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Anexo II

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

Facultad de Economía, Empresa y Turismo

Programa de doctorado en Perspectivas Científicas sobre el Turismo y la Dirección de Empresas Turísticas.

Título de la Tesis

Additional economic effects and externalities in transport infrastructure

Tesis Doctoral presentada por D. Aday Hernández González

Dirigida por el Dr. D. Ginés de Rus Mendoza

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Las Palmas de Gran Canaria, a de febrero de 2013

UNIVERSIDAD DE LAS PALMAS
DE GRAN CANARIA

DOCTORADO EN PERSPECTIVAS CIENTÍFICAS SOBRE EL TURISMO Y LA DIRECCIÓN DE EMPRESAS TURÍSTICAS

ADDITIONAL ECONOMIC EFFECTS AND EXTERNALITIES IN TRANSPORT INFRASTRUCTURES

Tesis doctoral presentada D. Aday Hernández González
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El Doctorando

El Director

Las Palmas de Gran Canaria, febrero de 2013

Resumen

La inversión en infraestructuras de transporte es una política muy utilizada por los gobiernos de diferentes ideologías para promover el crecimiento económico. Esta tesis aborda la conexión entre la inversión en infraestructuras y la existencia de efectos económicos adicionales, así como el tratamiento de otros efectos que no suelen recogerse en la evaluación económica de proyectos de inversión. Los efectos indirectos surgen en mercados imperfectos que tienen relación de complementariedad o sustituibilidad con el mercado de transporte en el que se realiza la inversión en infraestructuras. Además, estas inversiones interactúan sobre los mercados de factores, la distribución espacial de la actividad económica generando fuerzas de concentración y dispersión (economías de aglomeración), efectos sobre la competencia, y además de un conjunto de externalidades de distinto signo y magnitud.

El objetivo es, por tanto, desarrollar tanto a nivel teórico como empírico las líneas de investigación mencionadas. Para ello, la revisión de la literatura existente es una parte fundamental de esta tesis doctoral compuesta, además, por tres trabajos de investigación originales centrados a nivel empírico en la influencia de la alta velocidad ferroviaria en España, cuya importancia económica queda recogida en la elevada participación de dicha inversión en el gasto público en infraestructuras.

El primero de ellos es un análisis empírico de la influencia que la construcción de la alta velocidad española ha tenido sobre la densidad de empleo en las regiones afectadas por dicha infraestructura. El segundo contempla el efecto que la alta velocidad ferroviaria ha tenido sobre la reducción de los niveles de congestión y accidentes en las carreteras españolas derivada de la reducción del tráfico desviado. El tercero analiza los mecanismos de gestión de los mercados de emisiones proponiéndose una regulación alternativa a la existente que genera mejores resultados, en términos de bienestar social, en contextos de información imperfecta.

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PARTE I

RESUMEN EN LENGUA CASTELLANA

I. Introducción

La inversión en infraestructuras de transporte es una política muy utilizada por los gobiernos de diferentes ideologías para promover el crecimiento económico. Esta tesis aborda la conexión entre la inversión en infraestructuras y la existencia de efectos económicos adicionales, así como el tratamiento de otros efectos que no suelen recogerse en la evaluación económica de proyectos de inversión. Los efectos indirectos surgen en mercados imperfectos que tienen relación de complementariedad o sustituibilidad con el mercado de transporte en el que se realiza la inversión en infraestructuras. Además, estas inversiones interactúan sobre los mercados de factores, la distribución espacial de la actividad económica, generando fuerzas de concentración y dispersión (economías de aglomeración), sobre la competencia, y además producen un conjunto de externalidades de distinto signo y magnitud.

El propósito es, por tanto, comprender mejor los efectos de la inversión en infraestructuras de transporte sobre la actividad económica. Éstos pueden ser de carácter microeconómico, en los que esta tesis se centra principalmente, o agregados cuando la magnitud de la inversión tiene efectos sobre las variables macroeconómicas de la región.

Con frecuencia, la inversión de capital público es utilizada para estimular la actividad en el corto plazo, ya que durante el período de construcción existe un efecto multiplicador sobre el empleo; efecto keynesiano. Dicho efecto, por ser común a cualquier infraestructura, puede ignorarse generalmente en la evaluación de un proyecto concreto, siendo el fin del análisis económico encontrar cuál es el mejor modo de invertir dichos fondos, desde un punto de vista social, eligiendo entre los proyectos que compiten por los fondos públicos disponibles.

Para evaluar dicha contribución, los economistas clasifican los impactos de un proyecto en efectos directos, indirectos y adicionales. Los efectos directos son los que surgen en el mercado primario, es decir, el mercado donde se produce la intervención. Los efectos indirectos se generan en mercados secundarios relacionados con el mercado primario por la relación de complementariedad o sustituibilidad entre ellos y que han de ser recogidos en la evaluación social del proyecto. Para ello, dos características han de cumplirse; la existencia de distorsiones en dichos mercados secundarios y que las elasticidades cruzadas entre éstos y el mercado primario no sean cero. Además, existen los denominados efectos económicos adicionales que han de ser incluidos en la evaluación de un proyecto público ya que éstos no son doble contabilización y en determinados casos pueden ser sustanciales.

En esta última categoría se incluyen las economías de aglomeración, los efectos sobre los mercados en los que existe poder de mercado y que usan el transporte como un input y, los efectos sobre la competencia como resultado de la implementación del proyecto.

Las economías de aglomeración son una externalidad positiva que los agentes generan cuando se localizan cerca produciendo ganancias de productividad que no son recogidas en los ahorros de tiempo, ni pueden ser atribuidas a la existencia de fallos de mercado. Mientras, los efectos sobre los mercados en los que existe poder de mercado y que usan el transporte como input se caracterizan porque en ellos el precio es superior al coste marginal y la cantidad de equilibrio es subóptima. Una reducción de los costes de transporte incrementa la producción y reduce la pérdida de bienestar asociada el poder de mercado, efecto que no se recoge ni en el excedente del consumidor, ni en el del productor.

Por último, la implementación de un proyecto de transporte puede tener efectos sobre la competencia de los mercados. Cuando los costes de transporte son elevados, proyectos que los reducen pueden facilitar la entrada de nuevas empresas que encuentra rentable ofrecer sus productos en relación a la situación sin proyecto, en la que el incumbente está protegido por las barreras a la entrada que le proporcionan los costes de transporte.

En relación a las externalidades que surgen de los proyectos de transporte, destacan las medioambientales que pueden ser incluidas en los efectos directos o indirectos. En el caso de los efectos medioambientales directos, éstos surgen en el mercado primario e incluyen todos los costes (o beneficios, si los hubiera) derivados del período de construcción y operación del proyecto de transporte. Mientras que los efectos medioambientales indirectos son aquellos que ocurren en los mercados secundarios en los que existen distorsiones y que están relacionados con el proyecto, como puede ser el mercado de emisiones de sustancias contaminantes. En este último caso, la existencia de fallos de mercado da lugar a que exista oportunidad de regulación, asunto que también es tratado en esta tesis.

Se establece que bajo el supuesto de competencia perfecta en los mercados, podemos centrarnos únicamente en los efectos económicos directos. Sin embargo, la existencia de efectos intermodales y externalidades nos alejan del supuesto anterior y nos obligan a considerar tanto los efectos indirectos, como los efectos económicos adicionales en la evaluación económica de proyectos.

Siguiendo este argumento, los trabajos que han medido los efectos sobre la productividad del capital público, en general, y de las infraestructuras de transporte en particular, han mostrado que, pueden ser importantes aunque los resultados obtenidos deben ser interpretados con cautela.

La relación entre capital público y privado es incierta, ya que ésta puede ser de complementariedad o sustituibilidad. Si son sustitutivos, la inversión pública puede desplazar a la inversión privada, mientras que si éstos son complementarios, la inversión pública inducirá una mayor inversión privada afectando positivamente los niveles de empleo.

En relación al mercado de trabajo, las infraestructuras de transporte pueden generar mercados de trabajo mas amplios y eficientes. Si los trabajadores están en un mercado con información completa y perfecta movilidad, éstos pueden elegir su trabajo de manera óptima lo que mejora el *matching* entre oferentes (trabajadores) y demandantes (empresas) de empleo dando lugar a incrementos de productividad en el largo plazo.

Por otra parte, la movilidad del factor depende, en gran medida, de las infraestructuras de transporte y los cambios de éstas afectan, a su vez, a la localización de las empresas y a su propia organización afectando su acceso a los mercados de bienes y factores y, por tanto, a los niveles de productividad (economías de aglomeración).

Las economías de aglomeración se basan, principalmente, en la existencia de rendimientos crecientes a escala en la dimensión espacial y surgen de diferentes fuentes, tales como el mercado de trabajo, los mercados de inputs o el *spillover* tecnológico. Son externalidades positivas que generan los agentes económicos cuando se localizan cerca los unos de los otros y el transporte es esencial para promoverlos. En este sentido, los servicios de transporte tienen efectos significativos sobre la accesibilidad y la reducción de las barreras comerciales entre las regiones que, al final, determinan la ubicación de las empresas, los consumidores y los trabajadores.

Por otra parte, las economías de aglomeración están estrechamente relacionadas con las estructuras de mercado. Mercados aislados en los que el transporte no está lo suficientemente desarrollado, son más propensos a presentar estructuras de mercado poco competitivas. Por ello, el papel de las infraestructuras de transporte es claro; la mejora de la conectividad o la accesibilidad reduce los costes a los que se enfrentan los agentes creando mercados más amplios en los que surjan nuevas oportunidades y, también, nuevas amenazas para los operadores existentes aumentando las fuerzas competitivas y su eficiencia.

Por último, debemos incluir las externalidades, en general, y los efectos ambientales, en particular, como elementos de la política de transporte. La prestación de servicios de transporte y la construcción de infraestructuras afectan y se ven afectadas por las condiciones medioambientales y por la regulación en dicha materia, especialmente la regulación relativa a la emisión de gases contaminantes, asociados al calentamiento global.

A continuación, abordaremos los efectos macroeconómicos sobre las magnitudes agregadas y el papel de las infraestructuras de transporte en la convergencia entre regiones. Posteriormente, nos centraremos en el impacto de la infraestructura sobre el mercado laboral y en las economías de aglomeración. Finalmente, nos referiremos a las estructuras de mercado y su relación con las infraestructuras de transporte; así como a las externalidades, en especial, los accidentes, la congestión y a la regulación ambiental.

Efectos macroeconómicos y convergencia entre regiones

La inversión pública es considerada una herramienta para impulsar el crecimiento económico y el empleo en el corto plazo. Sin embargo, no puede ignorarse el posible efecto expulsión sobre inversiones más productivas, ni que los efectos finales no son siempre los esperados.

Aschauer (1989) evalúa el papel del Estado en el crecimiento económico y en la mejora de la productividad, otorgando un papel importante a la inversión pública. Su trabajo es el origen de una literatura amplia centrada en conocer la relación entre el nivel total de inversión en infraestructuras y el desarrollo económico, medido por el PIB, el crecimiento de la productividad o el empleo.

Atendiendo a la consideración de la infraestructura como un input que actúa en la función de producción, Munnell (1990a) también encuentra efectos positivos de la inversión pública sobre la producción y el crecimiento económico, afirmando que la desaceleración de la productividad de los EE.UU. se debió a una disminución en el crecimiento de la inversión en infraestructura pública.

Sin embargo, existen también otros trabajos que presentan resultados opuestos a los anteriormente mencionados. Algunos sugieren que el producto marginal del capital público es superior al privado (Aschauer 1989 y Fernald 1992); otros que es aproximadamente igual (Munnell 1990b); otros que es inferior al del capital privado (Eberts 1986 y Holtz-Eakin 1994) y, en algunos casos, incluso negativo (Evans y Karras 1994 y Hulten y Schwab, 1991).

Gramlich (1994) sostiene que la existencia de resultados tan diversos se debe, principalmente, a problemas estadísticos no resueltos previamente, entre los que destacan la causalidad inversa o endogeneidad entre la productividad del capital público y el crecimiento; la presencia de correlaciones espurias debido a la no estacionariedad de las series o, la omisión de variables relevantes. En este sentido, la dirección de la causalidad no es fácil de detectar estadísticamente, ya que la infraestructura puede liderar o derivarse del crecimiento económico. Para tratar el problema de la causalidad, varias soluciones empíricas incompletas han sido a menudo implementadas; la más recurrente es el uso de datos de panel.

Los datos de panel permiten el uso de *leads* (variables futuras) y *lags* (variables retardos). El problema es que podría existir un *lag* en ambas direcciones; por un lado, el tiempo necesario para que los agentes se adapten a cambios en la infraestructura y, por otro lado, el tiempo necesario para que el crecimiento de la producción genere umbrales de demanda que justifiquen la nueva infraestructura. También, podrían utilizarse variables *leads* si los agentes tienen expectativas sólidas sobre los cambios futuros en las infraestructura de transporte, anticipando la explotación de las ventajas competitivas potenciales. Todos estos problemas introducen dificultades en la estimación econométrica que explican, en parte, la amplia gama de resultados (Jiwattanakulpaisarn, 2008).

También, hay otros dos aspectos en los análisis macroeconómicos presentados que aún no han sido resueltos. En primer lugar, la medición de las variables puede ser problemática. El stock de infraestructura es una variable imperfecta para medir la efectividad de los servicios potenciales de dicha infraestructura y, por tanto, de su influencia sobre la productividad. En segundo lugar, las elasticidades macro obtenidas en los trabajos previos no son útiles cuando hay que tomar decisiones sobre proyectos específicos, para los que hay que considerar sus particularidades y su ubicación en el conjunto de la red. Como resultado, el papel de la dimensión espacial de la infraestructura tiene que ser analizado.

La inversión en una región depende de la provisión de infraestructura en otras regiones, además de depender de las condiciones locales y los modos de transporte existentes. La disposición de una nueva infraestructura no garantiza un mejor desarrollo de la región en la que se construye. La existencia de fuerzas de dispersión puede conducir a una deslocalización de las empresas reduciendo los beneficios esperados de la infraestructura.

Estos efectos pueden ser ignorados suponiendo la existencia de competencia perfecta y rendimientos constantes a escala, también en la dimensión geográfica; sin embargo, la propia naturaleza de la infraestructura hace que, con frecuencia, estos supuestos previos se incumplan. La modelización macroeconómica tradicional de la infraestructura no suele considerar su dimensión espacial y, por tanto, no puede recoger en su totalidad los efectos de dicha infraestructura sobre los mercados de trabajo y sobre la estructura competitiva entre (y dentro de) las regiones siendo ésta una de las razonas del desarrollo de la denominada nueva geografía económica.

En este contexto, el papel de los costes de transporte es crucial porque éstos actúan como una barrera a la entrada, lo que limita la capacidad de la infraestructura para producir fuerzas de concentración y especialización. Bajo el supuesto de altos costes de transporte, si se produce una caída de los costes entre ambas regiones se fomenta un incremento del comercio bilateral. Ahora bien, los resultados finales dependerán del tamaño de las regiones, de la movilidad de los factores, especialmente de la mano de obra y de los propios costes de transporte que son esenciales para producir un flujo de actividad entre ambas regiones.

Suponiendo que no existe movilidad del factor trabajo y que los costes de transporte son intermedios, Krugman y Venables (1995) muestran que son las regiones grandes, en términos de población, las que se benefician de la mejora de la infraestructura, concentrando en ellas la mayor parte de la actividad, lo que a su vez, genera diferencias en términos de los salarios reales. Sin embargo, una reducción adicional de los costes de transporte reduce la importancia para las empresas de ubicarse cerca de los mercados más grandes y, por tanto, los bajos salarios reales en la región de menor concentración podrían atraer a las empresas convirtiéndolas en exportadoras netas. El escenario cambia si suponemos movilidad del factor trabajo entre regiones y Krugman (1991) demuestra que es posible, en este caso, que toda la industria se concentre en una sola región.

Sin embargo, los modelos anteriores se basan en la existencia únicamente de dos sectores por región. Por esta razón, Venables (1999) extiende el modelo a un continuo de sectores que operan en competencia imperfecta mostrando que no existe un único equilibrio, lo que implica que dos regiones idénticas no necesariamente dividen en partes iguales sus cuotas de mercado y que el reparto final dependerá de las barreras comerciales y de los costes de transporte. En definitiva, los costes de transporte altos o bajos conducen a las regiones a mantener su cuota de mercado, mientras que para los niveles intermedios existen multiplicidad de equilibrios.

Puga (1999) explora la misma relación entre los costes de transporte y el comercio mostrando que las industrias se ubican cerca del consumidor y dispersan entre las regiones cuando los costes de transporte son altos, mientras que crean fuerzas de aglomeración cuando los costes son intermedios. El resultado se ve potenciado cuanto mayor sea la movilidad del factor trabajo porque los trabajadores se trasladan a lugares con salarios reales más altos, mientras que la falta de movilidad obliga a las industrias a dispersarse, resultados que están alineados con los descritos anteriormente en Krugman y Venables (1995).

La diferencia de los salarios reales entre regiones puede ser una consecuencia de los aumentos de productividad derivados de las economías de aglomeración. Venables (2007) formaliza este argumento y muestra que las estimaciones de la elasticidad de la productividad con respecto a la aglomeración pueden ser utilizadas para arrojar luz sobre la magnitud de este efecto. En su modelo teórico relaciona la productividad y la inversión en infraestructuras de transporte considerando el tamaño de la ciudad. El objetivo es distinguir cambios en los impactos que se derivan de las inversiones en transporte debido al efecto tamaño sobre la productividad (aglomeración), a partir de los beneficios económicos que se derivan de los recursos ahorrados en desplazamientos y de un aumento en la producción a nivel ciudad.

Sin embargo, la inversión en infraestructuras de transporte, condicionada por sus propias características tecnológicas, no es el único elemento que afecta a la dimensión espacial de la actividad económica. Hay, también, otras variables con influencia en la relocalización de la actividad, tales como los precios relativos de los factores de producción entre regiones o la situación económico-financiera (Vickerman, 1991).

De la discusión anterior, podemos establecer que no hay posibilidades de aplicar una regla común para conocer los efectos finales de una nueva infraestructura. Sin embargo, de la discusión sobre el papel de los costes de transporte concluimos que los ahorros de tiempo ahorro producidos por la mejora o construcción de una infraestructura de transporte no siempre generan convergencia regional, ya que el resultado final depende principalmente de los niveles iniciales de los costes de transporte y la movilidad de factores.

El efecto a largo plazo y la convergencia entre las regiones

Una vez examinado el papel de la inversión pública en las infraestructuras y la importancia de la dimensión espacial para caracterizar sus efectos sobre la actividad económica, pasamos a describir el efecto de la inversión pública en infraestructuras de transporte en el largo plazo y su capacidad para lograr la convergencia regional.

Encontrar que el capital público es productivo, no es suficiente para asegurar que la inversión pública estimula el crecimiento a largo plazo. Al menos tres aspectos han de ser considerados.

En primer lugar, hay que determinar si un incremento de la inversión pública induce a un aumento permanente, o sólo temporal, en el crecimiento económico. El modelo de crecimiento neoclásico de Solow (1956) predice que cualquier aumento en las tasas de ahorro nacional y la inversión tienen un efecto positivo y transitorio sobre el crecimiento económico; la tasa de crecimiento en el estado estacionario de la economía está totalmente determinada por el crecimiento demográfico y el progreso tecnológico. En dicho contexto neoclásico, un incremento en el gasto del capital público productivo induce un incremento temporal de la inversión. Sin embargo, el ritmo de acumulación del capital y del crecimiento económico, se reducen con el tiempo, ya que la acumulación de capital disminuye el rendimiento del capital y los incentivos para nuevas inversiones. En el largo plazo, el nivel de producción será mayor pero la tasa de crecimiento de la producción volverá a los niveles iniciales, antes del incremento del gasto público.

En segundo lugar, el efecto de un aumento de la inversión pública en el crecimiento económico es probable que dependa de la productividad marginal relativa del capital privado versus el capital público. En un contexto neoclásico, un incremento de la inversión pública aumenta (disminuye) la tasa de crecimiento económico en función de si el producto marginal del capital público es superior (inferior) al producto marginal del capital privado. Esta consideración valida las preocupaciones de Aaron (1990) y otros autores que afirman que el rango de estimaciones obtenidas en relación a las elasticidades del capital público es demasiado amplio como para aportar información robusta y útil para el proceso público de toma de decisiones.

En tercer lugar, el efecto de la inversión pública sobre el crecimiento es probable que dependa, en gran medida, de cómo dichas inversiones son financiadas. Estudios empíricos como los de Engen y Skinner (1996) encuentran evidencia de que aumentos en las tasas impositivas reducen la tasa de crecimiento económico. Por lo tanto, es de esperar que el aumento del capital público que, en la mayoría de los casos requerirá el correspondiente aumento de los tipos impositivos, estimulará el crecimiento económico sólo si el impacto sobre la productividad del capital público supera el impacto fiscal adverso.

Centrando el debate en el caso español, durante los años 80 y 90, los porcentajes del PIB español y alemán dedicados a la inversión pública en infraestructuras de transporte eran los mayores de la Unión Europea (UE) y su contribución al crecimiento fue considerado lo suficientemente alto como para continuar con esta política expansiva (Mas *et al.*, 1996). Sin embargo, dicho esfuerzo, lejos de disminuir progresivamente, hoy es el doble de la media de la Unión Europea, lo que siguiendo la teoría neoclásica ha llevado al agotamiento del crecimiento impulsado por la inversión en infraestructura (Mas, 2007). Como se ha dicho anteriormente, la acumulación de capital disminuye su producto marginal reduciendo así, su contribución al crecimiento económico. Ésta es la razón por la cual no se puede afirmar categóricamente que exista crecimiento de largo plazo y por la que hay que ser pesimistas con respecto a la contribución de las infraestructuras de transporte a la senda de crecimiento (Mas, 2007).

Otras consideraciones para evaluar el impacto de la infraestructura pública sobre el crecimiento económico son el mecanismo de financiación y la estructura tributaria. En España, nos encontramos con que la política de transportes no sólo está en manos del gobierno nacional, sino también de los gobiernos regionales. Por lo tanto, hay que contemplar la existencia y las consecuencias de los diferentes niveles de gobierno y los incentivos del sistema de financiación autonómico que son esenciales para explicar los mecanismos que favorecen la inversión de infraestructuras en transporte y la tendencia a la sobreinversión.

En España, la política fiscal actual ofrece pocos incentivos para un uso eficiente de fondos, y la razón principal es que no hay una correspondencia directa entre los gastos y los impuestos recaudados. El mecanismo ofrece incentivos, a nivel regional, para exagerar las necesidades de financiación de los Fondos Estructurales que, de lo contrario, irían a otra región.

En particular, para explicar el posible exceso de inversión de la infraestructura pública en España es importante, también, evaluar la eficacia de los contratos entre los diferentes niveles de gobierno. En este sentido, la incertidumbre asociada con la vida del proyecto y el reparto de riesgos hace más difícil lograr la eficiencia en la elección de los contratos (Socorro y de Rus, 2010).

Por otra parte, la regulación española reduce el interés de los agentes privados para evitar la proliferación de infraestructuras públicas de escaso valor social, ya que las renegociaciones de los contratos de concesión desequilibran la asignación de riesgos en perjuicio de los contribuyentes.

En conclusión, las políticas españolas de transporte e infraestructuras no se basan en una estrategia establecida que priorice los proyectos socialmente deseables, como muestra la apuesta por el tren de alta velocidad que es un modo de transporte con altos costes fijos y de mantenimiento (Campos *et al.*, 2009) y que requiere un volumen de demanda mucho más elevado de los actualmente existentes en España, con efectos discutibles sobre la convergencia de las regiones.

Además, esta infraestructura particular se asocia con la existencia de un "efecto túnel" (Gutiérrez Puebla, 2004). Éste se define como el potencial de desarrollo de los diferentes nodos de la red y la incapacidad para generar actividad económica en todo el territorio a lo largo del que se desarrolla. Por lo tanto, este efecto de polarización conduce a un aumento de la accesibilidad en los nodos de la infraestructura, aislando a las regiones intermedias de los polos de atracción de las empresas.

Para resumir esta subsección, podemos afirmar que hay tres aspectos que explican por qué la inversión en infraestructura no ha tenido impacto sobre el crecimiento económico y la convergencia entre las regiones: el producto marginal decreciente del capital, el sistema de financiación y los incentivos en el diseño de los contratos.

Efectos de las infraestructuras de transporte sobre el mercados de trabajo

La relación entre la infraestructura y el factor trabajo tiene dos vertientes. Por un lado, el trabajo es un input y un coste. Por otro lado, la inversión en infraestructura puede tener efectos positivos sobre el trabajo a nivel agregado que afecten tanto a la oferta como a la demanda del mercado; desde el lado de la oferta, la mejora de las infraestructuras de transporte reducen el tiempo de desplazamiento incrementando el número de trabajadores potenciales para una ubicación dada y, desde el lado de la demanda, las empresas pueden obtener ganancias de productividad derivadas de un mejor *matching* en el mercado laboral.

Así, la literatura existente enfatiza el papel que desempeña la infraestructura pública en las decisiones de producción y la localización de las empresas (Munnell y Cook, 1990). Por lo general, hay dos enfoques para analizar los efectos de la inversión en infraestructura sobre las empresas, la función de producción y la función de costes. El enfoque de la función de producción se centra en los cambios en los niveles de producción total, mientras que la función de costes pone énfasis en los cambios en los costes de transporte de los inputs y los productos.

En primer lugar, los cambios en la infraestructura de transporte pueden llevar a ajustes en los inputs utilizados, ya que puede proporcionar nuevas posibilidades de producción. El stock de la infraestructura de transporte puede ser introducido en la función de producción a través de dos canales diferentes; puede considerarse como un nuevo input, contribuyendo directamente a la función de producción, tal y como ocurre tradicionalmente con el trabajo y el capital. O, puede ser incluido como un factor que aumenta la productividad de otros inputs utilizados. En este caso, las mejoras en las infraestructuras de transporte puede considerarse generalmente como un incremento en la tecnología de producción que aumentan la productividad global. Este enfoque tiene la ventaja de captar la relación de complementariedad entre los factores, esto es, el stock de capital de la infraestructura no contribuye a la producción sin la utilización de los otros factores.

En segundo lugar, la infraestructura de transporte también puede aumentar la productividad de las empresas reduciendo los costes de transporte de los inputs y los productos. Es decir, un incremento en la fiabilidad del transporte permite a las empresas reducir los costes de stock o inventario o también permite mejorar el acceso a los clientes finales, alentando a las empresas a aprovechar las economías de escala al servir mercados más grandes. Esto se traducirá en una reducción de los costes medios a largo plazo que, a su vez, generan un aumento de la productividad. Además, la inversión en infraestructuras de transporte puede ser la responsable directa de aumentar la productividad del trabajo, mediante la reducción del tiempo de viaje (SACTRA, 1999).

