thus, the next step is to compare the price of residential properties, placing more weight on observations that have similar estimated probability ($\hat{P}_i$) by means of nearest neighbour estimator (see details in Heckman *et al.*, 1997, p. 623). Finally, through Average Treatment on the

[2] The subscript i is to describe the cross-sectional observations, as property 1 up to 227 ($i = 1, 2, \ldots, 304$). Also, the subscript k is to describe total property attributes ($z_1, \ldots, z_k$) or explanatory variables.

Treated (ATT), the change of residential property value derived from the TransMilenio infrastructure is obtained.[3]

IV. Data and Empirical Results

The data used in the SHP and PSM methods reported in this research come from a sample of 304 residential properties in Bogotá (in the vicinity of the TransMilenio Portal in Suba and intersection of Boyacá Avenue and Primera de Mayo Avenue). The observations were extracted from a survey and GIS[4] in 2008.

Based on the SHP model by means of standard maximum likelihood method and spatial weight matrix (W), defined as the threshold distance between each property and other properties within 623 m (Euclidian distance), Table 1 presents the estimates[5] of the Box–Cox function. Specifically, the results of the explanatory variables that are most important (minimum distance between the observed property and the closest TransMilenio station or terminal, spatial lag price and error) are deterministic (significant at 1% and 10% levels, respectively).

The observations imply that if the minimum distance between the observed property and the closest TransMilenio station or terminal goes up by 1% (or 1 m), on average, its price (per square metre) goes down by about 0.05% (or US$0.02), once was controlled for the housing attributes (total number of bedrooms, bathrooms, garages, kitchens, age) and housing accessibility (distance to the bank, mall and park) and spatial autocorrelation.

On the other hand, logit model[6] is the first step in PSM; its results are provided in Table 2, where, binary response variable (D) takes on the value of 1 ($D = 1$) if the residential property is less than 500 m from a TransMilenio station or terminal, otherwise 0 ($D = 0$) if it is more than 500 m.

Hence, the probability that a house might have at TransMilenio system accessibility is 0.01% once controlled for the deterministic explanatory variables (significant at the 1% level) or housing accessibility. Based on the probabilities produced by the logit

Table 1. Spatial hedonic price model

Dependent variable (price per square metre)			
Explanatory variables	Coefficient	Marginal effect	Elasticity
Constant	101 460***	–	–
W* (price per square metre)	(-0.0422243)*	–	–
W* error term	0.0022905***	–	–
Minimum distance between the observed property and the closest TransMilenio station or terminal	(-0.0082713)***	-0.02	-0.05
Minimum distance between the observed property and the closest bank	(-0.0219449)	-0.03	-0.03
Minimum distance between the observed property and the closest mall	(-0.002186)***	-0.01	-0.06
Minimum distance between the observed property and the closest park	(-0.0405559)**	-0.02	-0.01
Total number of bedrooms	895.2617**	13.79	0.09
Total number of bathrooms	304.0087	2.99	0.01
Ubication level (floor)	364.2438	4.90	0.03
Total number of garages	8868.799***	39.56	0.06
Total number of kitchens	13 801.82***	70.59	0.13
Age (constructed years)	(-189.8815)	-7.50	-0.14
Lambda (λ)	(-1.901517)***		
Theta (Θ)	0.8262217***		
Loglikelihood	(-4133.2238)		
Number of observations (n)	304		

Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.

[3] To ensure the existence of a common support for the group of properties compared, the sample contains properties that would have the same probability of having access to TransMilenio system but not account with it. Thus, their spatial distribution is near to major avenue where is possible construct the BRT project and because socio-economic aspects are similar in both zones of the study.

[4] XY-coordinates of the residential properties.

[5] In Geoda (spatial econometrics) and Stata 9 (Box–Cox form and PSM), through robust SEs and generalized least square methods to remove heteroscedasticity.

[6] Omitted spatial lags, because they were insignificant at the 10% level.