La reducción de los costes facilita a las empresas ampliar sus mercados y experimentar ganancias de productividad que podrían dar lugar a la reducción de precios de sus productos. La caída de los precios relativos estimularía la demanda de productos producidos por dichas empresas, lo que aumentaría, a su vez, la demanda de trabajadores y su impacto vendría determinado por la elasticidad precio-demanda del producto (Button, 1998). Además, un entorno más productivo podría ser favorable para atraer nueva inversión lo que estimularía la expansión de las empresas existentes y atraería inversión privada generando un aumento de la producción global y una mayor demanda de empleo.

Por lo tanto, las áreas del mercado de trabajo tienden a aumentar en base a la reducción de los costes de desplazamiento (SACTRA, 1999; Vickerman, 2002). La reducción de los costes de transporte permite a los trabajadores aumentar el área de búsqueda de empleo y hacer viajes más largos para un coste generalizado equivalente. La mejora de los servicios de transporte permite, por tanto, a las empresas contratar trabajadores provenientes de regiones más alejadas.

Además, la mejora de la accesibilidad anima, también, a nuevos trabajadores a incorporarse al mercado laboral por la aparición de nuevas oportunidades. Borjas (1996) sugiere que los costes de transporte afectan las decisiones individuales de las personas sobre su incorporación al mercado de trabajo sobre la base de que los costes del trayecto elevan el salario de reserva que, a su vez, reducen la probabilidad de ingresar en el mercado laboral. No obstante, la reducción del tiempo de viaje y los costes asociados, por la mejora de las infraestructuras, eliminan o reducen significativamente esta barrera facilitando a los individuos la búsqueda de empleos con salarios más altos o iguales que su salario de reserva.

La idea básica de esta corriente de la literatura es que la decisión de localización de las empresas y los hogares es simultánea (Carlino y Mills, 1987; Boarnet, 1994). Dado que los trabajos y los individuos se localizan de manera conjunta, algunas empresas pueden preferir ubicarse cerca de un gran número de clientes y mano de obra calificada. Además, pueden aparecer respuestas migratorias que conduzcan a un aumento de la población, lo que represente no sólo el aumento de clientes potenciales en el mercado local de las empresas, sino también un incremento de la fuerza de trabajo potencial en la región. Esa es la razón principal por la que estos efectos potenciales de inversión de infraestructuras de transporte en los mercados laborales y de productos también pueden ser un factor determinante de la ubicación de las empresas.

Sin embargo, en el largo plazo, los estudios proporcionan resultados no concluyentes. La literatura que versa sobre el impacto de las carreteras en el empleo es un claro ejemplo. Algunos estudios encuentran que el empleo está positiva y significativamente relacionada con el stock de infraestructura vial (Lombard *et al*, 1992; Dalenberg *et al*, 1998), el gasto público (Carroll y Wasylenko, 1994, Islam, 2003), y la disponibilidad de acceso a las autopistas (Luce, 1994, y Boarnet, 1994), otros estudios no muestran un efecto significativo (Duffy-Deno, 1998; Clark y Murphy, 1996). Mientras que otros trabajos establecen que un aumento del capital invertido en carreteras (Pereira, 2000) o del gasto público (Dalenberg y Partridge, 1995) podrían reducir la demanda de empleo agregada.

Podemos, por tanto, afirmar que el efecto de la inversión en infraestructuras públicas sobre el empleo ha sido ampliamente estudiado aunque no exista consenso sobre el signo y la magnitud de los resultados, generando incertidumbre en el diseño de políticas publicas destinadas a fomentar el empleo, a través de la inversión en la dotación de infraestructuras.

Los beneficios laborales asociados al gasto público en infraestructura podrían reducirse rápidamente después del período de construcción, por lo que deberíamos considerar si el efecto no es más que un cambio temporal del nivel de empleo debido al gasto del gobierno.

En cierta medida, el resultado final va a depender de la movilidad de la fuerza laboral. La concentración de la actividad económica induce a los trabajadores a trasladarse a la región más grande con el fin de encontrar mejores oportunidades de trabajo y salarios más altos. Este fenómeno, que se debe en parte a la reducción de los costes, puede generar un efecto sobre la productividad en la región más grande que puede tener efectos sobre los ingresos fiscales si existe un incremento en las horas de trabajo o, si éstos se trasladan a empleos más productivos.

Este efecto puede ser significativo a nivel individual y, al mismo tiempo, tener efectos sustanciales sobre el PIB, especialmente en el caso de las infraestructuras de transporte que son usadas principalmente por motivos de trabajo, como podrían ser el metro u otras infraestructuras de transporte local (Venables, 2007). Por tanto, éstos efectos deben incluirse en el análisis coste-beneficio ya que, por lo general, se ignoran al suponer la existencia de mercados de trabajo perfectamente competitivos.

Pilegard y Fosgerau (2008) muestran que las consecuencia de omitir imperfecciones en el mercado de trabajo pueden ser considerables. La reducción de los costes de transporte permite realizar la búsqueda de empleo en un área más grande por lo que, la duración esperada de los puestos vacantes se reduce, provocando que los beneficios compensen la pérdida derivada de los sobrecostes de transporte. Además, demuestran que las imperfecciones en el proceso de búsqueda abre una brecha entre el producto marginal del trabajo y el salario, tal que los beneficios finales de una mejora de transporte exceden los presentados en un coste-beneficio convencional.

La principal fuente de imperfección es la ausencia de información completa necesaria para alcanzar equilibrios en el mercado laboral en cada momento del tiempo. El trabajador se enfrenta, usualmente, a un *trade-off* entre su trabajo ideal y los costes de transporte; en primer lugar, un trabajador podría aceptar un trabajo que no coincide perfectamente con su trabajo ideal, pero en el que los costes de transporte son bajos compensado la pérdida anterior o, en segundo lugar, podría aceptar su puesto de trabajo más alejado que se vería compensado por los costes adicionales de desplazamiento.

En el caso de existir incertidumbre en el proceso de búsqueda, el trabajador tiene que elegir sopesando si buscar únicamente a nivel local evitando altos costes de transporte con un riesgo asociado de la duración del desempleo más alta o buscar en un área más amplia reduciendo la duración esperada del desempleo aunque afrontando costes de transporte más altos. Bajo este contexto, los trabajadores toman decisiones de búsqueda en base a los costes de desplazamiento y la duración del desempleo esperados. Como es habitual en este tipo de problemas, el trabajador maximiza su utilidad esperada alcanzando un resultado subóptimo.

Puede concluirse esta relación sosteniendo que, a nivel agregado, los resultados no son concluyentes. La movilidad del factor es un aspecto crucial para maximizar los beneficios potenciales de la mano de obra asociada a la construcción o mejora de la infraestructura y, el precio relativo del trabajo es fundamental para alcanzar el equilibrio final entre las regiones, teniendo en cuenta que dicho factor se remunera a su productividad marginal

A nivel regional o local, los efectos se caracterizan más fácilmente y se ha demostrado que existe un efecto de la infraestructura en la elección individual de los trabajadores y las empresas. La inversión de la infraestructura, si y sólo si reduce costes de transporte, mejora el *matching* en el mercado de trabajo y genera economías de aglomeración. Pero, este impacto también se vería afectado por problemas de información, en cuyo caso, parte de los beneficios asociados a la inversión en infraestructura se perderían debido a los costes de transporte adicionales que se incurren en el proceso de búsqueda de empleo.

Los efectos de las economías de aglomeración

Las economías de aglomeración son efectos sobre la dimensión espacial de la actividad económica que surgen de la proximidad de los agentes con independencia de si los rendimientos crecientes a escala se deben a la concentración de consumidor/proveedor (Glaeser *et al.*, 2001), a los efectos secundarios empresariales (Klepper, 2007) ó a la concentración en el mercado laboral (Marshall, 1920). Formalmente, hay, por lo tanto, una imperfección de mercado que es necesario analizar y cuyos principales mecanismos de transmisión son:

- *Spillovers* tecnológicos. Es más probable que las empresas aprendan las innovaciones de otras empresas si están físicamente cerca, y la evidencia sugiere que es lo es aún más si están cerca de empresas similares.
- Efectos en los mercados de factores. Al ubicarse juntos, los proveedores y los compradores pueden minimizar los costes de transacción y transporte, compartiendo una infraestructura costosa y manteniendo los precios bajos debido al efecto de la competencia.
- Efectos del mercado de trabajo. Es más probable que las empresas encuentren los trabajadores idóneos cuando se localizan cerca de mercados de trabajo más amplios.

Centrándonos en los *spillovers* tecnológicos como mecanismos de transmisión de las economías de aglomeración, Jaffee *et al.* (1993) proporcionan la evidencia más convincente de que la difusión de conocimientos es importante y se atenúa con la distancia geográfica. Su resultado se basa en que las citas de patentes están altamente concentradas en el espacio. Otros trabajos, como Jaffee (1989) y Acs *et al.* (1992) coinciden con los resultados anteriores.

Las economías de aglomeración podrían también surgir de la concentración de consumidores esencial para el suministro al por menor de productos, debido a la existencia de elevados costes fijos en la distribución. De hecho, las áreas con mayor número de personas tienden a tener un mayor número relativo de puntos de venta al por menor.

Glaeser *et al.* (2001) sostienen que hay cuatro formas fundamentales en el que las grandes ciudades fomentan el consumo. En primer lugar, pueden existir bienes y servicios disponibles en las grandes ciudades que no están disponibles en otras de menor tamaño; en segundo lugar, las grandes ciudades pueden ofrecer atractivos diversos; en tercer lugar, las ciudades de gran tamaño puede proveer bienes públicos que no serían posible en ciudades más pequeñas y, finalmente, la densidad de una ciudad grande permite que la velocidad de interacción entre los agentes sea mayor.

En relación al mercado de trabajo, existen varios aspectos de interés. Los trabajadores encuentran mejores oportunidades de empleo en las grandes ciudades (efecto urbanización) o en las concentraciones industriales (efecto localización), en consonancia con la idea de Marshall sobre la especialización de la mano de obra como ventaja competitiva. En segundo lugar, los trabajadores y las empresas hacen frente a riesgos de diversa índole en el mercado de trabajo (riesgo moral y selección adversa) por lo que la concentración los reduce, por ejemplo, a través de mecanismos de intermediación especializados.

En el mercado local, la concentración de la demanda fomenta la aglomeración (Corsetti *et al.*, 2005). Se supone que la existencia de rendimientos crecientes conducen a la concentración del empleo en fábricas de mayor tamaño creando, de este modo, mercados mayores, los cuales, en presencia de los costes de transporte inducen a otras empresas a elegir la misma localización. La idea subyacente es que la interacción entre las economías de escala internas en la producción y los costes de transporte conducen a un proceso de auto-refuezo de la aglomeración que surge cuando los agentes económicos se localizan cerca los uno de los otros (Marshall, 1920).

En este sentido, hay por lo menos tres dimensiones sobre las que las economías de aglomeración pueden ser estudiadas. La primera es la dimensión industrial. Esto es, el grado en que las economías de aglomeración se extienden a través de las industrias.

Henderson (1974) afirma que las externalidades son más fuertes en algunos sectores que en otros, por lo que es razonable sugerir que las ganancias de productividad en regiones más densas se deben en parte a un cambio en la estructura de la industria. Holmes y Stevens (2004) muestran que en las industrias de servicios, los pequeños establecimientos se localizan principalmente en las áreas aglomeradas, reforzando la creación de grandes urbes.

En el caso de la gran empresa, las multi-planta y de las multinacionales manufactureras, donde el *know-how* es un activo esencial, la mayoría de las empresas se oponen a la concentración geográfica con sus rivales por las pérdidas potenciales netas asociadas a la pérdida de información (Simmie 1998;

Cantwell y Iammarino, 2000). De hecho, este fenómeno se observa en sectores altamente tecnológicos con un uso intensivo de información (Arita y McCann, 2002; McCann *et al.,* 2002), así como sectores de fabricación más tradicionales, especialmente para empresas en el que la infraestructura de transporte sigue siendo importante en la decisión de localización.

La segunda dimensión es geográfica. La discusión de la aglomeración comienza con la idea de que la distancia geográfica es fundamental, ya que las economías de aglomeración se atenúan con la distancia; esto es, si los agentes están físicamente más cerca, entonces hay más posibilidades de interacción (Moomaw, 1983).

Rosenthal y Strange (2003) consideran que, en un modelo de creación de empresas, los impactos de empleo en la propia industria y sobre el empleo total dependen directamente del alcance geográfico de las economías de aglomeración. Henderson (2003) encuentra efectos de localización.

La tercera dimensión es temporal. Las economías de aglomeración no son un fenómeno estático y, es posible, que la interacción de un agente con otro agente en el pasado continúe teniendo efectos sobre la productividad en el presente. Esto significa que dos agentes que están separados temporalmente continúan afectándose el uno al otro y el grado en que estas interacciones están separadas en el tiempo definen el alcance temporal de las economías de aglomeración. Glaeser *et al.* (1992) y Henderson *et al.* (1995) lo incluyen en su modelo de crecimiento y demuestran que las características de una ciudad puedan afectar su crecimiento durante un período superior a los veinte años.

Pero, en teoría, este tipo de estimaciones pueden verse afectadas por la existencia de simultaneidad cuya principal solución es el uso de variables históricas, un ejemplo, es el uso de la variable densidad de población retardada que es un instrumento del tamaño de la ciudad (Ciccone y Hall, 1996). A excepción de Henderson (2003) que estima las economías de aglomeración utilizando datos de panel a nivel de empresa con estimador GMM (Método Generalizado de los Momentos), Ciccone y Hall (1996), Ciccone (2002), Henderson (2003) y Rice *et al.* (2006) entre otros tratan la endogeneidad mediante la estimación utilizando mínimos cuadrados en dos etapas (MC2E) con variables instrumentales para predecir la densidad.

Ciccone y Hall (1996), Rice *et al.* (2006), y Combes *et al.* (2006) instrumentan los niveles de densidad de empleo usando retardos sobre la densidad de población. Su tesis es que las densidades que observamos hoy se determinan por patrones previos de concentración de la población, que no están correlacionados con los niveles de productividad actuales. Por ejemplo, Ciccone (2002) utiliza como instrumento la superficie total de las regiones de la Unión Europea, mientras que Rosenthal y Strange (2005) utilizan datos sobre las características geológicas argumentando que la variación en la densidad se debe a dichas características que no se correlacionan con la productividad, ni con las habilidades del factor trabajo.

Sin embargo, la evidencia indica que si la aglomeración tiene un componente endógeno, éste parece inducir un sesgo no sustancial en las estimaciones de aglomeración. De hecho, Ciccone y Hall (1996) y Ciccone (2002) encontraron cambios muy pequeños en la estimación de las economías de aglomeración utilizando variables instrumentales en lugar de estimador mínimos cuadrados ordinarios. Del mismo modo, Rosenthal y Strange (2005) concluyen que la influencia de los regresores endógenos es pequeña, mientras que Henderson (2003) informa que la correlación entre las variables explicativas y el término del error es también insignificante.

En realidad, el problema de endogeneidad es muy difícil de abordar de manera satisfactoria, debido principalmente a las limitaciones de los datos disponibles. Esa es una de las razones principales por las que existe una línea de investigación actual que se centra en los incrementos de la accesibilidad como resultado de las mejoras en el transporte, (Ahlfeldt y Wendland, 2009, Bowes y Ihlanfeldt de 2001, Chandra y Thompson, 2000; Gatzlaff y Smith , 1993, Gibbons y Machin, 2005, McMillen y McDonald, 2004; Michaels, 2008).

Sin embargo, la mayor parte de estos trabajos siguen sin tratar la posible existencia de endogeneidad, ya que suponen la existencia de causas exógenas, tales como la presencia de grupos de presión político y dificultades orográficas o técnicas que impiden trazar una relación directa entre el diseño de la infraestructura, en el proceso de toma de decisiones, y la actividad económica de las regiones afectadas.

Los trabajos anteriores, además, usualmente simplifican el mundo real a uno en el que existen dos regiones conectadas por una infraestructura única, sin explicitar sus características. No tienen en cuenta que en un mundo más complejo, aumentos en la productividad dentro de la región estudiada pueden provenir de disminuciones en otras regiones debido a los cambios en la distribución espacial de la actividad económica.

Por lo tanto, esta línea de investigación se centra en los incrementos de accesibilidad que son incapaces de discernir si la correlación positiva entre aglomeración y productividad es una consecuencia de la aglomeración o, si la aglomeración, al mismo tiempo, es una consecuencia de la alta productividad.

Esta discusión muestra que las externalidades de aglomeración existen, sin embargo, su análisis se basa en que los datos de las industrias y áreas están usualmente agregados a nivel espacial y, en ocasiones, a escalas en las que la aglomeración no puede ser capturada. Por ello, Graham (2006) resume que para tratar empíricamente las economías de aglomeración se necesita de algunas propiedades deseables:

- El marco de modelización espacial debe evitar unidades predefinidas en áreas administrativas y debe permitir identificar la variación en las economías de aglomeración en una escala espacial pequeña. Un enfoque común es contemplar el empleo dentro de una cierta distancia, medida en términos de distancia o tiempo.
- La medida de aglomeración utilizada debe enfatizar la distancia o la densidad con el fin de incluir una dimensión de transporte.
- El análisis debe tener en cuenta una cobertura sectorial detallada.
- La estimación debería permitirnos aislar los rendimientos de la urbanización de los efectos a escala.

En virtud de las propiedades anteriores, los efectos de aglomeración pueden ser dependientes de la densidad efectiva y pueden ser definidas como la accesibilidad de cualquier empresa a cualquier industria localizada en un radio dado, lo que está claramente condicionado por la infraestructura de transporte.

Este hecho nos permite caracterizar la accesibilidad en términos de coste generalizado para capturar el efecto de las infraestructuras de transporte en la aglomeración. La existencia de más agentes en un radio dado puede exceder la capacidad de la infraestructura lo que también puede generar congestión del tráfico y reducir los beneficios potenciales de la aglomeración.

Las empresas, por tanto, consideran sus propios costes de transporte pero no si su uso de las infraestructura afecta a los costes de transporte de otras empresas.

Hay, pues, un conjunto de fuerzas opuestas que determinan, de manera conjunta, el tamaño de las ciudades y de las aglomeraciones.

En consecuencia, el efecto de las economías de aglomeración depende del impacto del sistema sobre la densidad efectiva en las zonas afectadas, como una medida del tamaño de la economía. Por ejemplo, en el caso del empleo, el objeto de análisis no sólo debe ser el número de puestos de trabajo creados , sino también ha de tenerse en cuenta el número de puestos de trabajo destruidos.

Las infraestructuras de transporte, en ese sentido, pueden mejorar la densidad efectiva atrayendo empleos o reubicándolos. El resultado final será positivo si produce incrementos de empleo en las ciudades y negativos si fomenta la dispersión de la actividad económica. Esa es la razón por la cual el efecto final debe incluir todas las áreas incluso las que pueden sufrir dicha dispersión.

Teniendo en cuenta el argumento anterior, la movilidad del factor trabajo es crucial como se ha afirmado a lo largo de esta sección. En esta línea, Monfort y Ottaviano (2000) afirman que los mercados laborales más eficientes pueden producir diferencias persistentes en las tasas de desempleo, entre las regiones condicionadas a la movilidad del factor trabajo. Si existe, el trabajo se moverá hacia regiones con salarios reales más altos mientras que de lo contrario, las diferencias salariales persistirían y actuarían como una fuerza de dispersión debido al aumento de los costes de producción.

Sin embargo, la movilidad de los factores depende directamente de la legislación y la infraestructura de transporte. La provisión de infraestructuras a nivel regional pueden actuar como un promotor para la generación de economías de aglomeración locales (Marshall, 1920). Venables (2007) muestra que la inversión en transporte puede fortalecer las externalidades de aglomeración disponibles para las empresas e inducir efectos positivos sobre la productividad incrementando de forma efectiva la densidad urbana.

Duranton y Turner (2008) estiman el efecto que el crecimiento de carreteras ha tenido en la población y el empleo. Este análisis se ha desarrollado utilizando una aproximación de variables instrumentales basados en un plan estatal de carreteras diseñado en 1947 (utilizado anteriormente por Baum-Snow (2007) para analizar el efecto que la construcción de autopistas tiene en la población de las ciudades). Duranton y Turner (2008) concluyen que un aumento del 10% en el stock de carreteras en las ciudades aumenta la población en un 2% y disminuye el porcentaje de hogares que carecen de recursos financieros.

Ahora bien, la movilidad de los factores, esencial para la creación de economías de aglomeración, se ve limitada por los problemas de capacidad de las infraestructuras de transporte. Cuando la demanda supera la capacidad máxima de la infraestructura, surge la congestión, externalidad negativa, que dificulta el desarrollo potencial de las economías de aglomeración. Además, las infraestructuras pueden quedar obsoletas, por razones tecnológicas o por el movimiento espacial de la población y de la actividad económica, lo que también reduce las posibilidades de generación de economías de aglomeración.

Graham (2007b) investiga la relación entre la productividad y la densidad de empleo, comparando dos medidas diferentes de la densidad: una en términos de distancia y la otra basada en el coste generalizado que, indirectamente refleja el efecto de congestión y, en consecuencia, la capacidad limitada de la infraestructura. El trabajo concluye que el crecimiento de la productividad se basa en economías de aglomeración urbana y que éstas pueden ser obtenidas tanto por el crecimiento del empleo como por la disminución de los tiempos de viaje subrayando el efecto negativo de la congestión en la creación de economías de aglomeración.

Resumiendo, cabe destacar la complementariedad entre la mejora de las infraestructuras de transporte y las economías de aglomeración. La aglomeración surge de la concentración de los distintos agentes económicos; consumidores, empresas o trabajadores y se transmiten a través de los procesos tecnológicos y los mercados de inputs, lo que genera beneficios positivos para los que se ubican juntos dando lugar a incrementos de productividad. Claramente, la movilidad de los factores es esencial para que los agentes se concentran y es allí donde la infraestructura de transporte juega un papel central.

Las economías de aglomeración están estrechamente ligadas a la existencia de un sistema de transporte eficiente que permita la movilidad de factores. Si no hay movilidad, no importa cuán eficiente es la infraestructura de transporte que no habrá economías de aglomeración y diferencias persistentes, en términos de salarios, pueden surgir entre las distintas regiones. Al mismo tiempo, si no hay un sistema de transporte eficiente, no importa cuán móvil son los factores que las infraestructuras de transporte afectaran dicha movilidad, lo que nos permite afirmar que existe una relación de complementariedad entre estos dos aspectos.

La infraestructura de transporte, en particular, se caracteriza por su capacidad limitada, si la demanda supera dicha capacidad aparece la congestión, a partir de la cual las externalidades negativas, la congestión, afectan a los beneficios potenciales de aglomeración.

La competencia imperfecta

En relación a los efectos económicos adicionales relacionadas con las estructuras de mercado podemos establecer dos: los efectos sobre los mercados en los que existe poder de mercado y que usan el transporte como un input y los efectos sobre la competencia como resultado de la implementación del proyecto.

Por un lado, las empresas con poder de mercado, que suponemos incapaces de discriminar precios perfectamente, fijan precios superiores al coste marginal, por lo que la cantidad demandada es inferior al óptimo social, lo que genera una pérdida de bienestar social, porque existen consumidores con una disposición a pagar por el bien superior al coste de producción pero que no pueden adquirir el bien.

Bajo este escenario, una disminución de los costes de transporte conlleva una reducción del precio de mercado y un incremento en el nivel de producción que, a su vez, genera una reducción de la pérdida de bienestar. Aunque los consumidores no están dispuestos a pagar más que el precio de equilibrio, ni los productores están dispuestos a producirlo, existe un beneficio adicional que no es capturado ni en el excedente del consumidor, ni en el del productor y que coincide con la diferencia entre el precio y la cantidad por el incremento de la producción.

Es importante tener en cuenta que el efecto puede ser negativo si en los mercados secundarios en los que existe poder de mercado, las empresas venden menos porque la reducción en los costes de transporte afecta positivamente un producto que es sustituto en los mercados secundarios.

Por tanto, bajo condiciones de competencia imperfecta, la valoración de los costes y beneficios a precios de mercado no es apropiada, lo que puede llevar a la existencia de distorsiones en la localización de fondos y en la toma de decisiones sobre proyectos públicos, produciendo una asignación subóptima entre las distintas industrias. Venables y Gasoriek (1999) estima que los beneficios económicos adicionales derivados de la competencia imperfecta podrían situarse en torno al 30% del total. Newbery (1997), por su parte, enfatiza que el coste de evaluar dichos efectos, por su complejidad, no siempre se ve compensada con la posible mejora de la estimación de los beneficios económicos.

Newbery (1997) señala que el efecto de la competencia imperfecta se debe a dos factores; el margen precio-coste y la elasticidad de la demanda. Venables y Gasoriek (1999) asumen un margen precio-coste de 0,2, y una elasticidad de la demanda en la región de 2, mientras que Newbery (1997) establece valores de 0,05 y 0,5, respectivamente. Por tanto, el efecto de la competencia imperfecta, en este último caso, sería del 2,5%. Finalmente, DfT (1999), a nivel empírico, establece que los márgenes precio-coste en diversos sectores en el Reino Unido entre 0,1 y 0,3.

Por otro lado, la implementación de un proyecto de transporte puede tener efectos sobre la competencia de los mercados en la región afectada. Esto es, cuando los costes de transporte son elevados, proyectos que los reducen pueden facilitar la entrada de nuevas empresas que encuentra rentable ofrecer sus productos en relación a la situación sin proyecto en la que el incumbente está protegido por las barreras a la entrada que le proporcionan los costes de transporte.

Este efecto de incremento de la competencia con la entrada de nuevas empresas se espera no sea sustancial en economías con infraestructuras de transporte maduras, ya que en estos países no se esperan incrementos significativos de la eficiencia derivados de la reducción de los tiempos de viaje por la intervención en el mercado de transporte. Sin embargo, este efecto podría ser más importante en aquellos proyectos que afecten a países o regiones que se encuentran aislados o con escasa conectividad, caso habitual de los países en vías de desarrollo.

Por lo tanto, se espera que la competencia tenga menor efecto en los países más desarrollados. Venables y Gasoriek (1999) muestran que el impacto de la reducción de los costes de transporte pueden conducir a una mayor aglomeración lo que genera efectos desiguales en las regiones conectadas por la misma infraestructura. En el caso de una distribución espacial del tipo centro-periferia, la reducción de los costes de transporte puede promover la reorganización de la producción en la región central generando fusiones, adquisiciones o quiebras que permiten a las empresas restantes satisfacer una mayor demanda a un coste más bajo.