Table 2. Logit model

Binary response variable (D = 1 and D = 0)		
Explanatory variables	Coefficient	Elasticity
Constant	(-43.02498)***	–
Minimum distance between the observed property and the closest bank	(-0.0089769)***	-4.22
Minimum distance between the observed property and the closest fire station	(-0.0296427)***	-66.09
Minimum distance between the observed property and the closest police station	0.0188992***	32.87
Minimum distance between the observed property and the closest museum	0.009136***	50.97
Minimum distance between the observed property and the closest parking lot	(-0.024989)***	-110.87
Minimum distance between the observed property and the closest hotel	0.0089844***	45.74
Minimum distance between the observed property and the closest inter-urban transport terminal	0.0094514***	73.86
Minimum distance between the observed property and the closest church	0.0118758***	11.24
Probability	0.00007428	
Loglikelihood	(-28.271899)	
Pseudo R^2	0.7947	
LR χ^2	218.90***	
Number of observations (n)	227	

Note: ***Significant at 0.01 level.

Table 3. Propensity score matching results

Method	Sample	Treated	Controls	Difference in price
Nearest neighbour (5)	Unmatched	US$510	US$462	US$48***
	ATT	US$510	US$451	US$59***

Note: ***Significant at 0.01 level.

model, these results were matched through nearest neighbour (5) (see Table 3).

Table 3 indicates that the difference in price is US$59 (per square metre), on average, between residential property with and without TransMilenio system accessibility. In other words, this shows that the development of the TransMilenio infrastructure has an important impact on the price of residential properties in the vicinity[7] (significant at 1% level).

V. Conclusion

This article utilized recent advances in HP approach, impact evaluation technique and a set of 304 housing in Bogotá (in the vicinity of the TransMilenio Portal in Suba and intersection of Boyacá Avenue and Primera de Mayo Avenue) to examine the impact of the TransMilenio infrastructure on the price of residential properties in the vicinity, using GIS and spatial econometrics.

The analysis of SHP reveals that if the minimum distance between the observed property and the closest TransMilenio station or terminal goes up by 1% (or 1 m), on average, its price (per square metre) goes down by about 0.05% (or US$0.02). The results of the estimation can be used to value changes such as follows.

Consider the location of a residence to 2500 m from TransMilenio station. The Box–Cox form predicts to willing to pay or marginal effect is US$50 (2500 · 0.02). In other words, US$50 is average received profit (per square metre) by the residential property owner to less than 1 m from TransMilenio station. Likewise, the PSM technique, through nearest neighbour (5), shows that the development of the TransMilenio infrastructure has an important impact on the price of residential properties in the vicinity.

Besides, the changes of residential property value, which is US$59 (per square metre), on average, are similar to that obtained (US$50) in SHP. In this way, both methodologies might be developed by the Colombian government as value-capture mechanisms that could be used to finance future phases of the BRT project.

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[7] Less than 500 m.

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Article “An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation”

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An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation

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An Economics Approach to Fixing the Fare of the Parking Lot Service in Bogotá Using Price Cap Regulation

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This article presents an application of the Ramsey Pricing approach to establish the price cap or pricing ceiling per minute for the parking lot service in Bogotá (Colombia), using the microeconomic framework for price fixing from a costs analysis (total fixed costs, total variables costs, average total cost and marginal cost) of the provision of parking lot service in Bogotá. These results were evidenced by means a dynamic panel data model for estimating total cost functions through GMM estimators (Generalized Method of Moments).Also, from the econometric outcome and using Ramsey Pricing approach and mathematical optimization (comparative statics), I obtained the maximum fare per minute that should pay the consumers of the parking lot service in Bogotá. I conclude that the current maximum fee per minute, paid by parking users, does not cover the fixed costs incurred by firms that provide legally this service in Bogotá.

Keywords: Ramsey Pricing, price cap, maximum fare per minute, microeconomic framework, parking lot service, Bogotá, total cost of production, dynamic panel data model, comparative statics.

JEL Classification Codes: R41; R48; C81.

Introduction

Currently at Bogotá, the size and the physical development of its road infrastructure are not appropriate for the mobility needs; also, they have been one of the main causes of the traffic congestion at the city. Moreover, due to the spatial restriction the motor vehicles users are using the sidewalks to park, which hindered the free movement of pedestrian.

For this reason, the Decree 1504 of 1998 was implemented to recover the public space, through the so-called "*parking bollards*" which were located in the main streets to close some parking zone (Judgment 874 from 1999 of the State Council) for clearing the sidewalks and achieve a greater pedestrian flow. Nonetheless, as a result, the number of legal and illegal parking lots at Bogotá increased considerably with fares out of control.

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Therefore, Decree 268 of 2009 (issued by the Mayoralty of Bogotá) was recognized to regulate the service tariff and its methodology was a legal decision without an economic criteria, hence is unknown whether or not this price is covering the fixed and variables costs of the firms that provide legally the parking lot service at the city and their profits are positives.

According to the above, the main aim of this article is to calculate the price cap per minute, which the parking users should pay for a legal service at Bogotá. In this way, the case study was based on microeconomic framework for price fixing from a costs analysis (total fixed costs, total variables costs, average total cost and marginal cost) of the provision of parking lot service in Bogotá[1].

These results were evidenced by means a dynamic panel data model to estimate total cost functions through GMM estimators (Generalized Method of Moments). Also, from the econometric outcome and using Ramsey Pricing approach and mathematical optimization (comparative statics), I obtained the maximum fare per minute that should pay the consumers of the parking lot service in Bogotá.

The remainder of the article is organized as follows. Section 2 provides the relevant related literature. Section 3 describes the microeconomic framework and analytical methodology. Section 4 briefly describes the data I use and presents my empirical results. Section 5 concludes.

Related Literature

To my knowledge, there are few studies on the topic at Colombia (Perdomo and Ramirez, 2011; Mendieta and Perdomo, 2008; Perdomo and Rubio, 2012). Whereas internationally there is a substantial amount of research on the parking regulation matter (Verhoef *et al.*, 1995; Shoup, 1997; Cowan, 2002; Anderson and Palma, 2004; Combes *et al.*, 2005; Matteo *et al.*, 2006; De Boger *et al.*, 2008; Qian *et al*., 2011). Therefore, their methodologies and results are important for the present paper, because the researches aforementioned shown some approaches to calculate the parking tariffs for the analysis of the parking demand using stated preferences (willingness to pay) and

[1] I used a secondary source of information, the data were provided by City Parking Company. It is a firm legally established in Colombia that is engaged in providing parking service at the major cities of the country.

random utility models. In a particular case, at France, was used generalized cost (is the sum of the monetary and non-monetary costs of a journey)[2] to calculate transport fee. As well, one of them showed the problem between land use and operation of the parking lots, its conclusion was that it is a problem of transport policy. On the other hand, at several studies on economic regulation (monopoly power at the communications market and transport market) have been applied the Ramsey Pricing approach to establish a price cap, therefore they are important in this article (Loube, 1995; Cowan, 2002, Perdomo and Ramirez, 2011), as well.

Besides, the methodologies of the aforementioned studies were supported by means descriptive statistics and conventional econometric techniques to determine their results. Nevertheless, unlike of the review literature, in this paper I used Ramsey Pricing approach and GMM estimators to estimate total cost function, average total cost and marginal cost of the provision of parking lot service in Bogota to regulate the fare paid by consumers.

Therefore, the following section describe the microeconomic framework and analytical methodology that is implicit in Ramsey Pricing to evidence whether or not the current fare of parking lot service is covering the fixed and variable costs incurred by legal private companies that are providing this service in Bogotá.

Microeconomic Framework and Analytical Methodology

Considering that in Bogotá the private parking market operates as a monopolistically competitive market[3], the fare paid by consumers was regulated by Decree 268 of 2009, which established a pricing ceiling per minute. Due to that the tariffs were discriminated unchecked by owners of the parking lot, according to the site or address where they were located into the city.

However, for my empirical illustration, in this paper for fare fixing of the parking lot service in Bogotá, the measures will be constructed using an economics approach to price fixing, cost analysis of the provision of a parking lot service (cost functions,

[2] See Mendieta and Perdomo (2008, pp. 13-15), for a review.

[3] See Varian (1993, pp. 427-433), Nicholson (2002, pp. 537-542), Cano (2001, p. 45) and Qian *et al.*(2011, p. 862) for a review.

marginal cost and average cost) and price cap (McCarthy, 2001; Campos and De Rus, 2004). As well, I used a dynamic data panel model by means Generalized Method of Moments (GMM) to estimate the cost total functions.

The fare fixing for the parking lot services can be accomplished using Ramsey Pricing[4] or price cap regulation because this mechanism has been applied in companies with market power to restrict their profitability, so they are limited by the regulator, which will seek to set a tariff equal to the marginal costs of production (Campos and De Rus, 2004, 263), which in turn corresponds to the socially optimal (see details in Campos and De Rus, 188). Thus the maximum fare per minute, which should impose the regulator for private market of the parking lots service (to owners and consumers) in Bogotá, will be on the intersection between marginal and average total cost, means that the price per minute of the service will be equal at of producing it (Figure 1).