Siguiendo el argumento anterior, Elborst *et al*. (2010) muestran que los beneficios económicos adicionales en proyectos que vinculan a un núcleo y su periferia son mayores que en aquellos proyectos que enlazan dos regiones altamente urbanizadas. Las regiones periféricas suelen ser más pequeñas que la región central y suelen presentar estructuras de mercado más propensas a la existencia de poder de mercado. De este modo, la reducción de costes permite a las empresas de la región central, normalmente más eficientes por la presión competitiva de su mercado, abastecer a las regiones periféricas provocando una reducción del poder de mercado de las empresas situadas en dichas regiones.

Ahora bien, este efecto no ha de confundirse con las ganancias de bienestar que surgen del incremento de la producción en los mercados con poder de mercado, explicado anteriormente.

Los efectos medioambientales, los accidentes y la congestión

La Comisión Europea ha prestado atención a los efectos medioambientales de las actividades de transporte, redactando documentos y recomendaciones sobre la política de transporte, tales como European Commission (1995), que aborda principalmente los sistemas de precios más adecuados para internalizar los costes externos, o European Commission (2006) que se centra en el uso eficiente de la infraestructura.

En general, el objetivo final de todos estos documentos es internalizar los costes externos, para mejorar la eficiencia del sistema de transporte, garantizar la igualdad de trato entre los modos y mejorar la seguridad a la vez que los impactos ambientales negativos se reduzcan.

Las externalidades producen diferencias entre los costes privados (soportados directamente por el agente) y los costes sociales (soportados por la sociedad). Esto introduce incentivos perversos en la oferta y la demanda de transporte lo que genera una pérdida de bienestar. Bajo esta definición, el precio óptimo se establece cuando el coste marginal social y el ingreso marginal social son iguales, y en el caso de los costes de transporte, éstos pueden clasificarse en varias categorías:

- Costes derivados de la restricción de capacidad. Incluye todos los costes asociados con densidades de tráfico elevados.
- Costes de los accidentes. Cubren todos los costes directos e indirectos relacionados con los materiales, gastos sanitarios, policiales,…
- Costes medioambientales. Incluyen todos los costes medioambientales relacionados con problemas de salud, daños a la propiedad, daños a la biosfera y riesgos de largo plazo. Se trata principalmente del ruido, la contaminación del aire y el cambio climático o el efecto invernadero.

En cuanto al cambio climático, es necesario diferenciar entre varias consecuencias (Watkiss, 2005):

- Aumento del nivel del mar. Implica la necesidad de protección adicional por la pérdida de humedales e incremento de tierras secas. Estos costes dependen de factores sociales y políticos que afectan las decisiones futuras en las que la protección está justificada.
- Consumo de energía. El impacto depende fundamentalmente de la temperatura, por lo que se ve claramente condicionada por un componente estacional de su demanda.
- Impactos sobre la agricultura. Dependen de los cambios regionales de temperatura y precipitaciones, así como de los niveles de dióxido de carbono atmosférico.
- Impactos en el suministro de agua potable. Dependen de los cambios en las tasas de precipitación y la evapotranspiración y los cambios en la demanda. La demanda de agua por los sistemas biológicos se ve afectada por factores climáticos, incluyendo la temperatura y la humedad.
- Impactos en la salud. Además de los efectos directos sobre la mortalidad que pueden ser muy pequeños, la propagación de enfermedades y epidemias podrían tener un impacto mucho mayor, sobre todo en las sociedades menos desarrolladas.
- Ecosistemas y biodiversidad. Se encuentran entre los efectos más difíciles de cuantificar y son uno de los efectos directos de la construcción de infraestructura.

En el caso de la contaminación del aire, Givoni (2003) distingue los efectos que alcanzan la estratosfera, la troposfera y la atmósfera. Según esta clasificación, los efectos ambientales globales están relacionados con las emisiones de gases en la troposfera y la estratosfera, mientras que las emisiones de contaminación local están relacionadas con la atmósfera que es la capa más cercana a la tierra. Con el objetivo de destacar su peligrosidad vamos a considerar, a modo de ejemplo, algunas de las emisiones más importantes. Por ejemplo, el óxido de nitrógeno, que afecta a la morbilidad y mortalidad humana, directa e indirectamente, a través del cambio climático, produciendo efectos negativas sobre la capacidad del sistema inmunológico, el óxido de azufre que afecta directamente al sistema respiratorio y puede causar enfermedades pulmonares y, el dióxido de carbono que surge de la combustión incompleta y que se emite, principalmente, por parte de la industria de transporte, afectando inevitablemente a la capa de ozono.

Este hecho abre la discusión entre cual de los modos de transporte es preferido, teniendo en cuenta los costes medioambientales. Desde este punto de vista, Givoni (2003) señala que el avión es más dañino para el medio ambiente, en términos operativos, que los trenes de alta velocidad, debido principalmente a sus efectos sobre el cambio climático. Este resultado está en consonancia con INFRAS/IWW (2004) que alcanza la misma conclusión recogiendo una definición más amplia de las externalidades e incluyendo los efectos del ruido, la contaminación del aire urbano, los accidentes y los efectos del cambio climático.

Hay que tener en cuenta que la comparación entre ambos modos ha de considerar que los efectos medioambientales de la operación de los trenes de alta velocidad difieren en función de la procedencia de dicha energía. Sin embargo, la diferencia entre los modos se está reduciendo y se espera continúe esa tendencia. En este sentido, Kagesson (2009) y Atkins (2004) obtienen resultados opuestos a los anteriores cuando incluyen los costes ambientales resultantes de la fase de construcción debido a que las infraestructuras de alta velocidad ferroviaria requieren, entre otros, un uso intensivo de maquinaria pesada altamente contaminante.

Otra fuente de externalidad es la reducción en el número relativo de accidentes y la congestión, que dependen fundamentalmente de la capacidad de la nueva infraestructura para desviar el tráfico de los modos alternativos.

En el análisis de los efectos económicos de la nueva infraestructura hay que incluir las externalidades junto a los beneficios y los costes de construcción, operación y mantenimiento de la infraestructura.

Regulación de las externalidades medioambientales

Los agentes económicos demandan la emisión de sustancias contaminantes para crear actividad económica, por lo que éstos tienen disposición a pagar por la misma y un coste asociado a su reducción. Por tanto, la creación, en principio posible, de un mercado regulado a través de la definición de los derechos de propiedad es una solución factible.

Para ello, podemos considerar dos tipos básicos de regulación: cantidades y precios. En el primer caso, se trata simplemente de limitar la cantidad máxima de sustancias contaminantes que se pueden emitir, dado que los agentes tienen una disposición a pagar por cada unidad hay un mercado y un precio de equilibrio en el que dicho mercado se vacía. En el segundo caso, podemos considerar un precio máximo de modo que los agentes puedan emitir hasta el punto en el que éste se iguala con su disposición a pagar. En ese caso, el precio indirectamente fija la cantidad máxima de sustancias.

Bajo el supuesto de información perfecta, la regulación en precios y cantidades son equivalentes, Weitzman (1974). Sin embargo, la incertidumbre asociada a la emisión final de contaminantes hace que la regulación anteriormente propuesta no sea directamente aplicable.

Por ello, los gobiernos han creado un conjunto amplio de alternativas para elegir como controlar las emisiones de sustancias nocivas. Entre los instrumentos más destacados encontramos normas, impuestos y permisos de emisión negociables y su elección tiene implicaciones de eficiencia.

En un mundo donde los costes de reducción son inciertos, las medidas anteriores pueden producir un volumen de emisiones que se desvíe del óptimo. Un sistema de regulación de la cantidad máxima en el nivel de emisiones esperada genera un nivel de emisiones inferior (superior) cuando los costes de reducción son mayores (menores) de lo esperado mientras, un impuesto óptimo, por otra parte, induce niveles de emisiones superiores (inferiores).

Weitzman (1974) muestra bajo el supuesto de coste marginal de reducción (MAC) y beneficio marginal de reducción (MAB) lineales que el sistema *cap-and-trade* reduce los costes sociales esperados en mayor medida que el mecanismo de regulación por impuesto unitario siempre y cuando la pendiente del MAB sea mayor que la de MAC.

Por esta razón, diversos trabajos se han dedicado a buscar instrumentos que puedan reducir aún más los costes sociales esperados. Roberts y Spence (1976) muestran que un sistema *cap-and-trade*[1] combinado con un precio máximo y subsidios sobre la reducción da lugar a un volumen de emisión más cercano al nivel eficiente *ex-post* que el que se alcanzaría bajo un impuesto por emisión o un sistema puro de *cap-and-trade*. A pesar de esto, el instrumento híbrido de Roberts y Spence es de difícil implementación por su complejidad.

Pizer (1999, 2002) analiza una versión más simple, que consiste en un sistema de *cap-and-trade* combinado con un precio máximo, conocida como válvula de seguridad, y muestra que dicho instrumento reduce sustancialmente los costes sociales, en comparación con un sistema puro *cap-and-trade* o un sistema impositivo.

Otra forma de reducir los costes sociales esperados sería indexar la cantidad máxima a una variable correlacionada (Quirion, 2005; Newell y Pizer, 2006). La regulación indexada ha sido usada en otros contextos. Por ejemplo, algunos sistemas de derechos de emisión permiten a las empresas emitir una cantidad determinada por unidad de producción. Otro ejemplo es el tipo de sistemas de certificados verdes para la industria eléctrica que encontramos en Noruega, Suecia y en el Reino Unido en la que se define el nivel objetivo (la cantidad de electricidad verde producida) como fracción del consumo total de electricidad. Por otra parte, en el contexto del cambio climático, las cuotas nacionales de emisión indexadas al PIB o población de los países se ha discutido como un medio para atraer a los países en desarrollo a un tratado sobre el clima, (Baumert *et al*. 1999, Lutter, 2000 y Ellerman y Sue Wing 2003).

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[1] Se trata de un sistema regulador o de control que fija un nivel de objetivo para las emisiones o el uso del recurso natural, y, después de distribuir las partes en ese orden, permite determinar su precio.

Mandell (2008) apunta otra posibilidad para reducir los costes sociales que consiste en dividir los emisores en dos grupos y dejar que un grupo sea objeto de regulación mediante un sistema impositivo sobre las emisiones mientras que el otro, este sujeto a un sistema de *cap-and-trade*. Éste muestra que estos dos instrumentos van en direcciones opuestas a partir del volumen de emisión eficiente ex-post cuando los costes de reducción se desvían de los esperados y que, por ello, es posible encontrar una combinación de los dos instrumentos que reduzca el coste social incluso cuando los emisores en los dos grupos no enfrentan el mismo precio. Estos mecanismos teóricos presentados se enfrentan siempre a las dificultades de implementación mencionados anteriormente y serán abordados con más detalle en el capítulo 4.

El papel de los accidentes y la congestión en la evaluación de la infraestructura

Los accidentes representan un coste externo en términos del sistema de salud, seguridad y los daños a terceros. Incluso cuando los usuarios internalizan parte del coste pagando por el seguro sigue existiendo una externalidad.

Es decir, los usuarios tienen en cuenta algunos de los costes asociados con la posibilidad de tener un accidente, pero no todos, por lo que algunos de ellos se transfieren a la sociedad en su conjunto, dando lugar a un uso excesivo, de los modos de transporte afectados, desde una perspectiva social, lo que genera una pérdida de bienestar social.

Entre ellos destacamos la pérdida de vidas, cuyo valor se estima en la literatura como el valor de una vida estadística, consistente en la disposición a pagar por reducir la probabilidad de morir en un accidente de tráfico, la pérdida de bienestar para la familia y amigos, y otros costes entre los que incluyen daños a la propiedad de los activos físicos. El primer coste es el más importante y el que más atención ha recibido en la literatura.

Por lo tanto, la externalidad tiene dos orígenes. Por un lado, los agentes no consideran la pérdida de bienestar de familiares y amigos y los daños a los activos físicos y, por otra parte, la decisión del conductor individual afecta a la probabilidad de accidente para todos los usuarios de la infraestructura.

Desde un punto de vista empírico, hay varios trabajos que han cuantificado los costes externos de los accidentes de tráfico. En Elvik (2000), el coste para los países de la OCDE oscila entre el 0,5 y el 5,7% del PIB. Otros autores consideran que estos han sido sustanciales (Maddison *et al*., 1996 y Pearce, 1993). Sin embargo, Peirson *et al*. (1997) realizan un análisis de carácter microeconómico donde muestran que estos han sido sobreestimada en muchos casos, ya que suponen que el número de accidentes tiene una relación proporcional con el flujo de vehículos (ver Vickrey 1968, 1969 y Newbery, 1987).

La congestión, a su vez, se produce por un desajuste entre la demanda o número de usuarios que desean utilizar una infraestructura o servicio en un momento dado y la oferta o capacidad de la misma para acomodar puntualmente a dichos usuarios que, además, rara vez es constante a lo largo del tiempo. Las consecuencias son incrementos de tiempo de viaje de los usuarios, esto es, el número de usuarios de la infraestructura de transporte tiene impacto sobre el tiempo de viaje individual y, por esta razón, la congestión puede considerarse como una externalidad en el sentido de que se genera por parte de unos agentes que no tienen en cuenta los costes que están imponiendo al resto de usuarios de la infraestructura.

Concretamente, la congestión podría diferir entre aquellas situaciones en las que la entrada a la infraestructura es libre y, por lo tanto, no existe ningún tipo de coordinación asociada con el uso de la infraestructura y aquellas infraestructuras donde la entrada está regulada mediante un sistema de adjudicación de *slots*, como es el caso de los aeropuertos. En el primer caso, el precio no juega ningún papel, mientras que, en el caso de que la entrada a la infraestructura esté regulada, la política de precios es crucial y puede ser utilizada no sólo para reducir el nivel de tráfico, sino también para transferir tráfico entre los períodos pico y valle.

Otro problema de la congestión, desde el punto de vista de la política de transporte es conocer la elasticidad de la reducción de la congestión con respecto a la oferta de infraestructura. Este aspecto es importante para poder realizar un análisis coste-beneficio sobre la conveniencia de la infraestructura. Cervero (2002) muestra que los estudios que evalúan los efectos de la nueva infraestructura determinan elasticidades positivas aunque éstas varían considerablemente en valor absoluto.

La congestión y los accidentes de carretera están en última instancia interrelacionadas, ya que ambas son externalidades generadas por los usuarios de la infraestructura. Sin embargo, su relación no ha sido ampliamente estudiada. Shefer y Rietveld (1997) y Shefer (1994) estiman una relación indirecta entre la congestión y los accidentes, aunque estos estudios utilizan la densidad de tráfico como *proxy* de la congestión. Los estudios que utilizan variables de flujo son Belmont y Forbes (1953), y Ceder y Livneh (1982) que estiman una relación en forma de U. Otros artículos tales como Turner y Thomas (1986) y Golob y Recker (2003) han demostrado que la relación entre el flujo de vehículos y la gravedad de los accidentes es negativo.

En resumen, los beneficios asociados a la reducción de la congestión se espera que sean inferiores a los relacionados con la reducción de accidentes. El primero está principalmente dirigido por la relación entre la capacidad y la demanda de la infraestructura mientras que el segundo es más dependiente de las condiciones del tráfico de la infraestructura.

La estructura de la tesis es la siguiente; el capítulo 1 revisa la literatura existente a lo largo de los contenidos que serán abordados en el resto de capítulos y que incluye los efectos macroeconómicos sobre las regiones afectadas por la inversión de las infraestructuras de transporte, los efectos sobre los mercados de trabajo, las economías de aglomeración y los efectos sobre la competencia en los mercados de bienes y servicios, esto es, el conjunto de efectos económicos adicionales derivados de la inversión. Finalmente, en ese mismo capítulo, se contempla una revisión de la literatura sobre los principios de la regulación medioambiental y sobre la importancia que las externalidades negativas como los accidentes y la congestión tienen en la evaluación de las infraestructuras.

El capítulo 2 se centra en los efectos, a nivel regional, que la inversión en la red de alta velocidad española tiene sobre la densidad de empleo. Como ya se ha destacado previamente, la alta velocidad ferroviaria ha sido el modo de transporte escogido por las elevadas inversiones necesarias para su construcción que dada su magnitud cabría esperar que generen impactos significativos de la actividad espacial.

En el capítulo se realiza una panorama de la literatura sobre la densidad de empleo y las ganancias de productividad, y el papel que las infraestructuras juegan en su generación concentrándose en las características de la alta velocidad ferroviaria y su capacidad para cambiar la distribución espacial de la actividad económica. A continuación, se explica el proceso de recogida y tratamiento de los datos así como un análisis descriptivo de los mismos. Además, se detallan las aproximaciones econométricas utilizadas para cuantificar las relaciones entre las variables de interés.

Finalmente, se muestran los principales resultados desde las diferentes bases de datos y estimaciones econométricas; discutiéndose y cuantificándose la importancia de la alta velocidad ferroviaria española en el incremento de la densidad de empleo. Además, se presenta una discusión de los resultados y sus implicaciones en términos de políticas públicas.

El capítulo 3 incluye una revisión de la literatura sobre los conceptos de congestión y accidentes, enfatizando su relación con las infraestructuras de transporte considerando las especificidades del caso español, las fuentes de los datos y la metodología empleada para estimar los mencionados impactos prestando atención particular a la aproximación econométrica y justificar su conveniencia. Además, se calculan los beneficios sociales de los accidentes y la reducción de la congestión.

El capítulo 4 se ocupa de la regulación medioambiental y la propuesta de un mecanismo regulatorio que permite en condiciones de incertidumbre alcanzar niveles de emisiones más cercanas al óptimo social que los mecanismos alternativos propuestos en la literatura existente. En la siguiente subsección, se presenta nuestra propuesta y se identifican las condiciones bajo las cuales se reducen los costes sociales esperados en comparación con el resto de instrumentos considerados.

En el capítulo 5, se resumen las principales conclusiones extraídas del conjunto de los análisis presentados y las recomendaciones de políticas públicas que se desprenden de la investigación realizada.

II. Objetivos

El objetivo de este trabajo consiste en contrastar diversas hipótesis sobre el impacto que las infraestructuras de transporte tienen sobre la actividad económica del país o región en el que se desarrolla. Las estimaciones empíricas presentadas se centran en la influencia de la alta velocidad ferroviaria en España, caracterizada por altos niveles de inversión durante las últimas dos décadas.

El primer capítulo presenta la revisión de la literatura académica relativa a la relación entre la inversión en infraestructuras y la existencia de efectos económicos adicionales y, el tratamiento de externalidades que no están recogidos en los ahorros de tiempo de los que se benefician los usuarios.

Se trata de una revisión de los trabajos existentes sobre los efectos económicos adicionales y los efectos medioambientales que la inversión en infraestructuras de transporte genera. El objetivo principal del capítulo es situar la investigación en el conjunto de los trabajos científicos previos, realizar un análisis crítico de la literatura existente e identificar los problemas metodológicos de la literatura para contextualizar nuestras aportaciones.

Los capítulos 2 y 3 están centrados en las aportaciones empíricas de la tesis. En el capítulo 2, el objetivo principal es cuantificar el impacto que la alta velocidad ferroviaria española tiene sobre las economías de aglomeración, medida como el efecto que la infraestructura tiene sobre la densidad de empleo a nivel municipal. De dicho análisis se derivan varios objetivos secundarios: en primer lugar, se estima el impacto de la inversión sobre las economías de aglomeración con el uso de estimadores de datos de panel dinámicos y variables instrumentales, lo que supone una aportación metodológica respecto a los trabajos previos recogidos en la literatura científica.

En segundo lugar, se construye una base de datos a nivel municipal, que permita descubrir los impactos de la infraestructura al nivel de agregación en el que las economías de aglomeración desarrollan todo su potencial. Este hecho nos permite aislar el impacto de la infraestructura sobre las regiones afectadas con el uso de técnicas de *matching* estadístico.

Finalmente, se discute sobre si los efectos calculados previamente pueden considerarse efectos netos de la infraestructura o se deben a la simple relocalización de la actividad económica, siendo, por tanto, el incremento generado en una región, una pérdida en sus regiones adyacentes.

En el capítulo 3, el objetivo principal es cuantificar el efecto que la construcción de la alta velocidad ferroviaria ha tenido sobre la reducción del número de accidentes y los niveles de congestión en los corredores afectados por dicha infraestructura en España. Un objetivo secundario es la construcción de una base de datos que permita dicho análisis y, el uso de herramientas econométricas que permitan cuantificar el efecto directo entre las variables de interés y el cálculo final de los beneficios que éstos generan a lo largo de la vida del proyecto.

En el capítulo 4, se trata de determinar un mecanismo de regulación que de lugar a un resultado eficiente en la asignación de los recursos en el mercado de emisiones de sustancias contaminantes con problemas de información entre el regulador y el emisor. Para ello, hay que minimizar el coste social esperado de la política regulatoria y obtener mejores resultados que los planteados en la literatura. Los objetivos secundarios son los siguientes: en primer lugar, comparar el modelo alternativo planteado con los existentes en la literatura científica, en segundo lugar, establecer un modelo que permita ser simulado a partir de valores reales tal que pueda entenderse e interpretarse de la manera más gráfica y directa posible.

III. Planteamiento

La inversión en infraestructuras de transporte afecta a la localización de la activad económica, y los gobiernos suelen invertir en infraestructuras dentro de la política de desarrollo regional.

Los proyectos de transporte son evaluados teniendo en cuenta los efectos sobre la accesibilidad, el medioambiente y la seguridad. Las evaluaciones estiman los beneficios sociales y los costes, relativos al caso base. Estos efectos sobre el bienestar incluyen ahorros de tiempo y mejoras de la fiabilidad y el confort, así como otros factores medioambientales.

Las guías y los métodos de evaluación están en constante desarrollo y esta tesis es parte, de algún modo, de esa evolución. Se centra en analizar la presencia y magnitud de algunos de los efectos económicos adicionales, que contribuyen al impacto de las actividades de transporte sobre la productividad y el PIB y surgen de la existencia de imperfecciones de mercado. Esto implica que la valoración individual de los impactos difiera de la valoración social de los mismos.

Un supuesto básico de la evaluación de proyectos convencional es que el bienestar social generado por una mejora en el transporte es igual al valor del ahorro de tiempo de viaje. Esta aproximación, es generalmente una simplificación aceptable cuando no existen imperfecciones de mercado. Sin embargo, los mercados son, en numerosas ocasiones, imperfectos y por tanto, es necesario capturar los efectos de dichas imperfecciones para alcanzar una evaluación completa que va más allá de los ahorros de tiempo de viaje.

El planteamiento de esta tesis es, por tanto, establecer métodos teóricos y empíricos que permitan cuantificar algunos de los efectos económicos adicionales que no son capturados en la evaluación de proyectos tal como, generalmente, se analiza en la práctica. Esta tesis identifica los principales impactos y emplea dichos métodos para su evaluación individual.

IV. Metodología

La metodología de la tesis se distingue en base al capítulo analizado. El capítulo 1 se ocupa de la revisión de la literatura que contiene un trabajo exhaustivo de recopilación de información, y contextualización de la tesis con respecto a los estudios previos, mientras que los capítulos 2 y 3 contienen el análisis empírico y el capítulo 4, se centra en una aproximación teórica.

El capítulo 1 recoge el análisis de literatura de manera transversal a los temas tratados en la tesis, ocupándose de cada uno de los aspectos relevantes en la discusión de las infraestructuras de transporte y los beneficios económicos adicionales, así como la regulación medioambiental y las repercusiones que estos tienen sobre las políticas de transporte, concretamente para el caso de la alta velocidad ferroviaria española. En dicho apartado, el esfuerzo metodológico se centra en la capacidad de análisis y síntesis necesario para la recopilación de información y el tratamiento de la misma.

En el capítulo 2, se analiza el impacto de la alta velocidad ferroviaria sobre la densidad de empleo en las regiones que la poseen controlando no sólo la dimensión espacial del problema, sino también la dimensión temporal. Para ello, ha sido necesario el uso de herramientas econométricas y el uso de datos a nivel municipal.

La razón de tal nivel de desagregación se debe a que las economías de aglomeración, en la mayor parte de los casos, se generan a nivel local o regional puesto que está muy relacionado con los cambios en la accesibilidad que proporciona la nueva infraestructura.

Con el objetivo de controlar la naturaleza espacial de la alta velocidad en España sobre las poblaciones circundantes en términos de incrementos de la densidad de empleo, se utilizan herramientas de georeferenciación, tales como los programas SIG (Sistemas de Información Geográfica). Para ello, fue necesario georeferenciar las líneas de alta velocidad existentes y determinar las áreas de influencia.

En la actualidad, existen cuatro corredores principales de alta velocidad en España, aunque en el análisis se excluyó el corredor Este porque se completó en

2010. Por tanto, se incluyen las rutas entre Madrid y Sevilla, Córdoba y Málaga y Madrid – Toledo (Corredor Sur), Madrid – Zaragoza – Barcelona y Zaragoza – Huesca (Corredor Norte) y Madrid – Valladolid (Corredor Noroeste), que conjuntamente conforman 18 estaciones y 1.665 kilómetros de alta velocidad.

Con el uso del SIG, establecimos de manera *ad hoc* círculos concéntricos alrededor de las estaciones de alta velocidad ferroviaria, con el objetivo de establecer áreas de influencia dentro de las cuales analizamos el impacto de las economías de aglomeración. El análisis se realizó para áreas de influencia con un radio de 10 y 20 kilómetros, no sólo para determinar si las estaciones de alta velocidad atraen empleo y actividad económica alrededor de las mismas, sino también para capturar el efecto dinámico espacial con el que determinar si los efectos, en caso de existir, son mayores cuanto más cercanos estamos de las estaciones.

Una alternativa sería incluir una variable que capturara la distancia del centro del municipio a la estación, pero el uso de datos de panel y efectos fijos eliminan esta posibilidad por tratarse de una variable constante en la componente temporal, razón por la cual, las estimaciones no son capaces de aislar su coeficiente. Además, la comparación entre las distintas áreas de influencia establecidas nos facilita la extracción de implicaciones de política, importantes en relación a la atracción de la actividad económica.