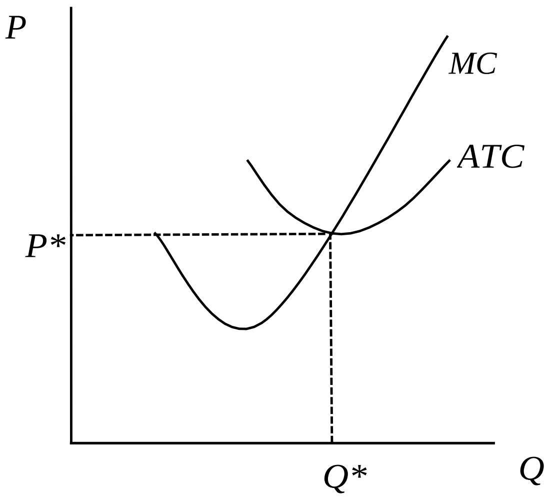

Figure 1. Marginal cost curve (*MC*) and average total cost (*ATC*), Nicholson (2002).

Figure 1 shows the relationship between the average total and marginal cost curves (*ATC* and *MC*, respectively) whose intersection at their minimum is the fare per minute adjusted (*P**, which is located on the *y* axis) and the optimal quantity (*Q**, in the *x* axis) or number of minutes (of the parking lot services) required to sale. Also, Table 1 list the total cost functions (linear, quadratic and cubic, Figure 2), where β_0, β_1, α_0, α_1, α_2, γ_0, γ_1, γ_2 and γ_3 are the parameters in each model. Because, with the information from

[4] See Campus and De Rus (2004, chaps. 5 and 6), Loube (1995), Sappington and Sibley (1992), Cowan (2002), Holguin and Jara (1999), for a review.

total cost curve (Figure 2) can be to construct the average and marginal cost curves shown in Figure 1.

Table 1. Total, Marginal and Average Cost Functions

Function	**Equation TC form**	$\boldsymbol{MC = \frac{\partial TC}{\partial Q}}$	$\boldsymbol{ATC = \frac{TC}{Q}}$
Linear	$CT = \beta_0 + \beta_1 Q$	β_1	$\frac{\beta_0}{Q} + \beta_1$
Quadratic	$CT = \alpha_0 - \alpha_1 Q + \alpha_2 Q^2$	$-\alpha_1 + 2\alpha_2 Q$	$\frac{\alpha_0}{Q} - \alpha_1 + \alpha_2 Q$
Cubic	$CT = \gamma_0 + \gamma_1 Q - \gamma_2 Q^2 + \gamma_3 Q^3$	$\gamma_1 - 2\gamma_2 Q + 3\gamma_3 Q^2$	$\frac{\gamma_0}{Q} + \gamma_1 - \gamma_2 Q + \gamma_3 Q^2$

Source: Nicholson (2002) and Mendieta and Perdomo (2008).

Likewise, Figure 2 shows the relationship between the total cost and output level (*TC* and *Q*, respectively), *TC* has units of dollars ($) on the *y* axis (for total cost), also it is divided into two parts, total variables costs (*TVC*) and total fixed costs (*TFC*).

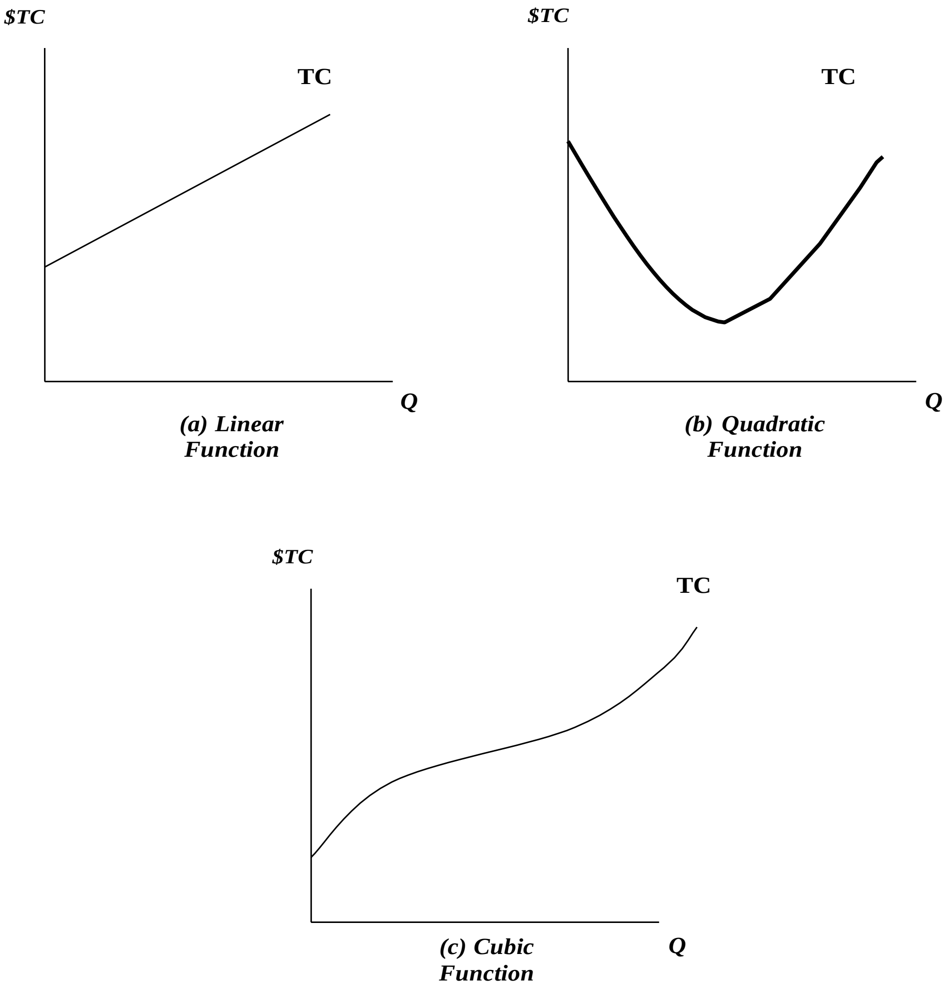

Figure 2. Total Cost Function in Table 1, Nicholson (2002).

In this way and in accordance with Campus and De Rus (2004), the total costs (*TC*) of a parking lot are given by the project cost per space, the land cost, the construction cost, the maintain costs and the annual operating cost (*TC*=*TVC*+*TFC*)[5]. Thus, from *TC* incurred by owners of the parking lot is possible to estimate the functions of the Figure 2 and Table 1. In this manner, from *TC* function estimated can be obtained the average total cost (*ATC*) and marginal cost (*MC*) of the service.

Therefore, the optimal output level (minutes required to sale, Q^*) to maximize the profits of the owners of the parking lot is on the intersection between *ATC* and *MC* (Figure 1). Thereby, Q^* can be substituted at the Equation 1 to calculate the fare per minute (P^*), which is equal to short-run marginal cost (Equation 1).

$$P^* = MC \quad (1)$$

$$P^t = (P^* + C_F)(1 + \hat{P}) \quad (2)$$

Nonetheless, the price ceiling (P^t) per minute, or second best pricing (Ramsey Pricing), for regulate the private market of the parking lot service in Bogotá is given by Equation 2. As can be seen, Equation 2 has two terms, the first term represent the inflation rate ($\hat{P}$) and the second term represent the fixed costs (C_F).

So, P^t can be determined using micro data underlying costs (fixed costs and variable costs) of production and operation of the parking lot service. Also, the functions in the Table 1 can be estimated by means of Generalized Method of Moments (GMM)[6] estimator and with this result to determine *MC*, *ATC*, Q^*, P^* and P^t through comparative static (Chiang, 1988, pp. 173-174).

[5] ***Total fixed costs* (*TFC*):** include the value of rents and commissions on share accounts, administrative costs (including staff on the payroll), liability insurance, utilities, payments for condo management and procurement. While ***total variables costs* (*TVC*)** relate to staff overtime, support staff, maintenance and repairs and electrical installations, adjustments, licensing paperwork, roads and signage, security and communication items, depreciation and amortization, supplies, tickets and cards , claims incidents.

[6] See Greene (2002), Gujarati (2003), Rosales *et al.* (2013), Perdomo (2011 and 2010), Perdomo and Hueth (2011), for a review.