Las bases de datos usadas en la construcción de los datos de panel fueron el Anuario Económico Municipal de La Caixa y el Instituto Nacional de Estadística (INE). La primera consiste en un conjunto de datos estadísticos e indicadores económicos de cada uno de los 3.252 municipios españoles que superan los 1.000 habitantes a fecha 1 de enero de 2009 y cuya población total representa el 96.8% del conjunto del país. Los datos estadísticos incluyen datos sobre el número de trabajadores, obtenidos a través del Servicio Estatal de Empleo, la población y su composición e indicadores de la actividad económica (número de vehículos a motor, sucursales bancarias, actividades industriales, comercio minorista, mayorista,…). La segunda fuente nos proporciona acceso a datos de población pertenecientes a un periodo anterior (1986-1991) que habían sido recogidos por el INE para todos los municipios españoles.

Una vez construida la base de datos, el trabajo consiste en establecer una ecuación que pudiera ser estimada empíricamente y que fuera capaz de explicar la densidad del empleo, expresada en logaritmos, para los municipios analizados, diferenciado si éstos están o no bajo el área de influencia de la alta velocidad ferroviaria. Para ello, se construyó una variable dicotómica que toma valor 1 en los años de operación de la alta velocidad y 0, en otro caso. El análisis conjunto incluye el uso de variables de control que capturan la influencia de la renta y las condiciones socio-económicas a nivel municipal.

Una vez dichas variables han sido definidas se procede al análisis descriptivo de las mismas, y se calcula la media condicionada a la existencia o no de la alta velocidad ferroviaria con el objetivo de observar si existen diferencias significativas para ese momento de la distribución entre los municipios bajo la influencia de la alta velocidad y los que no lo están.

Con posterioridad se construyen dos muestras diferenciadas que darán lugar a aproximaciones econométricas ligeramente distintas. En una primera aproximación, consideramos el conjunto de municipios españoles incluidos en la base de datos distinguiendo únicamente por su pertenencia a un área de influencia de la alta velocidad ferroviaria, a través de la variable binaria anteriormente mencionada, mientras en la segunda aproximación realizamos un experimento pseudo-natural.

En este caso, usamos el subconjunto de ciudades con alta velocidad y las comparamos con un número seleccionado de municipios. La selección de este segundo subconjunto se realiza en base a un proceso de *matching* estadístico, tal que somos capaces de identificar a los mejores candidatos para la construcción de una futura e hipotética estación de alta velocidad por las similitudes con estos que ya tienen una. Una vez han sido identificados, construimos también una hipotética área de influencia con círculos concéntricos de 10 y 20 kilómetros como en la muestra original.

Esta aproximación nos permite realizar una comparación entre dos muestras similares, debido a la eliminación de los municipios que nunca podrían tener una estación de alta velocidad ferroviaria y que, por lo tanto, podrían distorsionar los resultados. Este hecho incrementa la efectividad de las variables dependientes o de control, limitando el sesgo en las estimaciones que podrían aparecer por el sesgo de selección.

Finalmente, la estrategia econométrica se divide en dos etapas. Primero, realizamos estimaciones econométricas usando datos de panel con efectos fijos. En segundo lugar, abordamos la estimación de datos de panel dinámicos que permiten el uso de variables instrumentales.

En el capítulo 3, se aborda el impacto de la alta velocidad, una vez construida, sobre los accidentes y la congestión en las carreteras, a través de la desviación de tráfico de este modo. Durante la última década se ha invertido en nuevas infraestructuras, en especial, en la alta velocidad ferroviaria a pesar de lo cual la carretera tiene entorno a un 95% de la cuota de mercado de pasajeros y mercancías.

Desde un punto de vista metodológico, es necesario averiguar el efecto de la alta velocidad ferroviaria sobre la carretera, en términos de velocidad y reducción de accidentes, para lo que se acomete un método de estimación indirecto.

Una vez conozcamos dichos impactos es necesario conocer el valor de una vida estadística y la valoración monetaria de los daños personales para calcular los beneficios de la reducción de accidentes y el valor del tiempo para los beneficios de la congestión.

En el primer caso, el valor estadístico de la vida se obtiene de Bicket *et al.* (2006) valorada en € 1,302,000 y que se incrementa con la renta de acuerdo a la elasticidad unitaria (Bicket *et al.,* 2006). Dado que el coste social de dicha externalidad es el valor estadístico de la vida por el número de accidentes y que, en la última década, se ha producido un descenso de los mismos, la evolución de dicho coste es incierta.

La congestión, por su parte, está altamente presente en los alrededores de las ciudades, tiene un importante componente temporal. A nivel agregado, la amplia red de carreteras españolas mitiga los impactos que podría ocasionar, en términos económicos. Sin embargo, el hecho que la alta velocidad ferroviaria y las autopistas se construyen en el mismo corredor nos permite predecir el impacto que la alta velocidad tiene y que podría ser significativo dentro del contexto español.

La congestión tiene lugar en determinados periodos del día (periodos punta) y su coste condicionada por dos aspectos, la velocidad media y el valor del tiempo de los usuarios afectados. En el caso de España, la velocidad de circulación está limitada en las autopistas (120 km/h) lo que nos permitirá conocer el tiempo de congestión usando la diferencia entre la velocidad teórica de la carretera y la real.

El otro aspecto que determina los beneficios sociales de la congestión es el valor del tiempo que incluye el conjunto de usuarios de un vehículo privado, conductor y pasajeros. El valor del tiempo depende, entre otros factores, del propósito del viaje, siendo mayor para viajes de trabajo que de ocio. El valor del tiempo para España ajustado por la paridad del poder adquisitivo y expresado en Euros de 2002 es 12.71 euros para viajes de ocio y 25.95 euros para viajes de trabajo (Bicket *et al*. ,2006)

Además, hay que considerar que el valor del tiempo se incrementa bajo condiciones de congestión como resultado de la desutilidad adicional asociada a estas condiciones de tráfico. Así, Wardman (2001, 2004) considera que bajo circunstancias de congestión el valor del tiempo es 48% mayor que bajo condiciones de tráfico normal, Eliasson (2004) considera un factor de conversión de 1.5. La elasticidad entre la renta y el valor del tiempo en Europa es de 0.4-0.5 (Gunn *et al.*, 1996, Hensher and Goodwin, 2004), y 1 (Mackie *et al.*, 2001).

Los datos sobre los niveles de tráfico en las carreteras afectadas por la construcción de la alta velocidad provienen de los Mapas de Tráfico del Ministerio de Fomento que nos permite conocer tanto el número de accidentes, los flujos de tráfico, la velocidad de circulación y otras características de las carreteras españolas, anualmente para el período 1999-2008. Un modo simple de aproximar el impacto de una nueva infraestructura de transporte sobre el número de accidentes sería, como se citó anteriormente, conocer el tráfico de carretera desviado y la elasticidad de accidentes de tráfico. Sin embargo, esta información no está disponible, así que el efecto tiene que ser calculado indirectamente.

La información descrita ha sido extraída de las estaciones de aforo de las autopistas que circulan de manera paralela a los corredores donde la alta velocidad está presente. La base de datos es más amplia para los accidentes que para la velocidad, ya que no todas las estaciones de aforo recogen datos sobre la velocidad de circulación.

La existencia de datos anteriores y posteriores a la implementación de la nueva infraestructura, y el uso de un conjunto de variables de control, nos permite construir un contrafactual. Éste consiste en comparar los niveles de accidentes y congestión antes y después del periodo del comienzo de funcionamiento del tren de alta velocidad en el corredor. Por tanto, la diferencia entre ambos periodos (antes y después) nos proporciona el impacto de la infraestructura sobre los niveles de accidente y congestión.

En el proceso de recogida de datos hay que tener en cuenta que existen estaciones de aforo en las que la velocidad establecida está por encima de la máxima permitida por lo que estás han sido eliminadas con el objetivo de evitar problemas de sesgo en las estimaciones.

Las variables de control utilizadas pretenden capturar los elementos principales que pueden afectar los niveles de accidentes y congestión, tales como el porcentaje de vehículos pesados en relación al total del tráfico, la existencia de puntos negros, el tipo de carretera, el esfuerzo inversor de la región, así como una variable binaria que toma valor 1 cuando la carretera está afectada por la existencia de la alta velocidad ferroviaria y 0 en caso contrario.

La estimación se realiza con 1.530 observaciones recogidas de las estaciones de aforo del Ministerio del Interior existentes en los Mapas de Tráfico. Ambas estimaciones muestran resultados similares y altamente robustos a especificaciones alternativas.

Por tanto, este simple modelo nos permite capturar la mayor parte de la variación de la variable endógena y nos muestra que el efecto de la operación de la alta velocidad ferroviaria es significativa sobre la reducción del número de accidentes.

El caso de la congestión es ligeramente diferente porque no se trata de una variable directamente observable así que tenemos que centrar nuestro análisis en los cambios de velocidad asociados a la introducción de alta velocidad ferroviaria como modo de transporte alternativo. Con la correspondiente estimación de dicho impacto, podremos transformar los cambios de velocidad en cambios en tiempo y valorar el efecto de la congestión.

El procedimiento es el siguiente; una vez conocemos los ahorros en términos de tiempo, tenemos que multiplicar por el valor de tiempo de los usuarios para transformarlo en unidades monetarias, bajo el supuesto que el 30% de los viajes se realizan por motivos de trabajo. Finalmente, tendríamos que determinar el número de pasajeros y el número de kilómetros que los usuarios conducen para lo que se supone que el factor de carga de los vehículos ligeros es 1.3 y el factor de desutilidad aplicado por causas de la congestión es 1.5. También, es necesario conocer el origen-destino de los pasajeros que están en el corredor de la alta velocidad ferroviaria, ya que no todos los conductores recorren la línea completa y por tanto, estos no están afectados del mismo modo por los problemas de congestión.

En este caso y dada la ausencia de datos detallados a nivel de carreteras de origen-destino, utilizamos datos recopilados por la encuesta Movilia (Ministerio de Fomento, 2007). También se considera que los coeficientes de origen-destino son constantes a lo largo del tiempo y, por consiguiente, pueden ser aplicados al año 2010.

Finalmente, en el capítulo 4, la aproximación a la regulación medioambiental es teórica. El uso de herramientas matemáticas y el conocimiento de los modelos existentes permite la configuración de un conjunto de funciones matemáticas que interactúan entre sí y que, en este caso, caracterizan el mercado de emisiones de sustancias contaminantes. Con el objetivo de buscar la máxima simplificación posible en el análisis que, posteriormente, permitan sacar conclusiones directas sobre los parámetros de interés se ha optado por trabajar con funciones lineales.

Se propone un mecanismo de regulación alternativo a los propuestos de manera más reiterativa en la literatura, por lo que uno de los desafíos metodológicos es construir un modelo que permita la comparación de los resultados entre las distintas propuestas. De este modo, se estiman los valores de las condiciones de los parámetros bajo los cuales la alternativa propuesta, en esta tesis, es preferible a las alternativas existentes en la literatura

Dado que en estos modelos interactúan un gran número de variables y que, por tanto, en ocasiones aparecen interdependencia entre ellas se propone la realización de simulaciones con datos reales sobre el modelo planteado para conocer como éste se comporta bajo las distintas combinaciones de parámetros.

IV. Aportaciones originales

Los efectos económicos adicionales no pueden descartarse aunque estén lejos de tener una magnitud similar a los beneficios directos como los ahorros de tiempo. Los beneficios económicos adicionales, que son ignorados en una evaluación convencional, reflejan la existencia de imperfecciones en el mercado.

En el caso de las economías de aglomeración, éstas dependerán del impacto de la densidad efectiva, en términos de empleo, de las áreas afectadas. La densidad efectiva del empleo es una medida del tamaño económico de una localización que describe el nivel de aglomeración, a través del número de empleos. En este sentido, la tesis permite establecer una relación entre las infraestructuras de transporte y la densidad de empleo y aporta un mecanismo novedoso de estimación con el uso de datos de panel y el uso de efectos fijos que permiten aislar de manera nítida dichos efectos.

Finalmente, se propone un mecanismo de regulación de emisiones de sustancias contaminantes que alcanza mejores resultados que las propuestas en la literatura en un contexto de asimetrías de información entre el organismo regulador y los emisores de sustancias contaminantes. De este modo, se reduce la pérdida de bienestar esperada de los sistemas regulatorios propuestas para un amplio rango de parámetros. En este último caso, la aportación no es metodológica porque el modo de resolución del problema es estándar, consistiendo en el mecanismo de regulación propuesto.

V. Conclusiones obtenidas

La revisión de la literatura presentada ha puesto de manifiesto la necesidad de realizar mejoras en el tratamiento de los datos, la falta de datos comparables y fácilmente medibles, y los problemas metodológicos de gran parte de los trabajos empíricos existentes. Por ello, es necesario que la investigación siga avanzado para determinar los efectos económicos adicionales netos que nacen con la inversión de infraestructuras de transporte y que no son, siempre, incorporados a la evaluación coste-beneficio convencional.

En el análisis de los impactos que la alta velocidad ferroviaria tiene sobre la densidad de empleo y, por extensión sobre las economías de aglomeración, se realiza una comparación e interpretación en las dos áreas de influencia que han sido establecidas de acuerdo a lo explicado previamente en el apartado metodológico. Esta comparación se realiza desde dos dimensiones diferentes, comparando las bases datos, con y sin *matching* estadístico, para una distancia dada o comparando la misma base de datos para distintas distancias. Por un lado, se observa que la base de datos de municipios homogéneos elimina el sesgo de selección y proporciona un impacto más bajo a la construcción de la alta velocidad que la base de datos con el conjunto de municipios españoles.

Por otro lado, se demuestra que hay un descenso en el impacto que la alta velocidad ferroviaria tiene sobre las regiones circundantes a medida que se alejan. Esto es, la construcción de una infraestructura de alta velocidad incrementa la densidad de empleo alrededor de la estación de la alta velocidad, pero su impacto disminuye cuando nos alejamos del epicentro.

Si contextualizamos los resultados en relación a la literatura, hay que tener en cuenta que incrementos en la densidad de empleo son únicamente significativos cuando estos se trasladan a incrementos en la producción o productividad. En el presente trabajo, las estimaciones muestran que la existencia de la alta velocidad ferroviaria española proporcionan un incremento en la densidad de empleo del 3.6-4.7% si el área de influencia se extiende a los 10 kilómetros y 1.8-3.7% en el caso de los 20 kilómetros. Este resultado podría significar mucho o muy poco.

Dado los coeficientes presentados y sabiendo que el efecto se desvanece a medida que se incrementan las áreas de influencia debemos atender a la posible relocalización de la actividad económica, no sólo entre áreas de influencia sino en el seno de las regiones. De este modo, los *hinterlands* o epicentros de nuestro análisis (esto es, las estaciones de alta velocidad ferroviaria) reciben los beneficios sociales de la construcción de la infraestructura pudiendo afectar al desarrollo de otras regiones.

Podría argumentarse que los coeficientes estimados se deben al efecto multiplicador keynesiano del gasto público que nace de la inversión pública realizada y que, en principio, surgen con independencia de la naturaleza de dicha inversión. Sin embargo, la variable alta velocidad ferroviaria, toma el valor 1 únicamente en el período de operación del nuevo modo de transporte, evitando la posibilidad de que éstos efectos provinieran del periodo anterior.

Por otro lado, las estimaciones podrían verse afectados por la tendencia económica de los municipios, lo cual podría llevar a errores de magnitud en los resultados. Esto es, la existencia de dos municipios con tendencias divergentes en el tiempo que se vieran potenciadas por la introducción de la nueva infraestructura podría llevar a una sobreestimación de los efectos sobre la densidad del empleo. Sin embargo, el uso de un estimador de efectos fijos o intra-grupo y la comparación entre municipios con similares características mitigan estos inconvenientes.

El punto más controvertido, y de mayor trascendencia para la política pública, es discutir si los efectos capturados están relacionados con incrementos netos en la densidad de empleo y la actividad económica o si se deben a la relocalización de la actividad económica ya existente.

Nuestra explicación es la siguiente; las estimaciones econométricas presentadas no pueden distinguir entre las dos posibilidades. Consideremos dos regiones idénticas antes de la construcción de la línea de alta velocidad ferroviaria, esto es, con la misma densidad de empleo y población. La decisión de inversión es, por tanto, exógena y aleatoria, ya que la estación podía haberse construido en cualquiera de las dos ciudades. Ahora bien, las estimaciones no pueden distinguir entre la creación neta de actividad y la potencial relocalización de la misma entre las regiones. Si como resultado de la inversión en la alta velocidad ferroviaria, la región con la infraestructura incrementa la densidad de empleo, mientras la otra región no se ve afectada; podemos afirmar que el efecto estimado se debe a la creación neta de actividad generada por la nueva infraestructura. Sin embargo, si la infraestructura de transporte generara transferencia de puestos de trabajo entre regiones, produciendo la relocalización de la actividad económica; la diferencia entre densidades, esto es, el impacto estimado sería superior a la creación neta de empleo.

De este modo, los efectos estimados sobre el empleo que surgen de las economías de aglomeración por la construcción de la infraestructura no proporciona información relevante sobre la creación final de los efectos netos. El problema que surge, por tanto, es que los incrementos en la densidad del empleo y la productividad no pueden ser transferidos directamente a los beneficios de la infraestructura. En nuestro caso, no obstante, hay algunos indicadores sobre el posible impacto de la relocalización. A partir de la comparación de las áreas de influencia para la misma muestra podríamos inferir que la relocalización de la actividad económica está presente entre el epicentro y el círculo concéntrico a favor del primero. Sin embargo, no podemos analizar la relocalización esperada entre actividades; esto es, la redistribución industrial. Por ejemplo, el incremento de la actividad relativa a la alta velocidad ferroviaria podría tener efectos sobre otros modos de transporte; el autobús o las aerolíneas como modos de transporte alternativas se verían afectados negativamente así como sus actividades auxiliares.

Con relación al efecto que la alta velocidad ferroviaria tiene sobre la reducción de los niveles de congestión y accidentes, la incertidumbre asociada a la elasticidad cruzada de la demanda entre modos y, consecuentemente, el volumen de tráfico desviado de la nueva infraestructura desde modos alternativas impide el conocimiento directo de los beneficios sociales derivados de la reducción de los accidentes y la reducción de la congestión.

Sin embargo, la posibilidad de comparar el corredor antes y después de la introducción de una nueva infraestructura, controlando por un número de características nos permite estimar el impacto que la infraestructura de la alta velocidad ferroviaria tiene sobre el tráfico de carretera en términos de incrementos de velocidad y reducción de accidentes. Por tanto, este mecanismo indirecto nos da la oportunidad de calcular los beneficios previamente mencionados.

En el caso de la reducción de accidentes, éstos representan alrededor del 5% de los beneficios totales del tren de alta velocidad, mientras que la reducción de la congestión por carreteras derivadas de la creación de la red de alta velocidad representa el 0.03%.

En la cuantificación de los costes de la congestión hay que tener en cuenta que la demanda de transporte no es homogénea a lo largo del día por lo que un análisis más detallado que contemple esta condición podría estimar coeficiente ligeramente mayores que los obtenidos en este trabajo. Otro aspecto a considerar es que los resultados están sujetos a incertidumbre sobre la futura relación entre las variables, tales como el crecimiento en el valor del tiempo o el valor estadístico de la vida. En este sentido, los cambios significativos de cualquiera de estas variables pueden alterar los resultados significativamente. No obstante, todos los supuestos han sido realizados considerando la situación más favorable para el proyecto.

En el capítulo 4 se estudian las propiedades de una política de regulación en el que un grupo de emisores están sujetos a un impuesto por emisión y los otros están protegidos por un sistema de *cap-and-trade* y donde el impuesto de los primeros está indexado al precio del sistema *cap-and-trade*. Con tal política, el nivel impositivo se actualiza con respecto a la función de reducción de costes marginales del sector sujeto a la regulación *cap-and-trade*. El capítulo concluye que una política de indexación linear proporciona mejores resultados en términos la política de regulación estudiada que Mandell (2010) siempre que la covarianza entre los shocks de la función de costes, a la que se enfrentan los dos grupos sea distinta de cero. Mientras que la política de indexación propuesta ofrece mejores resultados que una economía sujeta a una regulación por cantidad o por precio en base a un conjunto de parámetros más amplio que la política mixta.

Por lo tanto, en aquellas economías, como la de la Unión Europea, en la que se combina una regulación basada en sistemas mixtos de precios y cantidades, el regulador puede reducir la ineficiencia esperada indexando los impuestos sobre las emisiones al precio que se establece en los mercados en los que se regula por cantidad. No obstante, las ganancias netas esperadas son pequeñas, al menos para el caso en el que las funciones de costes y beneficios sobre la reducción de emisiones sean positivas. Hay también que destacar que nuestro análisis no incluye supuestos, ni condiciones sobre la importancia potencial de su implementación, ni sobre las creencias a priori sobre la relación de la covarianza y los shocks de sus costes sobre los diferentes sectores.

PARTE II

TESIS DOCTORAL EN LENGUA INGLESA

Chapter 0. Introduction

Transport infrastructure policy is often used to promote economic growth. This dissertation tackles the connection between infrastructure investment and wider economic effects, not captured by savings of user's time. Transport investments generate indirect effects that arise from imperfect markets with complementarity or substitution relation with the market where the investment is undertaken. Moreover, investments interact with economic growth, input and product markets, externalities and the spatial distribution of the economic activity (agglomeration economies).

Under perfect competition, price equals marginal cost and direct benefits of users affected by the investment equals benefits of the project (Dodgson, 1973 and Jara-Diaz, 1986). This is utopic and we should also consider indirect and wider economic effects.

This dissertation aims to develop, theoretically and empirically, the previous research lines. We review the literature, as an essential part of this dissertation, and we focus on three original research. First, we examine, at empirical level, the impact that the construction of the Spanish high-speed rail has on employment density in the regions affected by the infrastructure. Second we discuss the impact of the Spanish high-speed rail on the reduction of road congestion and accidents because of the diverted traffic from roads to the high-speed network. Third, we examine the mechanisms of carbon markets regulation and we propose an alternative regulation generating improvements in the social welfare in a context of imperfect information.

This dissertation is organized as follows: in chapter 1, we review the literature including macroeconomic effects and convergence between regions derived from infrastructure investment, the effects on labour markets, the economies of agglomeration, and the effects on imperfect competitive markets. Lastly, chapter 1 addresses the relationship between environmental effects, accidents and congestion, the regulatory framework, and the role that accidents and congestion play in the assessment of the infrastructure.

Chapter 2 focuses on the regional effects of investment in the Spanish high-speed rail network, especially the impact on employment. It starts with a brief introduction about the role played by infrastructure on employment density and productivity gains, focusing on the characteristics of high-speed rail and its ability to change the spatial distribution of economic activity. We then explain how we collect and process data, and we give a descriptive analysis. We detail the econometric approach chosen to quantify the relationships between the variables of interest. Lastly, we show the main results from the different databases and econometric estimates, and discuss and quantify the relationship between the Spanish high-speed rail system and employment density.

In chapter 3, we review the literature of congestion and accidents, emphasizing their relation with transport infrastructure. We consider the specific Spanish case and the data sources and methodology used to estimate those impacts, paying particular attention to the econometric approach and its justification. We then calculate the social benefits of accidents and congestion reduction.

Chapter 4 deals with environmental regulation and the proposed regulatory mechanism that allows uncertainties in order to establish an optimal solution preferable to those proposed in the literature. We begin with a review of state of the art, then describe the model and summarize some of its results. We present our proposal and identify the conditions under which the expected social costs are reduced compared to the rest of instruments considered (a tax on emissions, a cap-and-trade system and the optimal combination of the two).

The last chapter of this dissertation sets out the main conclusions and some policy recommendations that follow the analysis.

Chapter 1. Literature Review

1.1. Introduction

Transport infrastructure policy is broadly used to promote economic growth. This dissertation tackles the connection between infrastructure investment and wider economic effects, not usually captured in the economic appraisal of investment projects. Transport investments generate indirect effects that arise from imperfect markets with complementarity or substitution relation with the transport market where the investment is undertaken. Transport activities interact with economic growth, input markets, product markets, externalities and the spatial distribution of the economic activity (agglomeration economies) that will be analysed in the dissertation.

This chapter aims to review the effects of transport infrastructure investment on economic activity. We focus on those impacts, not usually considered in a traditional appraisal, such as agglomeration economies, effects on imperfect competitive markets and environmental effects, among others.

This chapter has as its starting point impacts at microeconomic level, though it is obvious that the magnitude of infrastructure investment may have effects on aggregate variables, such as GDP, economic growth,... In fact, governments historically consider the construction or upgrading of transport infrastructure as a tool for enhancing economic activity

Public capital investment is often used to provide a short-term boost to the economy, except when it crowds out more productive investments, because construction activities have a rapid pass-through and a large employment multiplier. This is called a Keynesian effect and is, in principle, common to all possible alternative investments; therefore, the policy question should be how to find the best way of spending public funds on infrastructure.

To evaluate its contribution to society, economists classify the impact of a new project into direct, indirect and wider economic effects. Direct effects arise from the primary market, where the intervention occurs. Indirect effects stem from markets whose products are complements to or substitutes for the primary market, and the price differs from the marginal cost. Lastly, wider economic effects include the remaining impacts that may be important, such as agglomeration economies, effects on imperfect competitive markets or location effects.

Assuming that markets are perfectly competitive, or price equals marginal costs, we could appraise a project ignoring indirect effects[2], but the impact of a transport system cannot be limited to its direct effects. We should include intermodal effects, environmental effects, distortions at macro and micro level in the labour markets derived from agglomeration economies, which have effects on productivity, and other directly imposed external costs.

Regarding the effects on productivity of public capital in general, and of transport infrastructure in particular, there are many contributions that provide a range of results, and face some methodological problems, not fully solved. To some extent, the role of public capital is uncertain; on one hand, it may be a substitute for or a complement to labour—it may crowd out private investment or induce more private investment, affecting positively employment levels. On the other hand, labour markets are also affected directly through the transport infrastructure.

Transport infrastructure may generate larger and more efficient labour markets if there are perfect mobility and complete information. Workers would have complete information and would choose their jobs optimally, improving the matching between workers and firms, which generates productivity gains.

The spatial dimension is relevant under the assumption of perfect mobility. In fact, changes in transport infrastructure and service provision affect the location of firms, changing their accessibility to labour, input or good markets, which increase productivity levels. There is, therefore, a potential dynamic gain, known as agglomeration economics and included in the wider economic benefits.

Agglomeration economies are based on increasing returns to scale in the spatial dimension, and arise from different sources, such input markets or technological spillovers. Agglomeration economies are positive externalities generated by economic agents when they are located closer to each other, and transport is essential to promote them. In this sense, transport facilities and

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[2] There are different procedures for appraising a project. Cost-benefit analysis is the one to which we refer in this document, but there are other alternatives, such as cost-effectiveness or multicriteria analysis.

services have an important influence on a city's accessibility and the trade barriers between regions that, in the end, determine the location of firms, consumers and workers.

Agglomeration economies are also closely related to imperfect competition through transport infrastructure. Isolated markets, these where transport is not developed, are likely to be less competitive. The role of transport infrastructure is clear: the improvement of connectivity reduces the transport costs and new opportunities or threats appear for incumbent operators, increasing the market competitiveness. The final result is a reduction of market power and an increase of social welfare.

Lastly, we must include the externalities, in general, and the environmental effects, in particular, that also determine transport policy. Given their importance, environmental effects will be considered, in this dissertation, separately because the provision of transport services and the construction of infrastructure depend on environmental regulation, especially regulations of CO_2 (carbon dioxide) emissions.

The atmosphere disperses the pollutants associated with global warming around the world regardless of the place where they are emitted. The environmental regulation is central in the discussion of emission consequences and how they evolve, and affect the appraisal of transport policies.

This chapter is organized as follows. In Section 2 we review macroeconomic effects and convergence between regions, highlighting the long-term effects.. Section 3 reviews the impact of infrastructure on the labour market and Section 4 the role of agglomeration economies. Section 5 is devoted to discuss the effects of transport infrastructure on imperfect competition. Lastly, Section 6 describes the environmental impacts, emphasising the role of accidents and congestion.

1.2. Macroeconomic effects and convergence between regions

Public investment is a powerful mechanism for enhancing economic growth and employment in the short-run. However, the final effects are not always the expected effects and the possible crowding out effect on more productive investments should not be ignored.

Aschauer (1989) assesses the responsibility of the government in the economic growth and productivity improvement, giving importance to the public investment. His paper is the seed for a large body of literature focused on exploring the links between aggregate levels of infrastructure investment and economic performance measured by GDP, productivity growth or employment.

Considering the infrastructure as an input in the production function, Munnell (1990a) finds positive effects of public investment on output and economic growth stating that the productivity slowdown of the US was because of a decline in the growth of public infrastructures. However, other papers report opposite results. Some suggest that the marginal product of public capital is higher than the marginal product of private capital (Aschauer, 1989; Fernald, 1992); others say that is approximately equal (Munnell 1990b); others find that is lower than the marginal product of private capital (Eberts, 1986; Holtz-Eakin, 1994), and some authors find that the marginal product of public capital is even negative (Evans and Karras, 1994; Hulten and Schwab, 1991).

Gramlich (1994) argues that the wide range of estimates arises from a list of potential statistical problems, such as endogeneity between productivity and public capital, a spurious correlation due to non-stationary series, or the omission of relevant variables. The endogeneity and the direction of causality are not easily detected statistically[3]; public infrastructures may both follow and lead economic growth. To sort out it, several incomplete empirical solutions are implemented; the most common is the use of panel data.

Panel data allow the use of leads and lags. But, there may be lags in both directions; on one hand, agents need time to adjust to infrastructure changes, and, on the other hand, output growth need time to generate a minimum demand threshold that justifies the new infrastructure. Moreover, some leads should be considered if agents have expectations about future changes in transport infrastructure. All these caveats introduce confusion and difficulties into the econometric estimation, which partly explains the wide range of results (Jiwattanakulpaisarn, 2008).

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[3] Eisner (1991) discusses this question in detail.

There are also two other disadvantages of macroeconomic analyses. First, the measurement of variables may be problematic. The stock of infrastructure is an imperfect variable to measure the effectiveness of transport services and, therefore, its influence on productivity. Second, macro elasticity is useless to take individual decision about a project because it is context-specific—both in type (line or point infrastructure, etc.) and in its position within the network. Consequently, the spatial dimension needs to be discussed.

Investment in one region depends on local conditions, existent transport modes and the infrastructure provision in other regions. The construction of a new infrastructure, in fact, does not guarantee a better performance in the region where is built. Dispersion forces may lead to a delocalization of firms, reducing the expected benefits of the infrastructure.

We can ignore these effects, assuming perfect competition and constant returns to scale in the spatial dimension but these assumptions do not hold because the nature of infrastructure. The traditional modelling rarely considers the spatial dimension and it does not capture the effects on labour markets and on the competitive structure between (within) regions. This is the main argument for the development of the so-called new economic geography[4,5].

It considers that transport costs are crucial; they act as a barrier to entry, limiting the capacity of infrastructure to produce concentration and specialization forces. For example, if there is a fall in transport costs between two regions with high transport costs, this may end up generating a new two-way trade. The final result will, in practice, depend on how large these regions are, how mobile their factors (especially labour) are and how low transport costs must be to produce a flow of activity between the two regions.

On one hand, assuming non-mobility for labour between regions and intermediate transport costs, Krugman and Venables (1995) show that large populated regions benefit from infrastructure improvement as most of economic activity concentrates in these regions. This, at the same time, generates differences in real wages. However, an additional fall in transport costs could make less important for firms to locate close to large markets and low real wages

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[4] See Fujita et al. (1999) and Fujita and Thisse (2002) for a discussion of new economic geography.

[5] The assumption of increasing returns to scale is essential for agglomeration economies. Starret (1978) shows that agglomeration of activities cannot occur in a world of pure and perfect competition where space is homogeneous – a theory that is known as the “theory of spatial impossibility”.

of the smallest region could attract firms that would then become net exporters. On the other hand, assuming labour mobility between regions, Krugman (1991) finds that is possible that all industry concentrates in one region.

Previous models are based on only two sectors per region, which is somewhat unrealistic. Venables (1999) extends the model to a continuum of imperfectly competitive sectors, and shows that there is not only one equilibrium outcome in the industry location. This implies that two identical regions do not necessarily take half of the market share and the final division depends on trade barriers and transport costs. Puga (1999) explores the same connection between transport costs and trade. He shows that industries locate close to consumer demand and spread across regions when transport costs are high, while they concentrate when costs are intermediate.

In short, considering labour mobility, workers move to locations with higher real wages, whilst the lack of mobility induces industries to spread out, leading to similar results to the described by Krugman and Venables (1995).

The difference in real wages between regions may be a consequence of productivity gains derived from agglomeration economies. Venables (2007) formalizes this argument, and shows that estimates of the elasticity of productivity with respect to agglomeration can be used to shed light on the magnitude of this effect. His theoretical model links productivity to transport investment considering effects on city size. His objective is to distinguish changes in the impacts on productivity (agglomeration) arising from transport infrastructure investment derived from resources saved in commuting and from an increase in urban output.

We must take into account that transport infrastructure investment, conditioned largely by technological characteristics, is not the only element to change the spatial dimension of the economic activity. There are also other variables with greater influence on activity relocation, such as the relative prices of production factors between regions or the economic-financial condition (Vickerman, 1991).

From the discussion above, we can establish that it is not possible to apply a common rule to know the final effects of a new infrastructure. But, we have discussed the role of transport costs, and conclude that the time savings derived from transport infrastructure improvement or construction do not always generate regional convergence, because the final results depends mainly on the initial levels of transport costs and on the mobility of factors.

1.2.1. The long-term effect and convergence between regions

We focus on the effect of public investment on infrastructure in the long run, and its capacity to achieve regional convergence. To discover whether public capital is productive, it is not enough to show that the public investment will stimulate long-term growth. At least three considerations must be addressed.

First, we must consider whether a permanent increase in public investment induces a permanent, or a temporary, increase in economic growth. The neoclassical growth model of Solow (1956) predicts that any positive effect on economic growth of an increase in the national savings and investment rate is transitory; the steady-state growth rate is fully determined by population growth and exogenous technological progress. In this setting, an increase in spending on productive public capital projects induces a period of temporarily high investment, but the pace of capital accumulation, and of economic growth slow over time as the accumulation of capital diminishes the return to capital and the incentive for further investment. In the long run, the level of output is higher but the growth rate of output returns to the same level as it was before the public spending initiative.

Second, the effect of an increase in public investment on economic growth is likely to depend on the relative marginal productivity of private versus public capital. An increase in public investment raises (lowers) the economic growth rate depending on whether the marginal product of public capital exceeds (is exceeded by) the marginal product of private capital. This consideration validates the concerns of Aaron (1990); the range of empirical estimates of the output elasticity of public capital is too large to be informative to the public policy.

Third, the effect of public investment on growth is likely to depend on how the increased spending is financed. Empirical studies such as those of Engen and Skinner (1996) find evidence that increases in tax rates reduce the rate of economic growth. An increase in public capital, which, in most cases, will require an increase in tax rates, will stimulate economic growth only if the productivity impact of the public capital exceeds the adverse tax impact.

Concretely, in the case of Spain, during the 80s and 90s, the percentages of GDP devoted to public investment in transport infrastructure in Spain and Germany were the highest in the European Union (EU), and the contribution of this public investment to growth was high enough to continue this expansive policy (Mas et al., 1996). However, the investment is far from decreasing progressively and today the percentage doubles the EU average what, following the neoclassical theory, has led to a decrease in growth (Mas, 2007)[6]. The marginal production of capital diminishes with its accumulation, reducing its effect on economic growth. This is the reason why the effect on long-term growth is unclear and why we should be pessimistic with respect to the contribution that transport infrastructure makes to the economic growth, (Mas, 2007).

Another considerations to appraise the impact of public infrastructure on growth are the financing mechanism and the tax structure. In Spain, transport policy is in hands of national and regional governments. We must contemplate the incentives of different levels of government for the regional financing mechanism, essential to explain the promotion of transport infrastructure investment and the tendency to overinvest.

The fiscal policy provides too less incentives for an efficient use of funds, there is no a direct correspondence between expenses and collected taxes. It encourages regions to exaggerate their needs for funds from the Structural Fund because otherwise the funds would go to another region.

To explain the possible overinvestment in Spanish infrastructure, it is also particularly important to assess the effectiveness of contracts between different levels of government that play a crucial role. The uncertainty associated with the life of a project and the risk sharing in the project makes more difficult to attain efficiency in the choice of contracts (Socorro and de Rus, 2010). Moreover, the Spanish regulation reduces the interest of private agents to avoid the proliferation of public infrastructure projects with a reduced social value, since the renegotiation of concession contracts unbalances risk allocation to the detriment of taxpayers.

In conclusion, Spanish transport and infrastructure policies are not based on a strategy that prioritises socially desirable projects, as it shows the commitment

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[6] The economic crisis may change this scenario and the expansive policy could be over.

to high speed rail that is a transport mode with high fixed costs and expensive maintenance costs (Campos et al., 2009) that requires a higher demand level than the existent in Spain with reduced effects on the convergence between regions. [7]

This particular infrastructure is associated with a "tunnel effect" (Gutierrez Puebla, 2004). It develops the final nodes, lacking the generation of economic activity throughout the territory where it develops. There is a polarization effect that leads to increased accessibility at the nodes of the infrastructure, isolating intermediate regions from the poles (which attract business).

To sum up this subsection, we can say that there are three aspects to explain why infrastructure investment has not had impact on the economic growth and convergence between regions: the decreasing marginal product of capital, the financing system and the incentives scheme in the contract design.

1.3. Effects on labour markets

The relationship between infrastructure and labour has two aspects. On one hand, labour is an input and it is a cost. On the other hand, infrastructure investment may have positive effects on the aggregate level of the labour market. On the supply side, improvements in transport infrastructure reduce commuting time, increasing the number of potential workers for a given location, and on the demand side, firms may gain productivity derived from a better matching in the labour market.

The literature emphasizes the effect that public infrastructure can have on the production and location decisions of firms (Munnell and Cook, 1990). Typically, there are two approaches for analysing the effects of infrastructure investment on business performance: the production function approach and the cost approach. The production function approach focuses on changes in aggregate output levels, while the cost function approach emphasizes the changes in the transportation costs of inputs and outputs.

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[7] According to PEIT, the document prepared by the Spanish Ministry of Public Works covering its transport and infrastructure strategy for the period between 2005 and 2020, a total investment of 241,392 million Euros is planned, mainly for high-speed rail system.

First, changes in transport infrastructure may lead to adjustments in inputs and outputs because it may provide new possibilities for production. The stock of transport infrastructure may be introduced into the production function through two different channels. Firstly, it may enter as a new input, directly contributing to firm production, in the same way as labour or capital is typically considered. This means that production increases because it increases the stock of capital infrastructure. Secondly, it may enter as a factor that augments the productivity of other inputs employed by firms. In other words, improvements in transport infrastructure could be considered to be an increase in the technology of the production that could enhance overall productivity. This approach has the advantage of capturing the complementary relationship between the factors, since the stock of capital infrastructure does not contribute to production without consuming the other factors.

Second, transport infrastructure may also increase firm productivity by lowering the transportation costs of inputs and outputs. An increase in the reliability of transport may allow firms to reduce stock inventory costs or to improve access to customers, generating economies of scale by serving larger markets. It results in a reduction in long-term average costs, which can be translated into an increase in productivity (SACTRA, 1999).

The cost reduction allows firms to experience productivity gains and lower the prices of their products what helps them to expand their markets. A fall in relative prices stimulates the product demand, depending on the price elasticity, and as a consequence, firms increase their demand for workers (Button, 1998). Moreover, a higher productivity environment could be attractive to investment, and it may encourage the expansion of existing businesses and attract private investment into a region, generating an increase in overall production and a higher demand for employment.

Labour markets also increase in geographic size because of the commuting effect (SACTRA, 1999; Vickerman, 2002). A reduction in commuting costs enables workers to increase the area of their job search and to make longer journeys for equivalent generalized costs. In some cases, the improvement of transport services allows companies to hire workers from remote regions.

Moreover, improved accessibility to employment opportunities could encourage people to participate in the labour market. Borjas (1996) suggests that commuting costs affect people’s decisions to enter in the labour market;

commuting costs raise the reservation wage and lower the probability of entering in the labour market. Therefore, the reduction of commuting costs remove or reduce significantly this barrier to labour market participation by allowing people to seek a job that offers wages which are higher than or equal to their reservation wage.

The possible effects of transport infrastructure investment on labour and product markets are also an important determinant of firm location. The basic idea is that the location decision of firms and households is simultaneous (Carlino and Mills, 1987; Boarnet, 1994). Given that jobs and people locate spatially together, some firms may prefer to locate near a large pool of customers and skilled labour market. Migration response may lead to an increase in population, which represents not only an increased number of potential customers in the local market, but also potential labour force in the region.

In the long run, studies provide mixed and inconclusive evidence. The literature that tackles the impact of highway infrastructure on employment is a clear example. Some studies find that overall employment is positively and significantly related to the stock of highway infrastructure (Lombard et al., 1992; Dalenberg et al., 1998), government expenditure (Carroll and Wasylenko, 1994; Islam, 2003), and the availability of highway access (Luce, 1994; Boarnet, 1994); other studies reveal no significant effect of highway infrastructure stock (Duffy-Deno, 1998) or highway expenditure (Clark and Murphy, 1996). Some other studies also find that an increase in highway capital (Pereira, 2000) or public spending (Dalenberg and Partridge, 1995) reduces the demand for employment.

Concretely, the employment gains associated with government expenditure on infrastructure may decrease rapidly after the construction period, so that we should consider whether the effect is merely a temporal shift of the employment levels that could have been generated by other government expenditure. To some extent, the final result is going to depend on the mobility of labour force. The concentration of economic activity induces people to move to a larger region in order to find better job opportunities and higher wages. This phenomenon may generate an effect on productivity and on tax revenues in the larger region, whether there is an increase in the working hours or, whether workers move to more productive jobs.

This effect may be significant at an individual level and, at the same time, it may have substantial effects on GDP, especially in the case of transport infrastructures that are used for commuting, such as subways or other local transport infrastructure (Venables, 2007).

Regarding the role of information in the labour market, Pilegard and Fosgerau (2008) show that the effects of omitting search imperfections can be substantial. They show that imperfections in the search generate a gap between the labour marginal product and the wage, such that final benefits of a transport improvement are larger than those considered in a conventional cost-benefit analysis. The main source of imperfection is the lack of complete information necessary to clear the labour market at each moment in time, [8] and the worker usually faces a trade-off between the ideal job and his commuting costs. The worker could accept a job that does not perfectly match his ideal job but has low commuting costs, or accept a job located further from his residential place that offset the additional commuting costs.

Therefore, the worker has to choose balancing between searching only locally, avoiding higher commuting costs but having the risk of a longer duration of unemployment, or searching in a wider area to reduce the duration of his unemployment but, paying higher commuting costs. Under incomplete information, the worker takes his decision based on expected commuting costs and expected duration of his unemployment. As usual, the worker maximizes his expected utility achieving a second-best result.

At aggregate level, the results are inconclusive. The labour mobility is crucial to maximize the potential benefits for labour associated with the construction or improvement of the infrastructure and, the relative labour price is essential to attain a final equilibrium between regions, considering that the factor is priced at its marginal cost.

At a regional or local level, the effects are easily characterized, and it has been proved that the infrastructure has an effect on the individual choices of workers and firms. An infrastructure investment, if and only if it reduces commuting costs, improves the matching in the labour market and generates agglomeration economies. But this impact is also affected by imperfect information. If information were incomplete, part of the benefits associated with the infrastructure investment would lost because of the extra commuting costs in the job search.

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[8] We always work with the assumptions of perfect mobility of workers and no rigidities arising from subsidies or a minimum wage. It is assumed that the only friction in the labour market comes from information problems.

1.4. Agglomeration economies

Agglomeration economies are effects on the spatial dimension of the economic activity that arise from the proximity of agents with independency whether the increasing returns are related to consumer/supplier linkages (Glaeser et al., 2001), entrepreneurial spillovers (Klepper, 2007) or labour market pooling (Marshall, 1920). Formally, there is a market imperfection that needs to be analysed and whose mechanisms of transmission are:

- <u>Technological spillovers</u>. Firms are more likely to learn innovations of other firms if they are physically close, and these technological spillovers are more likely to arise if similar firms are close to each other.
- <u>Input market effects</u>. By locating together, suppliers and purchasers can minimise transport and transaction costs, sharing costly infrastructure and keeping prices down because of competition effect.
- <u>Labour market effects</u>. Firms are more likely to match better when they locate close to many workers.

Regarding technological or knowledge spillovers, Jaffee et al. (1993) provide the most compelling evidence that knowledge spillovers are important and attenuate with geographical distance. Their results are based on patent citations that are highly spatially concentrated. Other papers, such as Jaffee (1989) and Acs et al. (1992) find similar results.

Agglomeration economies may also arise from consumer’s concentration, essential for the provision of retail products due to high fixed costs for delivering products and indeed areas with more people tend to have more retail outlets. Glaeser et al. (2001) argue that there are four fundamental channels through which large cities enhance consumption. First, there are goods and services available in large cities that are not available elsewhere; second, large cities offer various charms; third, large cities provide public goods that would not be possible in smaller cities; and fourth, the relatively dense settlement of a large city allows a speed of interaction that would not be possible in a smaller one.

The concentration of demand also encourages agglomeration economies

(Corsetti et al., 2005). They assume that increasing returns lead to the concentration of employment in a large factory creating larger markets, which in the presence of transportation costs induce other firms to choose the same location. The idea here is that the interaction between internal scale economies in production and transport costs leads to a self-reinforcing of agglomeration, when economic agents locate close to each other (Marshall, 1920). [9]

Looking at labour market pooling, there are several interesting aspects. First, workers match better in large cities (the urbanization effect) or in industrial concentrations (localization effect) what is consistent with Marshall's idea about the specialization of the labour force as a competitive advantage.[10],[11] Second, labour market pooling is fundamentally about risk (moral hazard and adverse selection) and the concentration reduces them, for example, through specialized mechanisms of intermediation.

There are, therefore, at least three dimensions over which externalities may be studied; industrial dimension, geographical dimension, and temporal dimension.

The industrial dimension is the degree to which agglomeration economies extend across industries. Henderson (1974) says that externalities are stronger in some industries than in others, so it seems reasonable to suspect that productivity gains in dense regions are partly realized through a change in the industry composition.

In the service industries, Holmes and Stevens (2004) show that small establishments are mainly located in agglomeration, reinforcing the creation of large cities. In the large-firm, multi-plant and multinational manufacturing sector, where internalised knowledge is a firm's primary proprietary asset, most firms are averse to the geographical clustering of their knowledge-generation activities with those of their rivals because of the potential net losses associated with information spillovers (Simmie, 1998; Cantwell and Iammarino, 2000). It is not the case in the information-intensive high-technology sector (Arita and McCann,

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[9] For reviews of agglomeration literature, see Rosenthal and Strange (2004), Eberts and McMillen (1999), Henderson (1988), Moomaw (1983) and Gerking (1994).

[10] Economies of urban concentration, or urbanization economies, are external to the firm and the industry but internal to the city, with benefits arising from local public goods, the scale of markets, the proximity of input-output sharing, and other kinds of inter-industry interaction.

[11] Localization economies are external to the firm but internal to the industry, and are principally created through labour market pooling, the sharing of intermediate inputs, and knowledge sharing or 'technological spillovers'.

2002; McCann et al., 2002), as well as in the more traditional manufacturing sector, especially for those firms for which transport infrastructure is important in the location decisions.

The geographical dimension is based on the idea that geographical distance is crucial, as agglomeration economies attenuate with distance. Then, if agents are physically closer, then there is more potential for interaction (Moomaw, 1983). Rosenthal and Strange (2003) show, with a birth firm model, the impact on the total employment in the industry depends directly on the geographical scope of agglomeration economies. Most recently, Henderson (2003) has also found localization effects to be stronger.

The temporal dimension is essential. Agglomeration economics is not a static phenomenon, and it is possible that one agent's interaction with another agent at a point in the past continues to have an effect on productivity in the present. This means that two agents who are separated in time continue to affect each other, and the degree to which these time-separated interactions continue to be potent defines the temporal scope of agglomeration economies.

Glaeser et al. (1992) and Henderson et al. (1995) include this dimension in their growth models, and they both show that the characteristics of a city can have an impact on its growth over a period of twenty years or more. But, theoretically, this type of estimate may be affected by simultaneity or endogeneity whose main solution is the use of historical variables. For example, the use of long lags of population density as an instrument of city size or density (Ciccone and Hall, 1996). With the exception of Henderson (2003) who estimates agglomeration economies by using firm level panel data and GMM (Generalized Method of Moments) estimator, most of authors, among them Ciccone and Hall (1996), Ciccone (2002) and Rice et al. (2006), address endogeneity with instrumental variables a 2SLS (two stage least squares) estimator.

Ciccone and Hall (1996), Rice et al. (2006), and Combes et al. (2006) instrument current levels of employment density using long lags data on population density. Their hypothesis is that the densities we observe today are determined by previous patterns of population concentration, and that these patterns are not correlated with contemporaneous levels of productivity[12]. Ciccone (2002) uses, as a valid instrument, the total land area of European Union regions, while Rosenthal and Strange (2005) use data on geological features, arguing that variances in density are reflected in the underlying geology of the Earth and are uncorrelated with productivity and the skills of the labour force.

The endogeneity problem has proved to be incredibly difficult to address in a satisfactory way, largely due to data limitations Nevertheless, the evidence indicates that if agglomeration has an endogenous component, this does seem to induce a negligible bias in agglomeration estimates. In fact, Ciccone and Hall (1996) and Ciccone (2002) find only small changes in the estimates of agglomeration economies using instrumental variables rather than the least squares estimator. Similarly, Rosenthal and Strange (2005) conclude that the influence of endogenous regressors is small, while Henderson (2003) reports that the correlation between the regressors and the error term is also negligible.

Actually, other research stream focused on the increases in accessibility resulting from transportation improvements (Ahlfeldt and Wendland, 2009; Bowes and Ihlanfeldt, 2001; Chandra and Thompson, 2000; Gatzlaff and Smith, 1993; Gibbons and Machin, 2005; McMillen and McDonald, 2004; Michaels, 2008) does not tackle the possible endogeneity. Their results are based on the presence of political lobbying and geological or technical difficulties that prevent a direct relationship being found between infrastructure design and economic efficiency.

These accessibility studies simplify the real world in two regions connected by a single infrastructure, without specifying their characteristics. They do not consider that in a more complex world, increases in productivity in the studied region may come from reductions in other regions due to changes in the spatial distribution of economic activity. Therefore, this research line focuses on accessibility increases without distinguishing whether positive correlation between agglomeration and productivity is a consequence of agglomeration or a consequence of high productivity.

Previous discussion shows that agglomeration externalities do exist but the data is usually aggregated at spatial level, at a scale that limits to capture

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[12] This approach requires detailed spatial information on densities from several decades earlier, typically back to the 19th century, and these data tend to be hard to find, particularly for small spatial areas. Instruments based on contemporary data have also been used.

agglomeration economies. Graham (2006) sums up the desirable properties of a reasonable treatment of agglomeration:

- The spatial modelling framework should avoid predefined units such as administrative areas and should allow one to identify variation in agglomeration on a small spatial scale. A common approach is to contemplate employment within a certain distance, measured as distance or time.
- The measure of agglomeration used should emphasize distance or density in order to include a transport dimension.
- The analysis should allow for detailed sectorial coverage.
- The estimation should enable to isolate returns to urbanization from other scale effects.

Considering previous properties, agglomeration effects may be defined as the accessibility to any firm in any industry located in a given ward, which is dependent on transport infrastructure, and on effective densities. Therefore, we may characterize accessibility of users in terms of generalized cost.

Generalized costs include also the effect of congestion. Firms consider their own private costs, they do not internalize that their use of the infrastructure increases the transport costs of other firms. More agents in a given ward may exceed the capacity of the infrastructure, which may also produce traffic congestion, reducing the potential benefits of the agglomeration. There is therefore a set of opposing forces that together determine the size of cities and clusters.

In the case of employment, for example, the economic appraisal should take into account not only the number of jobs created in a location but also the number of jobs destroyed. Transport infrastructure, in that sense, may improve effective density by bringing jobs closer, and it may also relocate employment. The final result will be positive if transport infrastructure encourages an increase in employment of cities, and negative if it encourages the dispersion of economic activity. That is the reason to include all areas, even those that may suffer disagglomeration.

To generate productivity gains, the mobility of labour is crucial and depends on two factors: legislation and transport infrastructure. We focus on the second one; Monfort and Ottaviano (2000) say that more efficient labour markets may produce persistent differences in unemployment rates across regions. If there is mobility, labour will move towards locations with higher real wages, but, if not, wage differences will persist and act as a dispersion force by increasing production costs.

Marshall (1920) states that the provision of regional infrastructure can promote the generation of local agglomeration economies Venables (2007) shows that transport investment can strengthen agglomeration economies and induce positive productivity benefits by effectively increasing urban densities.