In empirical practice, of the aforementioned theoretical framework, this paper makes use of data for a balanced panel[7] (set 10 parking lots are observed over 36 month, from January 2010 to December 2012). Thus, the cost functions in the Table 1 to be estimated are the following:

$$Y_{it}(\mathrm{Q}, \boldsymbol{X}_{it}, \varepsilon_{it}) = f(\mathrm{Q}, \boldsymbol{X}_{it}, \varepsilon_{it}) \ (3)$$

i = parking lot 1 parking lot 2 ...., parking lot 10 and t = 2010:01, ..., 2012:12.

Where i is the individual dimension and t is the time dimension, Y_{it} is the dependent variable (total costs of production), $\boldsymbol{X}_{it}$ is the independent variable (Q-*Mins*-, number of minutes sold) and it is a vector of K time-varying explanatory variable, $\boldsymbol{\beta}$ the parameter vector and the error ε_{it} is independent and identically distributed (*iid*). Nonetheless, the balanced panel is a dynamic model because the number of time series observations is much large than the number of cross-sectional data, means that the series are highly autoregressive and the results of the Ordinary Least Squares (OLS) estimators would be unsatisfactory in this context.

Hence, the general approach is first-differences GMM[8] estimator because it produces more reasonable and satisfactory results (unbiased efficient estimator). Unlike OLS and Maximum Likelihood Estimation (MLE), the approach GMM does not require complete knowledge of the distribution of the data or of the disturbances. Only specified moments derived from an underlying model are needed for GMM estimation (Greene, 2002, p. 201). Also, the heterogeneity can be swept from the model by taking first differences in either the fixed or random effects cases, which produces

$$Y_{it} - Y_{i,t-1} = \delta(Y_{i,t-1} - Y_{i,t-2}) + (\boldsymbol{X}_{it} - \boldsymbol{X}_{i,t-1})' \mathrm{Q} + (\varepsilon_{it} - \varepsilon_{i,t-1}) \ (4)$$

In the context of a GMM estimator and assuming that the time series is long enough (36 month), one could use the lagged differences, ($Y_{i,t-2} - Y_{i,t-3}$) as one instrumental variable for ($Y_{i,t-1} - Y_{i,t-2}$). Also, the time varying explanatory variable $\boldsymbol{X}_{it}$ is strictly exogenous in the sense that

[7] See Gujarati (2003), Greene (2002), Baltagi (2005), Cameron and Trivedi (2009) and Rosales *et al.* (2013), for a review.
[8] See Arellano and Bond (1991), Chamberlain (1987), Arellano and Bover (1995), Blundell and Bond (1998), for a review.

$$E(\Delta X_{it}'\Delta\varepsilon_{it}) = 0 \quad (5)$$

Therefore, the corresponding moment equations that can enter the construction of a GMM estimator are

$$\frac{1}{n}\sum_{i=1}^{n} Y_{is}\left[(Y_{it} - Y_{i,t-1}) - \delta(Y_{i,t-1} - Y_{i,t-2}) - (\boldsymbol{X}_{it} - \boldsymbol{X}_{i,t-1})'\mathrm{Q}\right] = 0 \quad (6)$$

$$s = 0,\ldots,t\text{-}2;\ t = 2, \ldots, T.$$

Subscript s is the lagged differences, $(Y_{i,t-2} - Y_{i,t-3})$, that is the level of Y_{is} is uncorrelated with the differences of disturbances $(\varepsilon_{it} - \varepsilon_{i,t-1})$ that are at least two periods subsequent. So, the $T(T\text{-}1)/2$ orthogonality (or moment) conditions can be represented as

$$E(W_i\Delta\varepsilon_{it}) = E\left[W_i\left((Y_{it} - Y_{i,t-1}) - \delta(Y_{i,t-1} - Y_{i,t-2}) - (\boldsymbol{X}_{it} - \boldsymbol{X}_{i,t-1})'\mathrm{Q}\right)\right] =$$
$$E[W_i(\Delta Y_i - \Delta Y_{i,t-1}\delta - \Delta\boldsymbol{X}_{it}'\mathrm{Q})] = 0 \quad (7)$$

Where

$$W_i = \begin{bmatrix} Y_{i0} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Y_{iT-2} \end{bmatrix}$$