Concretely, Duranton and Turner (2008) estimate the effect that road growth has had on population and employment. The analysis is developed using an instrumental variables strategy based on a state highway plan designed in 1947 (which had been used previously by Baum-Snow (2007) to analyse the effect that the construction of motorways has on the population of cities). Duranton and Turner (2008) conclude that an increase in the road stock in a city by 10% increases population by 2% and decreases the percentage of households without financial resources.

But, the mobility of the factors, as it was aforementioned, essential to create agglomeration economies, is limited by the capacity problems of transport infrastructure. When demand exceeds the maximum capacity of infrastructure, congestion arises, a negative externality, which hinders the development potential of economies of agglomeration. In addition, the infrastructure may become obsolete, for technological reasons or spatial movement of population and economic activity, which also reduces the chances of generating economies of agglomeration.

Graham (2007b) investigates the relationship between productivity and employment density, comparing two measures of density: one which is based on distance and the other which is based on generalized cost and which indirectly captures the congestion effect, and the limited capacity of the infrastructure. He concludes that productivity growth is based on urban agglomeration economies and that these can be obtained by employment growth or, by decreasing travel times; this emphasizes the role of road congestion in the creation of agglomerations.

In short, it should be noted the complementary relationship between improving transport infrastructure and agglomeration economies. The agglomeration arises from the concentration of the economic agents; consumers, workers or businesses and they are transmitted through the technology and inputs markets, generating positive benefits for those who are placed together resulting in productivity gains. Clearly, factor mobility is essential for agent's concentration and transport infrastructure plays a central role to attain it.

Agglomeration economies are closely linked to an efficient transport system that allows the mobility of factors. If there is no mobility, no matter how efficient is the transport infrastructure that there will not be agglomeration economies and persistent wage differences may arise between different regions. At the same time, if there is no an efficient transport system, no matter how mobile is the factors that transport infrastructure will influence on such mobility. Transport infrastructure, in particular, is characterized by its limited capacity, if demand exceeds the capacity; the congestion appears affecting the potential benefits of agglomeration.

1.5. Imperfect competition

There are two wider economic effects related to markets: imperfect competition in markets that use transport as an input and the effects on competition as a result of a project.

On one hand, firms with market power, unable to price discriminate perfectly, set prices above marginal cost, so the quantity demanded is less than the social optimum, resulting in a loss of social welfare, because there are consumers with a willingness to pay above the cost of production who can not acquire the good.

Under this scenario, a reduction of transport costs carries a market price reduction and an increase in the level of production, which, in turn, generates a reduction in the loss of comfort. Although consumers are unwilling to pay more than the equilibrium price, or the producers are willing to produce it, there is an additional benefit not captured with consumer or producer surpluses. It coincides with the difference between the price and quantity by increasing production.

It is important to note that the effect can be negative if firms sell less because the reduction in transport costs affects positively a product, which is substitute in secondary markets.

Under imperfect competition, the assessment of costs and benefits at market prices is not appropriate, which may lead to distortions in locating funds and decision-making on public projects, producing a suboptimal allocation among industries. A transportation project may have effects on market competition in the affected region. That is, when transport costs are high their reduction can facilitate the entry of new companies. They find profitable to offer their products in relation to the scenario without the project in which the incumbent is protected by barriers to entry that provide them transportation costs.

This effect of higher competition is not expected to be substantial in economies with mature transportation infrastructure, since we do not expect significant increases in efficiency resulting from reduced travel times. This effect may be more important in those projects involving countries or regions that are isolated or with limited connectivity, usual case of developing countries.

Venables and Gasoriek (1999) show that the impact of transport costs reduction can lead to agglomeration economies that result in uneven effects regions connected by the same infrastructure. In the case of a spatial distribution of centre-periphery, reducing transport costs can promote the reorganization of production in the central region generating mergers, acquisitions or bankruptcies that allow the remaining companies to meet increased demand at a lower cost.

Following the above argument, Elborst et al. (2010) show that additional economic benefits in projects linking a centre and its periphery are higher than in those projects that link two highly urbanized regions. Peripheral regions are usually smaller than the central region and usually present markets more prone to market power. Cost reduction enables companies in the central region, usually more efficient by competitive pressure of market, supply to peripheral regions causing a reduction in the market power of firms located in these regions.

However, this effect should not be confused with the welfare gains arising from production increases in markets with market power, explained above.

1.6. Environmental effects, accidents and congestion

The European Commission highlights the environmental impact of transport activities, writing papers and recommendations on transport policy, such as European Commission (1995), which mainly discusses the most appropriate pricing systems to internalize external costs, or European Commission (2006) that focuses on the efficient use of infrastructure.

The final aim is to internalize external costs to improve the efficiency of the transport system, to guarantee equal treatment between modes of transport, and to improve safety, while negative environmental impacts are reduced.

The externalities produce a divergence between private costs (borne directly by the agent) and social costs (borne by society). This introduces perverse incentives to the supply and demand of transport, which leads to welfare losses. To solve it, the optimal price is set when the social marginal cost equals the marginal revenue; in the case of transport, these costs can be classified into several categories:

- Capacity restriction costs. It includes all costs associated with high traffic densities.
- Costs of accidents. It covers all direct and indirect costs related to materials, doctors and fatalities.
- Environmental costs. It includes all the environmental costs related to health problems, property damage, damage to the biosphere and long-term risks. These mainly arise from noise, air pollution, and climate change or greenhouse effects.

Regarding climate change, it is necessary to differentiate between various effects (Watkiss, 2005):

- Rising sea levels. It implies the need for additional protection against flooding in wetlands and drylands. These costs depend on social and political factors that affect decisions about the future, whence the protection is justified.
- Energy use. The impact depends fundamentally on temperature, but there is a combination of increases and decreases in heating demand based on seasonality.
- Impacts on agriculture. It depends on regional changes in temperature and rainfall, as well as from levels of atmospheric carbon dioxide.

- Impacts on the supply of drinking water. They depend on changes in the rates of precipitation and evapotranspiration, and changes in demand. The demand for water by biological systems is affected by climatic factors, including temperature and humidity.
- Impacts on health. Apart from the direct effects on mortality, which could be quite small, the spread of diseases and epidemics could have a far greater impact, especially in developing countries.
- Ecosystems and biodiversity. These are among the most difficult effects to quantify, and they are one of the direct effects of infrastructure construction.

In case of air pollution, Givoni (2003) distinguishes the effects in three different parts of the atmosphere: the stratosphere, the troposphere and the atmosphere. Using this classification, the global environmental effects are related to gas emissions in the troposphere and the stratosphere, while local pollution is related to emissions closest to the ground. To highlight the negative externality, we should consider some emitted substances. The nitrogen oxide affects directly human morbidity and mortality, and indirectly through climate change, produces effects on the immune system. The sulphur oxide affects directly the respiratory system and may cause pulmonary diseases, and carbon dioxide comes from incomplete combustion, emitted mainly from vehicles and unavoidably affects the ozone layer.

This leads to a discussion about which mode of transport should be preferred when one considers the environmental costs. Givoni (2003) points out that planes are more harmful to the environment, in operative terms, than high-speed rail, mainly due to the effects of aviation on climate change. This result is aligned with INFRAS/IWW (2004), though this follows a broader assessment of externalities by capturing the effects of noise, urban air pollution, the effects of accidents, and climate change.

The environmental costs of high-speed trains depend crucially on the way in which their energy has been generated, but the difference between modes is narrowing and is expected to continue to do so. Kagesson (2009) and Atkins (2004) obtain opposite results to those above when they include the environmental costs of the construction period, because the high-speed rail infrastructure require, among others, heavy use of highly polluting heavy machinery.

Another source of externality is the reduction in the relative number of accidents and in road congestion that depend crucially on the ability of the new infrastructure to divert travellers from alternative modes, and is unambiguously related to the time savings and pricing policy.

1.6.1. Regulation and theory of environmental externalities

Economic agents demand the emission of pollutant substances[13] to create economic activity, so they have a willingness to pay a cost associated with the reduction of emissions (abatement costs). It is possible to create a regulated market, through the definition of property rights.

To do that, we can consider two basic types of regulation: quantities and prices. Firstly, one can simply limit the maximum amount of pollutant substances that is allowed to emit; given that agents have a willingness to pay for each unit they emit, there is a market and an equilibrium price where the market clears. Secondly, we can consider a price cap per unit, so that agents can emit as much as they want but must pay the corresponding price. In that case, the price indirectly fixes the maximum amount of substances emitted.

In a world of perfect information, price and quantity regulation are equivalent, as Weitzman (1974) shows. But the real world is much more complex, and the uncertainty associated with the final emission of pollutants and the final source of these emissions makes the optimal approach extremely difficult to implement.

In that sense, governments have a rather large toolbox to choose from when they want to control emissions of harmful substances. Amongst the most prominent instruments we can find standards, taxes and tradable emission permits.[14] In some contexts the choice of instrument has only minor implications for efficiency; if, for instance, a planner is equipped with complete information he is able to attain the efficient emission level in a cost-effective way with any instrument.

In a world where abatement costs are uncertain, this is no longer the case, because they will, in general, yield an emission volume deviating from the

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[13] Johansson (1990) reviews the most important parts of the economic theory and measurement of environmental damage.

[14] See e.g. Bohm and Russel (1985) and Sterner (2003) for reviews of environmental policy instruments.

efficient one. A cap–and–trade system with a cap at the expected efficient emission level generates too few (many) emissions when abatement costs turn out to be higher (lower) than expected. The optimal tax, on the other hand, induces too many (few) emissions. Weitzman (1974) shows, under the assumption of linear marginal abatement cost (MAC) and marginal abatement benefit (MAB) schedules, that the cap-and-trade approach yields a lower expected social cost (environmental cost plus abatement costs) than the tax approach when the MAB function is steeper than the MAC function.[15, 16]

Much research has been devoted to finding instruments that may further reduce the expected social costs. Roberts and Spence (1976) show that a cap-and-trade system combined with a finite penalty for non-compliant behaviour and abatement subsidies results in an emission volume which is closer to the ex post efficient level than can be achieved with either an emission tax or a pure cap-and-trade system. Despite this, the hybrid instrument of Roberts and Spence has rarely—if ever—been systematically employed in practice, presumably due to its complexity.

Pizer (1999, 2002) analyses a simpler version, namely a cap-and-trade system combined with a price ceiling, or a so–called safety valve, and shows that such an instrument can substantially reduce expected social costs, when compared to a pure cap–and–trade system or a tax. It can be argued that most, if not all, cap–and–trade systems include a safety valve, either by way of a predetermined trigger price at which the regulator is obliged to sell additional permits or implicitly by a finite penalty for non-compliant behaviour.

Another way to reduce the expected social costs would be to index the cap level to a variable that is correlated with the uncertain MAC (Quirion, 2005; Newell and Pizer, 2006). Indexed regulation has been around for a while: for instance, environmental concessions often allow firms to emit a certain amount per output. Another example is the kind of green electricity certificate systems we find in Norway, Sweden and the UK in which the target level (the amount of

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[15] Weitzman's rule has proved to be rather robust in several dimensions; it also holds, with some adjustments, for the case of stock externalities (Hoel and Karp, 2002; Newell and Pizer, 2005), and for the case where the stochastic elements of the MAB and the MAC functions are correlated (Stavins, 1996). However, when we leave the realms of linear marginal schedules Weitzman's rule may lead to the wrong conclusions regarding both the optimal instrumental choice and the optimal control levels: see Malcomson (1978) and Yohe (1978).

[16] Of course, the optimal policy design is also influenced by other factors, such as implementation costs and transaction costs (Stavins, 1996), as well as indirect effects such as to what extent regulation rents are left in private hands (se e.g. Fullerton and Metcalf, 2002).

green electricity produced) is expressed as a fraction of total electricity consumption. Moreover, in the climate change context, national emission quotas that are indexed to countries' GDP levels or populations have been discussed as a means to encourage developing countries to sign a climate treaty (see Baumert et al., 1999, Lutter, 2000 and Ellerman and Sue Wing, 2003).

Mandell (2008) points at still another possible way of reducing social costs, which is to divide the emitters into two groups and let one group be subject to an emission tax and the other to a cap–and–trade system. He shows that since these two instruments go in opposite directions from the ex post efficient emission volume when abatement costs deviate from the expected ones, it is possible to find a mix of the two instruments that reduces social cost (as compared to a universal tax or a universal cap), even though emitters in the two groups do not face the same price on emissions so that abatement efforts are not distributed cost–effectively. The intuition behind this is that the linear combination of a cap–and–trade system and an emission tax is preferable to each policy on its own.

The different theoretical mechanisms presented here face an important problem of implementation and they will be discussed in more detailed in chapter 4.

1.6.2. The role of accidents and congestion in the evaluation of infrastructure

Accidents represent an external cost to the health system, police and damage to third parties—even when users bear part of the cost by paying for insurance.

In other words, users take into account some of the costs associated with the possibility of an accident, but not all, so some of them, are transferred to the society, leading to an excessive use, from a social perspective, of modes affected, leading to a loss of social welfare.

These costs correspond to the loss of life, whose values is known in the literature as the statistical value of life, consisting in the willingness to pay to reduce the probability of dying in a traffic accident, the welfare loss for family and friends, and other costs, including the damage to physical assets. The first cost is the most important and has received most attention in the literature.[17]

Therefore, the externality has two origins. On one hand, agents do not consider the welfare loss for family and friends, and the damage to physical assets and, on the other hand, an individual driver's decision affects the probability that any user of the infrastructure will have an accident.

From an empirical point of view, there are several studies that have quantified the external costs of road accidents. Elvik (2000) considers that the cost for OECD countries ranges from 0.5% to 5.7% of GDP. Other authors usually considered the external costs to be substantial (Maddison et al., 1996; Pearce, 1993). However, Peirson et al. (1997) published a micro-analysis which shows that these costs have been overestimated in many cases, since they assume that the number of accidents is proportional to the flow of vehicles (see Vickrey 1968, 1969 and Newbery, 1987).

Congestion, in turn, arises because there is a mismatch between the demand and the number of users willing to use an infrastructure or service at a given time and the infrastructure capacity or supply to provide the service to those users who rarely is constant over time. The consequence is increases of travel time, that is, the number of users of the transport infrastructure has impact on the individual travel time and, for this reason, the congestion may be considered as an externality. It is an externality because agents do not consider the costs they impose on others in their decision-making.

Concretely, congestion may differ between those scenarios in which the entry to the infrastructure is free (and there are no coordination associated with the use of the infrastructure) and infrastructures where the entry is regulated with slots (as is usually the case with airports). In the first case, there is no role for a price scheme, while in the case of regulated entry, the price scheme is crucial and can be used not only to reduce the quantity of traffic, but also to shift traffic from peak periods to valley ones.

In principle, our analysis is focused on the former case. Congestion has been widely tested in urban areas, in contrast to economies of agglomeration, and therefore the effect on productivity has been studied. In this sense, price charging

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[17] Blaeij et al. (2003) present a review of the most important, and Viscusi (2003) a critical review of mechanisms based on estimation approaches in the market.

schemes resulting from congestion have been studied and implemented in some cities such as Stockholm, London and Milan.

Another issue of congestion, from the point of view of transport policy, is the elasticity of the congestion reduction with respect to the supply of infrastructure. This aspect is important for appraising the investment. Cervero (2002) shows that studies assessing the effects of new infrastructure over an area usually conclude that there are positive elasticities, but their elasticities can vary considerably.

Congestion and road accidents are ultimately linked each other, since both are externalities generated by infrastructure users. However, their relationship has not been widely studied. Shefer and Rietveld (1997) and Shefer (1994) estimate that there is an indirect relationship between congestion and accidents, although their studies used traffic density as a proxy for congestion. Belmont and Forbes (1953) carried out studies using flow variables, and Ceder and Livneh (1982) estimate that there is a U-shaped relationship. Other articles such as those of Turner and Thomas (1986) and Golob and Recker (2003) have shown that the relationship between the flow of vehicles and the severity of accidents is negative.

In summary, the benefits associated with the reduction of the congestion is expected to be lower than those related to reducing accidents. The former is primarily directed by the relationship between the capacity and demand infrastructure while the second is dependent on the traffic conditions of the infrastructure.

Chapter 2. Regional Effects of Infrastructure: The Investment in High-Speed Rail Networks

2.1. Introduction

Transport infrastructure is fundamental for the smooth operation of the internal market, the mobility of people and goods, and the economic, social and territorial cohesion. In particular, it is seen as performing this role through its effect on competitiveness and employment.

Transport has a double effect on the labour market. On one hand, transport improvements reduce commuting time and increase the number of potential workers in a given location (SACTRA, 1999; Vickerman, 2002). A reduction in commuting costs enables workers to increase their job search area and to make longer journeys for equivalent generalized costs. On the other hand, firms may get productivity gains from better matching in the labour market and lower transport costs of inputs and outputs. This cost reduction helps firms to expand their markets. Firms that experience productivity gains would lower their prices, stimulating the demand for their products and the demand for workers (Button, 1998).

Transport improvement also has an impact on labour market participation (Borjas, 1996). Commuting costs are part of the individual reservation wage and its reduction affects the decision of labour market participation by allowing people to seek a job offering a wage above their reservation wage. Moreover, the location decision of firms and households is simultaneous (Carlino and Mills, 1987; Boarnet, 1994). Thus, jobs and people locate spatially together, generating agglomeration economies and productivity gains because of improvements in the labour matching which depends on employment density.

Regarding transport infrastructures, these play a key role in the EU policy, and total investment during the 2000-2006 period was 859€ billion. The cost of establishing an efficient trans-European transport network (TEN-T) has been estimated at over 1.5€ trillion for the 2010-2030 period.

Spain has also followed the European strategy and has bet intensively on transport infrastructure. The Spanish government has promoted heavily the development of a high-speed rail (HSR) network as shown in the Strategic Infrastructure and Transport Plan (PEIT). The PEIT includes the main activities in infrastructure and transport between 2005 and 2020, with a total investment of 241,392€ million. It values significantly the possibilities that infrastructures have for regional cohesion and employment, as proven by its commitment to create a HSR network which aims to have 90% of the mainland Spanish population located within 50 km of a station.

The need for assessing the economic effects of HSR is doubtless. In the Spanish case, the existing economic literature casts serious doubts upon the socio-economic profitability of such transport infrastructures under the current conditions (traffic, time values, time savings, costs, etc.). As shown by the cost-benefit analyses of de Rus and Inglada (1997) for the Madrid-Seville and de Rus and Roman (2005) for the Madrid-Barcelona line, the social benefits accruing from its construction and operation do not cover the costs that society affords.

The main goal of this paper is to quantify the potential impact on employment density that might arise from infrastructure provision given its characteristics of non-tradable input. This paper examines the effect that the construction of high-speed lines has had on employment density in the municipalities close to the network.

The link between employment density and productivity is commonly known as agglomeration economies. Marshall, in 1890, was the first to define the concept and emphasise the role that regional infrastructure plays in their development. After his contribution, many researchers have been interested in discovering how these infrastructures are related to the creation of economic activity and employment.

Venables (2007) develops a theoretical model that shows the relationship between the provision of transport infrastructure and agglomeration economies through the employment density. He concludes that there exist agglomeration benefits not captured in a standard cost-benefit analysis and that this should be considered in an economic appraisal of transport improvements. Following this idea, Graham (2007a) estimates, based on the previous theoretical model, the agglomeration elasticities that proved to be particularly significant in the service sector.

The paper examines changes in employment density at municipality level. This provides a new dimension. There are many articles which focused on microeconomic level considering changes at individual level, Graham (2007a), Ciccone and Hall (1996) and Ciccone (2002), among others, show for the United States, and the European Union, that there are positive and substantial externalities arising from the increase in the density of cities, particularly for service industries.

Other papers focus on aggregate impacts with mixed and inconclusive results. Some studies find that overall employment is positively and significantly related to the stock of highway infrastructure (Lombard et al., 1992; Dalenberg et al., 1998), government expenditure (Carroll and Wasylenko, 1994; Islam, 2003), and the availability of highway access (Luce, 1994; Boarnet, 1994), other studies reveal no significant effect of highway infrastructure stock (Duffy-Deno, 1998) or highway expenditure (Clark and Murphy, 1996). Some other studies also find that an increase in highway capital (Pereira, 2000) or public spending (Dalenberg and Partridge, 1995) reduces the demand for overall employment.

The paper quantifies employment density at an intermediate level, considering municipality information level for the 1991–2008 period in order to obtain a disaggregated view of the effects of the construction and operation of the Spanish HSR network on employment.

The relevant period allows us to capture if employment gains associated with government expenditure on infrastructure may decrease rapidly after the construction period, so that we should consider whether the effect is merely a temporal shift of the employment levels that could have been generated by other government expenditure.

The use of panel data is an advantage of our approach. It allows us to control for unobservable effects in the municipalities and for endogeneity when we consider the dynamics of employment. The endogeneity arises from the inclusion of the lagged dependent variable.

None of previous papers considers this aspect. Even those papers that focus on the accessibility increase resulting from transportation improvements, which could have significant effects on the regional development (Ahlfeldt and Wendland, 2009, Bowes and Ihlanfeldt, 2001, Chandra and Thompson, 2000; Gatzlaff and Smith, 1993, Gibbons and Machin, 2005, McMillen and McDonald, 2004; Michaels, 2008) do not include the treatment of the potential endogeneity.

However, these papers present two fundamental weaknesses. The first is related to the lack of instrumental variables, so the argument of exogeneity of the shocks is based on political lobbies and orographic or technical difficulties that prevent drawing a direct relation between the design of infrastructure and the arguments of economic efficiency. The second, the inability to quantify the net effects of the infrastructure, i.e. the methodology is unable to differentiate between the net increases and the relocation of the economic activity.

However, it should be taken into account that previous models simplify the real world into a model of two regions, which are linked by a single infrastructure, without explicitly modelling the characteristics of this infrastructure. Furthermore, they do not consider that in a more complex world, increases in productivity within the studied region may come from decreases in other regions because changes in the spatial distribution of the economic activity, an issue that is also discussed in this paper.

The chapter is organized as follows. Section 2 explains how we collected and processed data and presents a descriptive analysis. Section 3 gives a detailed presentation of the econometric approaches to quantify the relations of interest and shows the main results from the different databases and different econometric estimations; we also discuss and quantify the relationship and the importance of the Spanish HSR in increasing employment density. Section 4 presents a discussion of the results and their implications on public policy. Lastly, Section 5 summarises the main conclusions.

2.2. Data

To test the impact of HSR network on employment density, we use an unbalanced panel data sample based on 3,252 Spanish municipalities with more than 1,000 inhabitants in Spain on 1st January 2009 whose population represents 96.8% of Spain for 10 years (2008–1998).

Employment density $\left(denemp_{it}\right)$, our endogenous variable, is the number of employees per square kilometre and municipality. Given that there is no information about the spatial distribution within the boundaries of the municipality, we assume that employees are uniformly distributed within. This dependent variable is obtained from the Public Employment Service, while data on the rest of variables are collected from the municipal Economic Yearbook "la Caixa" database and the Spanish the National Statistics Institute (INE).

The exogenous variables are a set of economic indicators where income should play a central role. But, the lack of an income variable at municipality level forces us to look for proxies. We do an auxiliary regression for NUTS3 regions[18], where income variable is available, with respect to a set of variables; population level $(population_{it})$, the number of motor vehicles $(vehicles_{it})$, excluding buses, financial office density $(denfin_{it})$, and the number of retail establishments per 1,000 inhabitants $(retpop_{it})$. The set of variables have a joint explanatory power (R^2) of the income variable equal to 0.85, reason why we take these as exogenous variables of the employment density at municipality level.

The effect of the HSR on employment density is also determined by HSR_{it}, characterised as a binary variable that takes a value of 1 in the years of operation and 0 otherwise. We also include $time_{it}$ capturing business cycle effects and temporal dimension, essential to isolate the effects of the HSR investment on employment density.

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[18] There are three levels of Nomenclature of Territorial Units for Statistics (NUTS) defined. This category refers to regions belonging to the third level (NUTS 3), the most disaggregated one, such as provinces in Spain or districts in Germany.

Table 2.1. Definition of variables and descriptive statistics

Variable	Definition	Mean	Standard Deviation
Denemp	Number of employees per square kilometre and municipality.	72.97	4.53
Population	Number of resident people in a municipality.	10,353.39	41,677.86
Vehicles	Number of motor vehicles, excluding buses.	2186.37	3.35
Denfin	Number of financial offices per square kilometre.	0.3	1
Retpop	Number of retail establishments per 1,000 inhabitants.	$2.13 \cdot 10^{-5}$	$1.51 \cdot 10^{-5}$
HSR	Binary variable: 1 when HSR is operating and 0 otherwise.	0.03	0.16
Time	1 for the first year of the database (1998) and 10 for the last one (2008).	5	2.72

2.2.1. Data treatment (GIS)

The HSR network develops along the territory and has economic effects on the surrounding populations of its stations. The spatial dimension of its effects requires the use of Geographic Information System (GIS)19 to reference the database geographically. The use of GIS allows us to discuss the impact of the transport infrastructure considering the scope of the distance with respect to the infrastructure on employment, essential for the productivity increases, Marshall (1920).

First, we localize HSR stations geographically. Spain has four main corridors, though we exclude the Eastern Corridor because it was completed in

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[19] Geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. GIS is the merging of cartography, statistical analysis, database technology. A GIS can be thought of as a system—it digitally creates and "manipulates" spatial areas.

2010. Our examined routes are Madrid–Cordoba–Seville–Malaga and Madrid–Toledo (Southern Corridor), Madrid–Zaragoza–Barcelona and Zaragoza–Huesca (Northern Corridor) and Madrid–Valladolid (Northwest Corridor), a total of 18 stations and 1,665 km of track[20].

Second, we capture the spatial dimension, establishing concentric circles around the HSR stations. The aim is establish influence areas to examine the impact on the employment density. It is performed for an area of 10 kilometres (Figure 2.1). [21]

Figure 2.1. An influence area of 10 kilometres

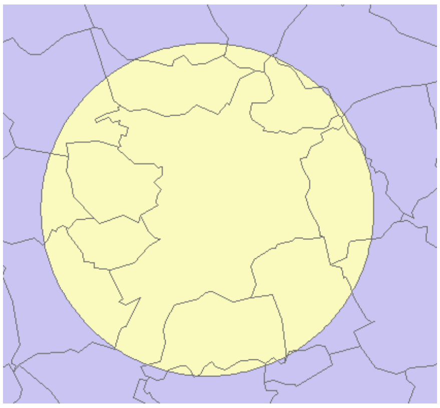

Figure 2.1 shows a concentric circle of 10 kilometres around the HSR station that limits the influence area of the infrastructure. When the whole surface of the municipality is in the circle, we treat it as affected by the infrastructure. But, the circle, in some cases, divides the surface of municipalities. Then, we consider, as affected by the HSR, only the proportional part of the municipality that is in the circle, assuming that all the variables are distributed uniformly over the surface of the municipality.

Table 2.2 differentiates the municipalities between those under an influence area of 10 km around HSR stations and those that are not.

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[20] For a critical view of the infrastructure of the HSR, see Bel and Albalate (2010).

[21] The analysis was also carried out for influential areas of 5, 15 and 50 km.

Table 2.2. The difference between municipalities with and without HSR in an area of 10 kilometres

Variable	HSR = 1	HSR = 0	Difference (HSR = 1 – HSR = 0)
Denemp	93.69	72.24	21.45
Population	10,447.42	6,977.88	3,469.54
Vehicles	780.55	2252.96	-1472.41
Denfin	0.31	0.19	0.12
Retpop	4.87 · 10-5	2.06 · 10-5	2.81 · 10-5

Average for municipalities with a HSR is above those without, except for *vehicles*. We can ensure that municipalities under the HSR influence area are usually larger and have greater economic activity. Specifically, the average of *denemp* is 21.45% higher for those municipalities under the HSR influence than for those not.

The negative sign of *vehicles* could be related to the influence of tourism on the number of vehicles in a region. Tourism generates a latent high demand for cars, thanks to car rental companies and the HSR is not always present in the most developed tourist regions, which are also usually characterised by the intensive use of private vehicles.

2.2.2. Matching

We build a database with the set of Spanish municipalities with the aim of comparing those who are under the influence area of a HSR station with the rest of municipalities. But, we are comparing a group affected by the construction of a HSR with other group of municipalities whose characteristics may differ substantially. That is, the control group may not be comparable with the affected group.

This selection bias leads to biased estimates. To eliminate this potential bias, and to evaluate the effect of the HSR network on the employment density, we use a statistical matching. It allows us to create a quasi-experiment because for every city where there is a HSR station, we find those cities without HSR that have similar observable characteristics.

Particularly, we apply a propensity score matching. It consists of running a logistic regression, whose dependent variable is binary, $HSR = 1$, if participate; $HSR = 0$, otherwise obtaining the propensity score, $\log\left[p / (1-p) \right]$, where $p(x) = \Pr\left(HSR = 1 \middle| X = x \right)$.

It consists of equalling both groups with relation to some characteristics to reduce the heterogeneity. These are the unemployment rate, the percentage of foreign labour force and an economic activity index reported by “la Caixa” at a municipality level, obtained as a function of the total collection of taxes on economic activities.

Once we have identified the most similar cities to those, which have a HSR station, we build concentric circles of 10 kilometres, as in the original sample. Lastly, we estimate the impact of the operation of a high-speed line on employment.

2.3. Static versus dynamic model

The econometric strategy to estimate the impact of the HSR on the employment density is as follows. Considering the two databases, we will examine the data using panel data with fixed effects estimation that allows us to eliminate unobservable effects at the municipal level, such as topographical features, institutional design and geographical location, which remain unchanged over time. But, this approach does not capture the dynamics of employment.

The alternative approach is to estimate the impact using dynamic panel data estimation methods, including lags of the dependent variable as explanatory ones. Thanks to the use of instrumental variables, we can control for the endogeneity. Econometric endogeneity arises because the inclusion of lagged dependent variable is going to be correlate with the fixed effects and, therefore, estimates are biased and inconsistency.

2.3.1. Fixed effects

Considering only the fixed effects approach, the function to estimate is:

$$\begin{aligned}\ln\left(denemp\right)_{it} &= \beta_0 + \beta_1 population_{it} + \beta_2 \ln\left(vehicles\right)_{it} + \beta_3 denfin_{it} + \\ &\beta_4 retpop_{it} + \delta_1 HSR_{it} + \delta_2 time_t + U_{it}\end{aligned} \qquad (1)$$

Employment density, the dependent variable, is expressed in logarithms, where the subscript *i* represents the municipality and *t* the year. We estimate a log-linear function whose coefficients must be interpreted as a percentage of change in the employment density for unitary changes of the exogenous variables. Moreover, estimations consider the use of clustered standard errors for robustness. Clusters are built at municipal level.

Fixed effects model assists in controlling for unobserved heterogeneity when this heterogeneity is constant over time and correlated with independent variables. This constant can be removed from the data through differencing, for example by taking a first difference, which will remove any time invariant components of the model.

These invariant components are not observable and are usually associated to historical, geographical and institutional factors for municipalities, α_i. Since α_i is not observable, it cannot be directly controlled for, and the procedure eliminates α_i by demeaning the variables using the within transformation.

Another alternative to the within transformation is to add a dummy variable for each municipality *i* but, we would require that the number of time observations per municipality, is much larger than the number of individuals in the panel, that is not the case.

Moreover, it would be interesting to include a variable to capture the distance from the centre of the municipality to the station, but fixed effects eliminate this possibility. This variable is constant in the time component and estimations are unable to estimate its coefficient. To solve this problem, we will provide the same analysis for a larger area of 20 km. The comparison between both areas will provide information about the spatial dynamic of the employment density.

First, we examine the problem considering influence areas of 10 km around the stations of HSR for the two samples considered in the article. Table 2.3 shows the estimations related with the equation (1) previously presented.

Table 2.3. Fixed effects estimations

Explanatory variables	**Original database**	**Matching database**
population	$1.2 \cdot 10^{-6}$ $(4.65 \cdot 10^{-6})$**	$1.54 \cdot 10^{-5}$ $(7.53 \cdot 10^{-6})$ ***
$\ln(vehicles)$	0.031 $(3.12 \cdot 10^{-3})$***	0.093 (0.026)***
denfin	0.061 (0.026)**	$5.69 \cdot 10^{-6}$ $(6.35 \cdot 10^{-5})$
retpop	-8,627.47 (1023.69)***	-6,532.59 (1,563.89)***
HSR	0.173 (0.039)***	0.14 (0.036)***
time	0.011 $(6.66 \cdot 10^{-4})$***	0.013 $(2.18 \cdot 10^{-3})$***
intercept	3.93 (0.04)***	3.94 (0.18)***
Observations	36,715	5,746
Municipalities	3,146	519
F test	161.32***	3,721.8***
R^2	0.32	0.43

The first column shows the estimation for the original database that includes all the Spanish municipalities. HSR has a significant impact on changes in the dependent variable in the surrounding region, such that a HSR station around a municipality increases employment density by around 18.88%[22] and an R^2 equal to 0.37.

Considering the matching database, the explanatory power of the model has increased with an R^2 equal to 0.43 and an effect of the HSR on employment density equal to 15.02%. The reduction of the impact is because part of the effect captured with the original sample is based on effects, not only directly related to the impact of the HSR, but also related to database.

2.3.2. Dynamic model

The function takes the form

$$\ln\left(denemp\right)_{it} = \beta_0 + \beta_1 \ln\left(denemp\right)_{it-1} + \beta_2 population_{it} + \beta_3 \ln\left(vehicles\right)_{it} + \beta_4 denfin_{it} + \beta_5 retpop_{it} + \delta_1 HSR_{it} + \delta_2 time_t + U_{it}$$

(2)

This model captures the dynamic effect of the employment density and for which the speed of adjustment is governed by β_1. But, $\ln\left(denemp\right)_{it-1}$ will be correlated by construction with the fixed effects and with lagged errors. Thus, $\ln\left(denemp\right)_{it-1}$ is effectively an endogenous explanatory variable in equation (2).

The endogeneity arises when some of independent variables are correlated with the error term, and it introduces biases and inconsistency in the estimated parameters. However, the model generates internal moment conditions that, subject to a rank condition, will ensure identification in spite of serial correlation of unspecified form and the endogeneity of lagged dependent. Essentially, we are exploiting the strict exogeneity of independent variables in order to use their lags and leads that do not have a direct effect on $\Delta \ln\left(denemp\right)_{it}$ as instruments for $\Delta \ln\left(denemp\right)_{it-1}$.

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[22] The interpretation of the coefficient is not direct, given that we have estimated a log-linear function. The impact is equal to $e^{Intercept+\beta_{HSR}} / e^{Intercept}$.

The role of the lagged $\ln(denemp)$ is structural, and we consider models where its effect is identified regardless of the form of serial correlation. The main solution is thus to find a new variable vector, called instrument Z. In our case, we use lagged exogenous variables. Hence, we estimate considering panel data estimations and instrumental variables.

Table 2.4 shows the estimations considering the equation (2).

Table 2.4. Instrumental variables estimation

Explanatory variables	**Original database**	**Matching database**
$\ln(denemp)_{t-1}$	0.71 (0.0036)***	0.83 (0.0011)***
population	$1.61 \cdot 10^{-6}$ ($2.36 \cdot 10^{-7}$)***	$2.31 \cdot 10^{-6}$ ($2.03 \cdot 10^{-7}$)***
$\ln(vehicles)$	0.11 (0.003)***	0.14 (0.012)***
denfin	0.03 (0.004)***	$0.08 \cdot 10^{-5}$ ($4.03 \cdot 10^{-6}$)***
retpop	-2,940.23 (92.96)***	-2,733.96 (409.59)***
HSR	0.039 (0.005)***	0.037 (0.008)***
time	0.0046 ($1.83 \cdot 10^{-4}$)***	0.014 ($7.37 \cdot 10^{-4}$)***
Intercept	0.37 (0.018)***	0.82 (0.07)***
Observations	28,298	4,662
Municipalities	3,146	519

*** 1%, ** 5%, *10% of significance.

The standard errors are between parentheses.

The first column shows the analysis of the original sample that includes the set of Spanish municipalities. The variable HSR has a significant impact on changes in the dependent variable in the surrounding region, such that a HSR station around a municipality increases employment density by around 3.98%, much lower that the obtained in Table 2.3 with the fixed effects estimation.

When we consider the case of the matching database, we show that the impact is still lower than Table 2.3, and equal to a 3.76% increase in terms of the employment density when municipality locates to less than 10 km from a HSR station.

Results suggest that the dynamic behaviour of the employment density is relevant and it biases previous result (Table 2.4). β_1 is 0.71 considering the original database and it determines the share of the $\ln(denemp)$ that depends on previous period. This speed of adjustment increases when we consider the matching database; municipalities are more similar so previous pattern of the employment density is more relevant than the impact of HSR, and HSR estimate reduces instead.

Lastly, we need to know if the impact of the infrastructure on the employment density decreases when we move away from the station.

2.4. Results for a concentric circle of 20 km

We estimate not only whether high-speed stations could attract employment and economic activity around them, but also the spatial-dynamic effect in order to determine whether the effects, if any, are greater the closer we move to the stations. The aim of this section is to determine whether there exist spatial effects for employment density around the station and if these are diluted as we expand the influence area.

As previously, we use the two different databases: the first column considers the original database and the second column shows the estimation of the matching database for the dynamic panel data estimation.

Table 2.5. Estimates for an influence area of 20 kilometres

Explanatory variables	Original database	Matching database
$\ln(denemp)_{t-1}$	0.91 (0.0065)***	0.93 (0.0039)***
population	$3.26 \cdot 10^{-6}$ ($8.53 \cdot 10^{-7}$)***	$2.31 \cdot 10^{-6}$ ($2.03 \cdot 10^{-7}$)***
$\ln(vehicles)$	0.1 (0.002)***	0.14 (0.012)***
denfin	0.01 (0.003)***	0.013 (0.004)***
retpop	-1,378.36 (75.75)***	-1,162.04 (40.56)***
HSR	0.027 (0.002)***	0.024 (0.003)***
time	0.0047 ($1.33 \cdot 10^{-4}$)***	0.017 ($2.17 \cdot 10^{-4}$)***
intercept	0.37 (0.013)***	0.32 (0.02)***
Observations	28,010	10,402
Municipalities	3,115	1,163

*** 1%, ** 5%, *10% of significance.

The standard errors are between parentheses.

In these estimates, we see that for all Spanish municipalities, the impact of the HSR is 2.74%, while in the second database the impact reduces to 2.42%.

2.5. Discussion

In this section, a comparison and interpretation of the analysis in the two areas of influence is performed. Table 2.6 can be understood from two different dimensions, comparing databases for a given distance or comparing the same database for 10 and 20 kilometres.

Table 2.6. Summary of results[23] (Panel data with instrumental variables)

	10 kilometres	20 kilometres
Original database	$\delta_{HSR}^{10km} = 1.0398$	$\delta_{HSR}^{20km} = 1.0274$
Matching database	$\delta_{HSR}^{20km} = 1.0376$	$\delta_{HSR}^{20km} = 1.0243$

On one hand, matching database, with more homogeneous municipalities, eliminates selection bias and gives a lower impact to the construction of the HSR. On the other hand and comparing distances, we observe a decrease in the impact of the HSR stations, as we move away from the epicentre. The construction of a HSR increases employment density around the HSR station, but its impact diminishes as we move away from it.

Regarding the estimated effects, we must discuss their relation with the literature. Our estimates show that the Spanish HSR leads to an increase in employment density of 3.76–3.98% for an influence area of 10 km, and 2.74–2.43% in the case of 20 km. This result may mean much or too little.

Labour is an input and not an output, and increases in employment density are only significant when they are translated into increases in output or productivity. We must differentiate when increases of productivity arise from net increases, or spatial relocation of the economic activity. Net increases generate economic benefits that must be included in an economic appraisal of the

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[23] The results are expressed in a unitary scale.

infrastructure, while spatial relocation may generate productivity increases that arise from regions where the economic activity relocate. Therefore, productivity increases, to be considered a benefit, must compensate productivity decreases of the depressed region.

Considering our previous estimates, we can say there is a relocation of economic activity; the impact decreases with the distance of the infrastructure. This may have important consequences in terms of public policy. But, we should first discuss the exact meaning of our impacts and the differences with the existing literature.

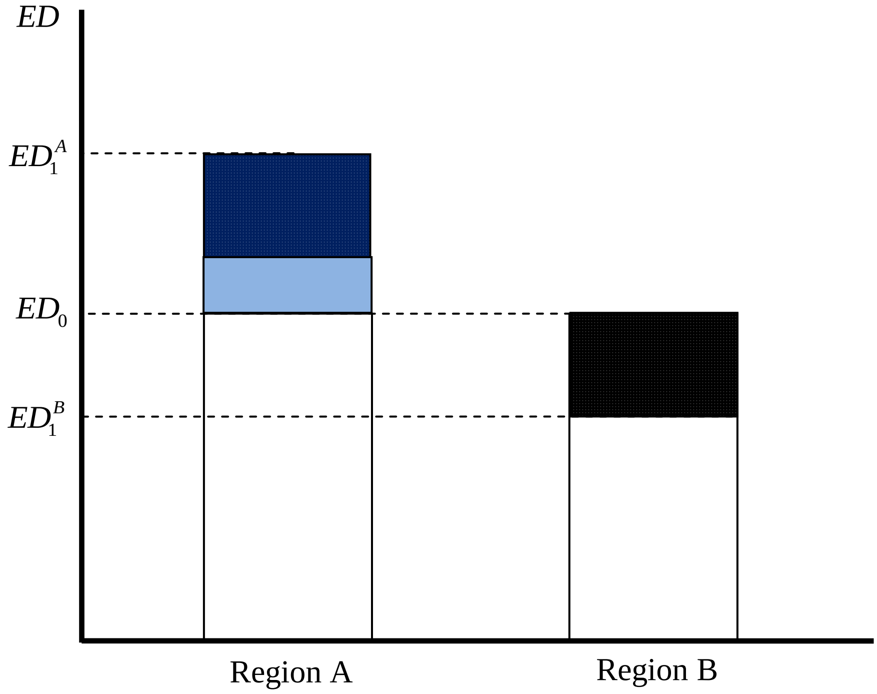
On one hand, one could argue that the estimates could include the Keynesian multiplier effect of public investment during the construction period. But, this effect would be rather similar to any other investment of equal magnitude and therefore, it should not be considered an additional benefit of the transport infrastructure. Moreover, the HSR variable takes the value of 1 only in the operation period, so it does not include effects from construction period.

On the other hand, estimates could be affected by municipalities’ trend. The introduction of HSR affects the employment density of municipalities; if municipalities’ trends are enhanced by the new infrastructure, and we consider two municipalities with divergent trends, the final impact of HSR on employment density could be biased. The use of a fixed effect estimator, the dynamic panel data, and the construction of a matching database mitigates the potential bias.

The most controversial point is to discuss whether the estimated effects are net increases or relocation of employment density and economic activity. For example, Venables (2007) assumes that productivity outside the studied area remains unchanged and, therefore, there is no possibility of the relocation of activity that could lead to a reduction in agglomeration benefits. Oosterhaven and Elhorst (2003) and Ahlfelft and Fedderson (2009), among others, find substantial additional benefits without being able to determine whether they are net creations or relocation of economic activity.

Our explanation is as follows. Let consider a country where there are two regions that before the construction of HSR had identical size and employment density: one builds a HSR infrastructure and the other does not. Graphically, the result can be seen in Figure 2.2.

Figure 2.2. Total effect = Net effect + Relocation of activity



At $t=0$, region A and B have the employment density ED_0. At $t=1$, the HSR starts to operate and the economic activity of both regions relocate and employment density levels are ED_1^A, and ED_1^B, respectively. We observe two different phenomena; the relocation from region B to region A, and the creation of net effects. The relocation is depicted in Figure 2.2 with the stripped square, while the blue square represent the creation of net effects.

The difference between ED_0 and ED_1^A, or ED_1^B show the total effect on employment density of the construction of the HSR. In region A, the total effect is composed by the sum of the net effect (blue square) and the relocation of economic activity of the region B (stripped square), which, in turn, is equal to the reduction of total employment density in region B.

The problem is that estimates only capture the total effect. In an extreme case where total effect is equal to relocation effect (blue square is equal to zero); the region A still growths in terms of employment density and the region B still decreases. Therefore, we would overestimate the impact of the infrastructure and we would include, in an economic appraisal, the total effect as additional benefits, even when they are not.

To sum up, it seems that estimated effects on employment that arise largely from agglomeration economies does not always provide relevant information about the creation of final effects. Thus, increases in employment density and productivity cannot be transferred directly to the benefits from the infrastructure. The impacts found in the literature and that translate the agglomeration elasticities to increase user benefits have to be assessed with caution.

In our case, there are some indications about the possible impact of relocation. First, Table 2.6 shows comparing different influence areas (10 and 20 kms) for the same database, that there may be some spatial relocation of economic activity in favour of epicentre. Second, Table 2.7 compares the average employment densities for municipalities with and without a HSR for an influence are of 10 kilometres.

Table 2.7. Mean comparison $ln(denemp)_{it}$ of the regions with and without HSR, before and after the starting of the HSR (area 10 kilometers)

	Before the starting of the HSR	After the starting of the HSR	Difference (After HSR-Before HSR)
Regions without HSR	4.30	4.27	-0.03
Regions with HSR	4.54	4.56	0.02

Table 2.7 shows that regions with and without HSR have different behaviour, in terms of $\ln(denemp)_{it}$, depending on whether they are under the influence of a HSR station or not. The results can be easily explained by the relocation of economic activity. $\ln(denemp)_{it}$ in regions with HSR evolves positively after the starting of the HSR while in regions without HSR decrease.

The institutional framework and funding system may have a role in the relocation effect. Let consider two levels of government; national and regional ones. The national government provides funds for infrastructure construction that are chosen by regional governments. The regional government is interested in overtaken new projects─even without creation of new economic activity. The regional government does not internalise the relocation effect and only worries about attracting new economic activity, no matter its origin. However, the situation would change if national government chooses the project to overtake. In this case, the internal relocation would not be considered as an additional benefit, except it generates net gains in productivity.

The problem arises, therefore, from the opposite incentives that the different levels of government may have. While regional governments are interested in attracting public investment, the national government applies efficiency criteria for the whole nation including the possible relocation of economic activity. Therefore, The final result could be an overinvestment in public infrastructure, if relocation effect is not considered.

2.5. Conclusion.

In this chapter, we estimate the impact of the introduction of the HSR on employment in Spain. The use of fixed effects and dynamic panel data allows us to control for the existence of unobservable characteristics at municipality level and the dynamic effect of the employment. This approach generates endogeneity, solved by the use of instrumental variables.

Our results confirm that the impact on employment density depends on the distance considered. If the area of influence is 10 km around the stations, the increase in terms of employment density is 3.76%, but this effect reduces as we move away from the station (2.43% for areas 20 km away). This provides evidence of a spatial-relocation of the economic activity.

From an economic policy point of view, we are interested in knowing whether public HSR investment creates additional effects resulting from agglomeration economies. We discuss whether estimated impacts are attributable to net increases or relocation of economic activity between regions. We conclude that it is difficult to differentiate between these two effects, both in this work and in the existing economic literature. Though, we give some evidences about the presence of relocation of economic activity between regions with and without HSR after it starts to operate.

The results presented in this paper should be interpreted with caution for several reasons. First, they belong to a developed economy with mature transport infrastructure network and where its potential to concentrate or disperse economic activity may be less than a developing economy.

Lastly, the effects of relocation, if significant, could produce inefficient competition for public funds between regions. These could be embedded in a race to be the first to enjoy the facilities and additional benefits at the expense of other regions reducing the total welfare.

Chapter 3. Social Benefits of High-Speed Rail: The role of accidents and congestion[24]

3.1. Introduction

High-speed rail infrastructure took off after the 1974 petrol crisis and since then has been expanding all over the world. European countries decided to develop a new, fast mode of transport that would not guzzle fossil fuels. Italy was the first to inaugurate a high-speed line in 1977, but the French led the technological boom introducing the first high-speed line between Paris and Lyon in September 1981. They were soon followed by Spain, which introduced the Alta Velocidad Española (AVE) in 1992. At the end of 2009, Europe had 6,214 kilometres of high-speed rails.

To date, national governments and supranational organizations continue spending significant amounts of public resources in HSR. The European Commission envisages an expenditure of 250€ billion in priority projects, devoting a large part to HSR infrastructures. The US government includes HSR passenger services as a centrepiece of the national transport policy, and China announces a $162 billion expenditure to expand its railway network.

The use of public funds urges the need for economic assessment, for which the flow of social costs and benefits must be computed. High-speed rail infrastructure projects entail high investment costs in the construction period that must be offset by the net social benefits of the operation period. The benefits can be broadly classified as: time saving, accident reduction, willingness to pay of the generated traffic, cost savings for alternative modes of transport, and congestion reduction—the release of alternative infrastructure capacity.

One should also consider environmental externalities and wider economic benefits such as productivity increases and regional development, whose overall effect is not well understood. On one hand, Janson et al. (2010) defend the

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[24] This paper won the accesit prize from the Cátedra Pasqual Maragall of University of Barcelona.

convenience of high-speed rail as a clean and efficient transport system from then environmental point of view. On the other hand, Kagesson (2009) and Atkins (2004) obtain opposite results when they account for the environmental costs generated during the construction period.

As far as wider economic benefits and regional development are concerned, Puga (2002) and Vickerman (1995, 2006) suggest that regional benefits are not significant because the high-speed rail infrastructure is not designed for freight transport; this limits the mobility of goods and inputs and, consequently, the capacity to create agglomeration economies. Moreover, the spatial distribution of economic activity depends on the conjunction of institutional arrangements and the relative ratio of factors of production between regions. It is not obvious that less developed regions get benefits from new infrastructures (Vickerman, 1991 and Puga, 2002), which should rather be quantified for each particular project.

Regarding accidents and congestion reduction, the benefits depend on the capacity of the new infrastructure to divert traffic from alternative transport modes, which is unambiguously related to time savings, quality differences, and pricing policy of each mode.

The importance of accident reduction is reflected in current levels of accidents and deaths on the road. In Europe, 40,000 people killed in road traffic accidents each year, and some projections indicate that in 2020 traffic accidents will become the third most likely cause of death worldwide for adult men aged 15–44 years.[25] For every death on Europe's roads there are an estimated 4 permanently disabling injuries such as damage to the brain or spinal cord, 8 serious injuries and 50 minor injuries.

The benefits associated with congestion reduction arise mainly from within large cities and their surroundings, where high-speed rail is not an alternative mode of transport. Again, the infrastructure cannot be used for freight transport, which reduces its potential to lower congestion levels—since slow traffic, a prominent cause of congestion, is not affected.

Road congestion is important because it competes with agglomeration forces that generate increases in productivity. Graham (2007a) investigates the links between returns to urban density, productivity and road traffic congestion. A comparison of spatial variance in estimates indicates that road traffic

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[25] World Health Organization, 2003.

congestion plays an important role in explaining diminishing returns for the most highly urbanised locations, which indicates a direct relationship between productivity growth and congestion.

This paper examines the impact of the Spanish high-speed rail network on road accident and congestion reduction. This exercise is straightforward if one knows the amount of traffic diverted from road to rail for each line and the associated speed increases. Unfortunately, this is not the case. The lack of reliability—or outright absence—of diverted traffic data forces us to look for alternative procedures to compute the social benefits of the new infrastructure.

The main goal of this chapter is to estimate the impact of the high-speed rail system on speed and accident levels for Spanish roads affected by the corridors. In both cases, we estimate congestion and accident reduction controlling by a set of corridor and road characteristics. Estimations allow us to know the changes that the new infrastructure has brought to roads as a first step towards the computation of the social benefits from congestion and accident reduction.

This chapter is organized as follows. In Section 2 we review the literature on congestion and accidents, focusing on the impact of the transport infrastructure. Section 3 describes the peculiarities of the Spanish case and the data sources. Section 4 examines the methodology employed and shows the estimation results, explaining in detail the econometric approach and justifying its convenience. Section 5 is devoted to the computation of the social benefits of accident and congestion reduction. Lastly, some noteworthy conclusions and policy recommendations are drawn from the previous sections.

3.2. The role of accidents and congestion in infrastructure assessment

Accidents impose a cost to society via the health system, security and emergency services, and material damages—even though users bear part of the cost by paying for insurance. The total cost is quantifiable from a social point of view and constitutes an externality of transport infrastructure and services. That is, users bear some, but not all, of the costs associated to an accident; if an accident takes place, some of these costs are transferred to the rest of society. As a consequence, road users may take more risks or use cars more intensively than what is socially desirable, generating inefficiencies and welfare losses.

The costs of an accident can be split into: (a) the loss of life—the value of which is known in the literature as the statistical value of life; (b) the welfare loss for relatives and friends; and (c) other costs—including material damage to physical assets. The first of these is the most important and, consequently, the most studied in the literature. Blaeij et al. (2003) review a range of estimations of the statistical value of life, and Viscusi (2003) performs a critical review of estimation procedures based on market approaches.[26,27]

There are two sources for the externality: first, people do not internalize costs (b) and (c) above; second, they neither internalize the effect of their driving style on accidents. For these reasons, the introduction of pricing mechanisms that incorporate external effects gives the right incentives to market participants, reducing the size of the externality.