Based on these orthogonality conditions, a consistent GMM estimator of the parameter of interest is obtained by minimizing

$$\left(\frac{1}{n}\sum_{i=1}^{n} W_i'\Delta\varepsilon_{it}\right)' \boldsymbol{A} \left(\frac{1}{n}\sum_{i=1}^{n} W_i'\Delta\varepsilon_{it}\right) \quad (8)$$

$\boldsymbol{A}$ is an initial positive define matrix and an efficient two-step version of it is obtained using

$$\boldsymbol{A} = \left(\frac{1}{n}\sum_{i=1}^{n} W_i'\Delta\hat{\varepsilon}_{it}\Delta\hat{\varepsilon}_{it}'W_i\right)^{-1} \quad (9)$$

Where $\Delta\hat{\varepsilon}_i$ are residuals based on initial consistent estimation of $\hat{\boldsymbol{\theta}}(\hat{\boldsymbol{\theta}}_{GMM} = \delta, \mathrm{Q}')$, therefore total cost function in Table 1 will be chosen to derive *MC*, *ATC*, *Q** and *P** through comparative static. Further details of the GMM estimator can be found in Blundell and Bond (1998).

Data and Empirical Results

The data I use is a balanced panel of 10 parking lots[9] observed over 36 month, 2010:01-2012:12. This data was kindly made available to me by City Parking Company. The total fixed and variables costs are measured at the end of the parking lots accounting monthly, and sales is used as a proxy for output (*Q*) or the amount of minutes monthly sold in these parking lots.

Table 2. Descriptive Statistics

Variables	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Total Cost (*TC*)[10] (Monthly)	360	13,579	6,526	3,605	44,526
Minutes (*Q*) (Monthly)	360	295,879	122,664	64,576	640,166

Table 2 presents the descriptive statistics of the variables in the model. Monthly total cost ranges from US$3,605 to US$4,526 for a parking lot and its mean monthly total cost was US$13,579. Also, we can see the mean amount monthly sold by a parking lot, which was 295,879 minutes or 9,863 minutes per day. In this way, the results in Table 2 are reasonable to apply the econometric techniques described above.

Therefore, Generalized Method of Moments[11] estimates of the quadratic and cubic total cost forms are reported in Table 3. Thus, quadratic and cubic functional forms satisfy conditions to determine *MC*, *ATC*, *Q**, *P** and to find the intersection between *ATC* and *MC*, due to that linear function does not support a relative (or local) minimum point. In other words, the fixed cost (β_0) of this form in the Table 1 is an absolute (or global) minimum because the first-order condition or *MC* (β_1) is a constant.

[9] These places are located in Bogotá and their addresses are the following: Calle 100, Calle 122, Calle 94, Calle 95, Carrera. 15, Calle 81, Calle 84, Calle 85, Calle 104 and Parque 93.
[10] Constant of June 2011 prices in US Dollars.
[11] The Generalized Method of Moments estimation of the models was carried out using Stata (version 11) computer program.

Table 3. Dynamic Panel Data Model (GMM estimator)

Dependent variable- total cost (Constant of June 2011 prices in US Dollars)	Quadratic Form	Cubic Form
Explanatory variables	**Coefficient**	**Coefficient**
Constant (Fixed Cost)	12,579***	10,526***
Minutes (Q)	0.47	47.13*
Minutes^2 (Q^2)	0.0000194	-0.000142*
Minutes^3 (Q^3)	-	0.00000000016**
Number of observations (*n*)	360	360
Note: *, ** and ***Significant at 0.10, 0.05 and 0.01 levels, respectively.		

However, according with the results in the first and second column of Table 3, the appropriate total cost function for the parking lots in Bogotá is the cubic form. Because, of all functional forms, only their explanatory variables were significant at the 10% and 5% level. In addition, the signs (positive, negative and positive) are the coefficients values corresponding to this theoretical functional form in the Table 1 and constant value is the monthly cost fixed (US$10,526). Thus, from result, the average total cost (*ATC*) and marginal cost (*MC*) were obtained using comparative statics

$$ATC = \frac{TC}{Q} = \frac{10{,}526}{Q} + 47.13 - 0.000142Q + 0.00000000016Q^2 \quad (10)$$

$$MC = \frac{\partial TC}{\partial Q} = 47.13 - 2 * 0.000142Q + 3 * 0.00000000016Q^2 \quad (11)$$

As shown in Figure 1, the marginal cost curve must intersect the average total cost curves at their respective minimums (Q*). Thus *ATC*=*MC*, then I have

$$\frac{10{,}526}{Q} + 47.13 - 0.000142Q + 0.00000000016Q^2 = 47.13 - 2 * 0.000142Q + 3 * 0.00000000016Q^2 \quad (12)$$

Solving[12] the equation 12 for Q, can be found the optimal (Q*)

$$Q^* = 438{,}132 \quad (13)$$

[12] Using Derive (version 5) computer program.

Therefore, the monthly optimal sale for a parking lot in Bogotá is 438,132 minutes or 14,604 minutes per day. In other words, the owners of the parking lots in Bogotá should sale this amount per day to do not have economic loss or it is the optimal output to maximize profit. Thereby, as shown in Equation 1 and replacing $Q*$ (438,132) in MC the monthly variable cost is equal to $P*$

$$P^{*} = 47.13 - 2 * 0.000142(438{,}132) + 3 * 0.00000000016(438{,}132)^{2} \quad (14)$$

$$P^{*} = 15 \qquad (15)$$

Thus, the variable cost is US$15 or US$ 0.002 per minute[13], the fixed cost is equal US$10,526 or US$0.24 per minute[14] and the Colombian rate inflation in 2013 was 3% ($\hat{P}$). Therefore, as shown in Equation 2, the price ceiling (P^t) per minute for the parking lot service in Bogotá should be US$0.27.

$$P^{t} = (0.02 + 0.24)(1 + 0.03) = 0.27 \quad (16)$$

Nevertheless, according with the Decree 268 of 2009, the current fare per minute for the service in Bogotá (US$0.05) does not cover the total cost incurred by legal private companies that are providing this service in Bogotá.

Conclusions

The main objective of the paper was to calculate the price cap per minute, which the parking lot service users should pay for a legal service at Bogotá, based on microeconomic framework for price fixing from a costs analysis (total fixed costs, total variables costs, average total cost and marginal cost).

These results were evidenced by means a dynamic panel data model to estimate total cost functions through GMM estimators (Generalized Method of Moments). Also, from the econometric outcome and using Ramsey Pricing approach and mathematical optimization (comparative statics) I obtained the maximum fare per minute that should pay the consumers of the parking lot service in Bogotá.

[13] 15/9,863 = 0.002. 9,863 is the amount of minutes sold per month for a parking lot, it is the mean per day in the Table 2 (295,879/30).

[14] 10,526/43,200 = 0.24. 43,200 is the amount of minutes that has a month (60 minutes*24 hours*30 days)

Also, these results were possible from the secondary microeconomic statistical information (provided by City Parking) on the activity of 10 parking lots in the city, collected monthly from January 2010 to December 2012. Thus, it was possible to establish a cubic total cost function estimated by means of a dynamic panel data model with generalized method of moments (GMM).

Therefore, from the estimated results of the model and using mathematical optimization (comparative statics) it was established that the minimum amount of minutes that an owner of a parking lot must sell monthly according to its capacity and to minimize costs, is approximately 438,132 minutes.

Thus, the maximum fare per minute for the service users should pay is US$0.27 including total cost and rate inflation under the Ramsey Pricing approach. This setting allows their earnings to be equal to zero, without incurring economic losses. Nevertheless, given the current fare per minute ($ 0.05) by Decree 298 of 2010 for the year 2011 is below to the estimated economically. These results and analysis enable the state agencies responsible for regulating these prices to establish them from a financial standpoint in order to not overvalue or undervalue them and thus be able to be impartial with consumers and service producers.

Furthermore, the results obtained in this study help to understand what should be the methodology for setting maximum prices and be able to regulate the monopoly power in the service of parking lots and other activities that maintain structures of imperfect competition and to establish prices above the socially optimal when the product is important in the society consumption.

However, for entities in charge that can carry out the implementation of this type of analysis, should create a data collection microeconomic system as the one used in this work, in the same way as performed by the regulatory companies of public services in Colombia through a Unique Information System Utilities (ISU).

Finally, the results obtained in this study are a first approach to the implementation of economic regulation with price cap for parking service in Bogota. Therefore, they are the first preliminary results and open doors to new lines of research in order to deepen the study of the problems mentioned.

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