Lastly, from an empirical point of view, several articles have quantified the importance of the external costs of road accidents. Elvik (2000) estimates a cost ranging 0.5–0.57% of GDP for OECD countries. Maddison et al. (1996) and Pearce (1993) also find that costs are substantial. However, a microeconomic analysis conducted by Peirson et al. (1997) shows that many studies have overestimated them by assuming a number of accidents proportional to the number of vehicles (Vickrey, 1968 and 1969, and Newbery, 1987).

Congestion, meanwhile, arises because there is an excessive demand for the infrastructure at certain times. The infrastructure cannot absorb the peak demand, which means that users spend too much time on their journey. The externality appears, again, because people do not consider the costs they impose on other users—such as extra time and fuel consumption.

Congestion has been treated extensively in the urban context, as opposed to agglomeration economies; not only its direct effects but also its indirect effects on productivity. Two solutions stand out: pricing systems, like those implemented in some European cities such as Stockholm, London and Milan, and

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[26] See Maibach et al. (2008) and Link et al. (2003) for specific estimate for the United States and Martínez et al. (2004) for the Spanish case.

[27] This literature stream evaluates the trade-offs between money and the risk of death. Schelling (1968) was the first who considered this approach to the statistical value of life.

building of new infrastructures, either enlarging the current stock or developing alternative modes of transport.[28]

For our study, it is important to know the elasticity between infrastructure supply and the reduction of congestion. This figure is essential to compute the cost-benefit ratio of infrastructure investment. Cervero (2002) shows that project appraisals that look at the effects of new infrastructure in surrounding areas always find a positive elasticity, though its magnitude may vary considerably.

Congestion and road accidents may be seen as the two sides of the same coin, since infrastructure users generate both kinds of externalities. However, this relationship has not been studied in depth. Wang et al. (2009) find that traffic congestion has little or no impact on the frequency of road accidents on the M25 motorway in London. Shefer and Rietveld (1997) and Shefer (1994) estimate an indirect relationship between congestion and accidents, using traffic density as a proxy for congestion. They find that the average speed of traffic is usually higher in less congested road networks, which is likely to result in more serious injuries or fatalities. Thus, traffic congestion may lead to more, though less severe, accidents.

This suggests a lower external cost of accidents in congested roads, which creates a potential dilemma for policy makers since traffic congestion improves road safety while also affecting economic productivity through reducing mobility.

Other approaches consider flow variables. Belmont and Forbes (1953), Ceder and Livneh (1982), and Ceder (1982), find a U-shaped relationship between the flow of vehicles and the severity of accidents, while Turner and Thomas (1986), and Golob and Recker (2003) find a negative correlation.

Lastly, the effect of high-speed rail on congestion and accidents in alternative modes depends on the cross-demand elasticity between modes. De Rus and Inglada (1997) find that the Madrid–Sevilla line attracts more traffic from the air than from the road. Yet, the benefits of road accidents and congestion reduction are 4.6% of the total benefits of the infrastructure. In the same vain, Levinson et al. (1997) show that high-speed rail infrastructure is a good alternative for reducing accidents and congestion, in spite of its high investment costs. Considering other infrastructures, Albalate (2011) tests the

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[28] See Eliasson (2009), for a cost-benefit analysis of the implementation of the pricing system.

accident costs of building a toll motorway parallel to an existent road where optimal pricing is not implemented. He finds an elasticity of accidents involving victims with respect to price of 0.5.

3.3. Data and empirical strategy

3.3.1. A preamble on the Spanish case

During the last decade Spain has invested around 250€ billion in new transport infrastructure (equivalent to an average investment effort of 1.5% of GDP) over the period 2005–2020. Of these, rail transport concentrates more than 48% through an ambitious network of high-speed lines.

In terms of expenditure in HSR, Spain is a reference. It has 2,700 km of high-speed rail infrastructure, which places Spain as the second country in the world, only after China, and as the first in Europe in high-speed rail kilometres. The network, at the end of 2010, linked 17 Spanish provinces and 24 cities, and about 51% of the population at the provincial level.

However, road transport is still the absolute leader in market share for freight transport. In the case of passenger traffic the picture is the same and the market share of road transport is even higher than the European average. This can be partly explained by acknowledging that the road network is also extensive: The current road network has 24,797 kilometres of which 35% are motorways.

Regarding accidents, the construction and upgrading of infrastructure, the improvements in passive safety, and several legislative changes, have allowed a reduction in the fatality rate—which reached an alarming figure at the beginning of the decade. The fatality rate per thousand inhabitants ranked Spain as the third country in the EU-15, just behind Portugal and Greece, and with similar rates to poorer countries such as the Czech Republic and Cyprus. But efforts to reduce the number of fatalities have paid off and in 2009 Spain’s rate was below the average EU-15 and near those of Finland, Denmark, and Luxembourg.

To measure accident costs it is also essential to know the statistical value of life. The statistical value of life increases with income. Bicket et al. (2006)

assume a unitary income elasticity and find a statistical value of life, adjusted for purchasing power parity, of 1,302,000€ in 2002 euros.[29] During the last decade Spain has experienced an increase in the statistical value of life and a reduction in the number of accidents, so the overall effect is ambiguous.

Congestion is common around cities, and has an important temporal component. On one hand, the extensive road network in Spain mitigates the impact of congestion. But since high-speed rail lines and motorways share the same corridors, the impact of the high-speed rail network may be significant. On the other hand, congestion usually occurs only at certain periods of the day (peak periods), and its cost depends on two things: traffic speed, and the value of time.

Speed is limited on motorways, which allows quantifying the extra time invested as the difference between the maximum and actual speeds. The maximum speed is currently set at 120 km/h, higher than in other European countries (90 km/h in Norway, Sweden and others) but lower than the 130 km/h in Austria, Holland, France and others.[30]

The value of time for private vehicles depends, among other things, on the purpose of travel, being higher for working than for non-working trips. Bicket et al. (2006) say that the Spanish value of time, adjusted by purchasing power parity and expressed in 2002 Euros, is 12.71€ per non-working travel hour and 25.95€ per working travel hour. Furthermore, the value of time increases in conditions of congestion as a result of the additional disutility that congestion generates. Wardman (2001, 2004) calculates that the value of time under congestion is 48% higher than under normal traffic conditions. Eliasson (2004) computes a value for the multiplier of 1.5, whereas Steer Davies Gleave (2004) lowers it to 1.2. Yet, most computed values for the elasticity between income and the value of time in Europe lie in the range 0.4–0.5 (Gunn et al., 1996; Hensher and Goodwin, 2004). Many papers assume a unitary elasticity, though.

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[29] Viscusi (2003) suggests that people are more reluctant to take risks when they do not directly control the means of transport. The willingness to pay to reduce the risk of accident would be higher in the case of trains than in the case of roads. This argument is not considered in this paper.

[30] The Spanish government reduced the maximum speed to 110 km/hour for a 4 month period, from March to June 2011.

3.3.2. Data and methodology

We require information at road level to estimate impacts of high-speed rail. Traffic maps, collected by the Ministry of public works, detail the number of accidents, traffic flow, speed, and other characteristics of each Spanish road for each year from 1999 to 2008. We draw information of road gauging stations parallel to high-speed rail corridors. Our database is larger for accidents than for speed, since not all gauging stations include speed data.

To quantify the effect of high-speed rail infrastructure on road accidents we must know the diverted road traffic, and its influence on road accidents. This information is not available, so the effect must be estimated indirectly. Econometrics provides new possibilities for estimating the impact without knowing the diverted road traffic. We may perform a counterfactual analysis comparing the situation before and after the first year of operation of the high-speed rail line. Finally, we can compute the impact of high-speed rail on accident and congestion considering instrumental variables estimates.

Table 2.8 provides descriptive statistics for the variables of interest, $Accidents_{it}$ represents the number of accidents at a 7 km distance from each gauging station; $Speed_{it}$ is the average speed at each gauging station; $Light_{it}$ is the average daily intensity of passenger cars, vans and caravans; $Heavy_{it}$ is the average daily intensity of articulated lorries, trucks without trailers, trucks with trailers, buses and special vehicles; $Heavy\ traffic\ proportion_{it}$ is the ratio between the daily average for light and heavy vehicles, which captures traffic composition; $Hazard$ is the ratio of fatalities to injuries per accident; $Investment\ effort_{it}$ is the ratio between road investment and GDP of the province where the road is located; HSR_{it} is a binary variable that takes the value 1 in the years of operation of the high-speed rail and 0 otherwise.[31,32]

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[31] The current road network has 3,285 gauging stations, which have an automatic counter that allows us to know the intensity of traffic, and the speed at which the vehicles are moving. Every accident is assigned to a gauging station according to the point at which it occurred.

[32] In 1993, Spain accepted the definition of fatality in the Vienna Convention, so that a fatality occurs if a person dies at the scene of the accident or dies during the following 30 days from injuries sustained in the incident.

Table 3.1. Descriptive Statistics[33]

Variable	Average	Standard Deviation	Minimum	Maximum
Accidents	1.12	1.83	0	53
Speed	97.79	16.33	48	125.7
Light	20,552.69	23,132.15	0	156,731
Heavy	4,829.79	4,196.95	0	50,776
Heavy traffic proportion	0.34	0.42	0	0.94
Hazard index	0.73	0.42	0	19.72
Investment effort	0.01	0.006	$9\cdot10^{-4}$	0.06
HSR	0.62	0.49	0	1

Table 3.1 shows descriptive statistics of our relevant variables. The proportion of heavy traffic is 34%, the ratio of heavy and light vehicles, that is, 20,553 and 4,830. The coefficient of variation of the number of accidents is 1.63, the average speed is 97.79 km/h, and the road investment at provincial level ranges from 1% to 6% of the provincial GDP.

Those gauging stations where the speed is above the maximum have been removed.

3.4. Results

Our aim is to isolate the impact of high-speed rail on accidents and congestion controlling some characteristics. We shall estimate this impact by Ordinary Least

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[33] Accidents and speed are estimated independently, though we present variables together.

Squares.

3.4.1. Accidents

In the case of accidents, we estimate the equation:

$$Accidents_{it} = \beta_0 + \beta_1 Light_{it} + \beta_2 Heavy\ traffic\ proportion_{it} + \beta_3 Hazard\ index_{it} + \beta_4 Investment\ effort_{it} + \beta_5 HSR_{it} + \delta_1 Year_t + \delta_2 Road_i + U_{it}$$

where we include the following variables:

- $Light_{it}$ is the daily number of cars, caravans and vans that pass the gauging station in either direction.
- $Heavy\ traffic\ proportion_{it}$ represents the traffic composition. The expected relationship between the number of accidents and the percentage of heavy vehicles is positive, because the presence of heavy vehicles reduces the speed of traffic (Abdel-Aty and Radwan, 2000).
- $Hazard\ index_{it}$ describes the composition of an accident, allowing us to capture potential hazard points along the route. The design of the road at this point may be one of the causes, as emphasized by McGee et al. (1995).
- We have also introduced a binary variable, $Road_i$, which takes the value 1 for observations on the same road and 0 otherwise. Our goal is to capture fixed constraints of each road, which may determine the number of accidents. Milton and Mannering (1996) study the impact of the state of the road and traffic conditions on accidents in urban areas, while Agent and Deen (1975) focus on highways.
- $Investment\ effort_{it}$ represents the relative road investment at provincial level.
- Lastly, we introduce a set of dummy variables for each year. $Year_t$ aims to capture technological or legislative changes.

Table 3.2 shows the results of the estimation.

Table 3.2. Estimation Results
Regression Model of Accidents involving High-Speed Rail

Explanatory variables	OLS
Light	$6.15 \cdot 10^{-5}$ $(1.22 \cdot 10^{-6})$***
Heavy traffic proportion	0.153 (0.051)***
Hazard index	0.019 (0.042)
Investment effort	1.648 (4.079)
HSR	-0.14 (0.068)***
Road dummies	YES
Year dummies	YES
Intercept	0.42 (0.231)**
Observations	1,530
F test	143.12***
R^2	0.74

Note 1: significant to *** 5%, ** 10%.
(Standard errors)

The estimation shows highly robust results to alternative models. Our model explains 74% of the variations of accidents per kilometre, and the impact of high-speed rail is significant. The operation of the HSR leads to a reduction of

0.14 accidents per kilometre.

The variables included can be classified into traffic, traffic composition, hazard rate, investment, and control dummies. The variable that measures the number of vehicles on the road, $Light_{it}$, has a significant, but close to zero, effect on the number of accidents; $Heavy\ traffic\ proportion_{it}$, which captures the traffic composition, has a larger impact. That is, a higher proportion of heavy traffic results in a greater number of accidents.[34] The hazard rate, which measures the proportion of fatalities compared to injuries, is not significant. At road level, the hazard rate may be constant, that is, hazard rates at different gauging stations are similar.

This simple model allows us to capture three-quarters of the variation in the endogenous variable, and shows that the HSR operation has a significant effect on the number of accidents.

3.4.2. Congestion

Congestion is measured by the speed changes associated with the introduction of the high-speed rail. This estimation is, therefore, an intermediate step to compute the cost of congestion. In particular, we run the regression:

$$Speed_{it} = \beta_0 + \beta_1 Light_{it} + \beta_2 Heavy\ traffic\ proportion_{it} + \\ \beta_3 Hazard\ index_{it} + \beta_4 Investment\ effort_{it} + \beta_5 HSR_{it} + \delta_1 Year_i + \delta_2 Road_i + U_{it}$$

As in the previous case, we incorporate a set of dummies to capture the temporal component and the peculiarities of the road.

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[34] Other functional forms for this variable have been estimated, including a second order effect, but it is not significant.

Table 3.3. Estimation Results
Regression Model of Speed involving High-Speed Rail

Explanatory variables	MCO
Light	$1.31 \cdot 10^{-4}$ $(5.79 \cdot 10^{-5})$
Heavy traffic proportion	-10.79 (1.53)***
Hazard index	-7.69 (3.95)**
Investment effort	-43.41 (108.43)
HSR	9.68 (2.26)***
Road dummies	YES
Year dummies	YES
Intercept	99.19 (5.23)***
Observations	477
F test	14.26***
R^2	0.46

Note 1: significant to *** 5%, ** 10%.

(Standard errors)

There are fewer observations because some gauging stations do not report information on average speeds. The model explains 46% of the variation in the endogenous variable.

The effect of the high-speed rail system is significant, and its coefficient is 9.68. The introduction of high-speed rail increases the average road speed by more than 9 kilometres per hour. In other words, there is a congestion reduction due to the new infrastructure.

The remaining estimates have the expected sign. An increase in the proportion of heavy traffic or in the hazard index has a negative effect on the speed. $Light_{it}$ has a significant effect, but close to zero.

Lastly, road investment effort, which has a significant impact on accidents, does not have effect on speed: the accident reduction is currently considered as a secondary aim in the Spanish road investment policy (Ministerio de Fomento, 2005).

We find that high-speed rail infrastructure has a significant impact on accident and congestion reduction, which are common externalities of road transport. Therefore, any cost-benefit analysis should take them into account—as we do in the next section.

3.5. Social benefits of the reduction in accidents and congestion

We use our estimated coefficients to compute the social benefits of congestion and accidents reduction.

3.5.1. Accidents

To estimate the social benefits of road accident reduction we use $\beta_{HSR}^{A} = 0.14$–it measures the reduction of accidents per kilometre once HSR starts to operate–the statistical value of life, and the number of fatalities and injuries per traffic accident. The average number of fatalities and injuries per accident is 0.11 and 1.75 in high-speed lines, the statistical value of life is 1,302,000€, and the statistical value of an injury is 161,800€ in 2002 euros (Link et al., 2003). With these figures, we compute the social benefit of accident reduction per road kilometre and year. The formula is:

$$SB_{accident\ reduction\ per\ \mathrm{kilometre}} = \beta_{HSR} * \left(Fatalities * Statistical\ value\ of\ \ economic\ life\right) + \\ + \beta_{HSR} * \left(Injures * Statistical\ value\ of\ \ economic\ injured\right)$$

This formula gives the social benefit per kilometre of road affected by the high-speed rail network. With the updated values, we find that the social benefit is 69,579€ per kilometre in 2010. Multiplying by the number of kilometres (1,512) we obtain an annual social benefit of 105,224,196€.

The relative importance of this figure depends on the cost of the new infrastructure. Savings amount to a reduction of 69 fatalities in the whole network or, equivalently, 70% of total costs of maintenance.[35] Since maintenance costs only represent 6%-8% of total costs (de Rus, 2011), the social benefits of the reduction in accidents lie in the range 4.2–5.6% of total costs.

3.5.2. Congestion

Congestion is not directly observable, we observe speed instead. Speed is measured in kilometres/hour but social benefit of congestion reduction must be written in monetary units. We, thus, need to transform speed changes into time units' changes comparing the time per kilometre before and after the HSR operates.[36]

After this transformation, we multiply the resulting number by the value of time to transform time into monetary units. Values of time are taken from Link et al., 2003 and updated to 2010 monetary units and they depend on the purpose of travel and traffic conditions. First, we classify them into working and non-working journeys; in particular, we assume that 30% of journeys are made for working—with a higher opportunity cost. Second, we also consider a factor of disutility caused by congestion equal to 1.5.

$$VT = 1.5 * \left(0.3 * WT + 0.7 * NWT\right),$$

where WT and NWT are the values of time for working and non-working

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[35] It is assumed that the cost of maintaining the infrastructure is €100,000 per kilometre, excluding the maintenance and operation costs of the rolling stock.

[36] The time variable is the inverse of the speed in kilometers per hour. Thus, the savings are the difference between the inverses of the speed before and after the new infrastructure $\left(\frac{1}{Speed_{without\ \mathrm{HSR}} + \beta_{HSR}} - \frac{1}{Speed_{without\ \mathrm{HSR}}}\right)$.

purposes, respectively.

Lastly, we must multiply time changes and the weighted average timesavings by the number of passengers assuming that each light vehicle has a load factor of 1.3. Then, we apply the formula:

$$SB_{congestion\ per\ km} = \Delta Time * VT * Passengers$$

The social benefit of congestion reduction per kilometre and passenger amounts to 0.033€ for 2010. The aggregate social benefits depend on the number of kilometres. Not all drivers are equally affected by congestion because they do not always travel the whole corridor and, therefore we must take into account the origin and destination of passengers.

Lacking a detailed origin and destination matrix of road users, we use data from the Movilia survey (Ministerio de Fomento, 2007), assuming that coefficients are constant over time and adequate for 2010. Therefore, the aggregate congestion reduction of all corridors amounts to 2,644,440€ per year.

The figure is therefore slightly higher than the cost of one fatality, and equals to the cost of maintaining 27 kilometres of high-speed rail infrastructure. This is equivalent to 0.03% of the total cost of the network.

3.6. Policy conclusions and recommendations

Cost-benefit analysis is an essential tool for evaluating a new investment from the point of view of transport policy and public infrastructure. In this task, the estimation of social benefits is crucial to determine the social convenience of the investment.

The exercise is not straightforward. The lack of knowledge of the volume of traffic diverted to the new infrastructure makes it hard to quantify the social benefits of the reduction in accidents and congestion.

However, comparing the corridor itself with and without the new infrastructure, and controlling for a number of characteristics, allows us to estimate the impact that the high-speed rail infrastructure has on road traffic, for speed increases and accident reduction. Thus, this indirect approach allows us to compute the benefits mentioned above.

In the case of accident reduction, social benefits ought to be taken into account, since, at least in the Spanish case, they represent about 5% of the total costs of the high-speed rail system. On the other hand, congestion reduction does not seem to be important quantitatively.

We must note that much of the congestion is by its very nature intra-day, so a temporal analysis that took this into account could give slightly higher coefficients.

We should also keep in mind that the goal of a high-speed rail system is not the reduction of accidents and congestion, so its social convenience cannot be justified by these considerations alone. There are alternative policies to reduce accidents and congestion, such as a pricing system that reflects the true cost of the externalities.

Another aspect to consider is that the results are sensitive to the future evolution of exogenous variables such as the value of time or the statistical value of life. Significant changes to any of these variables may alter the results. In any case, all assumptions were taken considering the most favourable case for the project.

Chapter 4. Indexing Emission Carbon Taxes to Emission Permit Prices: A good idea?

4.1. Introduction

Governments have a rather large toolbox to choose from when they want to control emissions of harmful substances.[37] In some cases the instrumental choice has only small efficiency implications. For instance, when equipped with complete information the planner would be able to induce the efficient emission level in a cost-effective way regardless of instrument used. In a world where abatement costs are uncertain this is no longer the case, however. Instruments utilizing the price mechanism, such as taxes and tradable permit systems, may still find a cost-effective allocation of abatement efforts, but will in general yield an emission volume that deviates from the efficient one. The optimal cap will be too low (high) when abatement costs turn out to be higher (lower) than expected while the optimal tax will induce too much (little) emissions. Weitzman (1974) shows that the optimal instrumental choice depends on the relative steepness of the marginal abatement cost (MAC) function; the cap-and-trade approach yields lower expected social cost (environmental cost plus abatement costs) than the tax approach whenever the marginal abatement benefit (MAB) function is steeper than the MAC function and vise versa.[38] In general, these instruments will not press down expected social cost to its minimum, however.

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[37] See e.g. Bohm and Russel (1985) and Sterner (2003) for reviews of environmental policy instruments.

[38] This is an important result and the intuition behind it holds also for stock externalities (Hoel and Karp, 2002; Newell and Pizer, 2003), in the sense that a relative steep MAC function increases the likelihood for the emission tax to be the preferred instrument. Interpreted literally it may lead to wrong conclusions, for instance when we leave the realms of linear marginal schedules (Malcomson, 1978; Yohe, 1978) and when the uncertainties regarding the MAB and the MAC functions are correlated (Stavins, 1996). Of course, the optimal choice of policy instrument is also influenced by other factors, such as implementation costs and transaction costs (Stavins, 1995) as well as indirect effects such as to what extent regulation rents are left in private hands (see e.g. Fullerton and Metcalf, 2002).

Much research has been devoted to find instruments that further reduce expected social costs. Roberts and Spence (1976) show that a cap-and-trade system combined with a finite penalty of non-compliant behavior and an abatement subsidy results in an emission volume closer to the ex post efficient level than what an uniform emission tax or a pure cap-and-trade system is capable of. However, such a full-fledged hybrid policy has not come into systematic practical use, presumably due to its perceived complexity.[39] Pizer (1999, 2002) shows that a cap-and-trade system combined with only a price ceiling (a so-called safety valve) may substantially reduce expected social costs.[40] Mandell (2008) notes that for a given positive cost shock the tax policy and the cap-and-trade policy produce volume errors of opposite directions and that the regulator therefore could induce an aggregate emission volume closer to the ex post efficient one by taxing some emitters and letting the others be subject to a cap-and-trade system. Mandell (2008) shows that the expected allocation gain of such a policy mix may outweigh the expected cost-effectiveness loss arising since the emitters in the two groups do not face the same price on emissions. Still another way to reduce expected social costs is to index the emission cap level to some variable correlated with the cost shock. Indexed emission caps have been around for some time.[41] Despite this, formal analyses of their performance under uncertainty are still rather few (Quirion, 2005; Newell and Pizer, 2005). Also emission taxes may be indexed (over and above that of securing their real value). But, as noted by Newell and Pizer (2005), indexing an economy wide uniform tax will not yield anything that cannot be achieved by the means of an indexed economy wide emission cap. However, governments often employ mixes of policy instruments. For instance, the EU has a cap-and-trade system for carbon emissions from energy intensive industries (the EU ETS) while other emitters (e.g. the transport sector, households and light industries) are subject to carbon or fossil fuel taxes. It has been suggested that these taxes should be indexed to the GDP (SGOR, 2008) or to the EU ETS price. It is easy to

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[39] This seems also to be the case for the sliding controls studied in Yohe (1981).

[40] It should perhaps be noted that most, if not all, cap-and-trade systems are equipped with a safety valve, either explicitly by a predetermined trigger price at which the regulator is obliged to sell additional permits or implicitly by a finite penalty of non-compliant behavior.

[41] Performance standards often allow firms to emit a certain amount per output. A more recent example is the kind of green electricity certificate systems we find in Norway, the UK and Sweden, which express the target level (for the production of green electricity) as a fraction of total electricity consumption. In addition, national emission quotas that are indexed to countries' GDP-levels or populations have for long been discussed as a means to attract developing countries to a climate treaty, see Baumert et al. (1999), Lutter (2000) and Ellerman and Sue Wing (2003).

think of realizations for which such an indexation would enhance efficiency. However, it is equally easy to think of the opposite. Formal analysis of the pros and cons of such a policy measure is lacking.

The purpose of this paper is to fill some of this gap. We study the properties of an environmental policy that (a) tax some emitters and let the others be subject to a cap-and-trade system and (b) index the tax level to the permit price. As indicated above, such an index policy may be attractive if the permit price is correlated with the cost shocks hitting the taxed firms. We restrict our focus to linear index functions, and in line with most of the literature on optimal instrumental choice under uncertainty the analysis is conducted under the assumption of linear marginal cost and benefit schedules.

The rest of the paper is organized as follows. Section 2 outlines the model and recapitulates some results of earlier literature. Section 3 presents our indexation schedule and identifies conditions under which it reduces expected social cost relative an emission tax, a cap-and-trade system, and the optimal combination thereof. Section 4 concludes.

4.2. The Model

Consider a government that wants to control the emissions of some fully mixed pollutant, i.e., one for which the environmental cost only depends on the aggregate emission level (*e*). Abatement costs are taken to be uncertain at the point in time when the government decides upon control levels. Thus, the government will not be able to set the emission cap, the emission tax or any other control variable at the level that equates marginal abatement benefits (MABs) with marginal abatement costs (MACs). We assume that the government wants to minimize expected social costs (i.e., the expected sum of abatement costs and environmental costs). Throughout the analysis we assume that the uncertainty is resolved before households and firms act, that markets are competitive, that the government may monitor the emissions of households and firms and enforce compliance at low costs (henceforth ignored), that private costs of noncompliance are prohibitive, and that other transaction costs and income effects are negligible.

We assume the following linear MAC and MAB functions.

(1) $$MAB = f + ge$$

(2) $$MAC_i = \theta_i \left(x_i - e_i + \varepsilon_i \right), \text{ i = 1, 2}$$

where the parameters f, g and θ_i are strictly positive, and ε_i is a stochastic variable that follows a symmetric distribution over (-∞, ∞) with the mean 0 and variance σ_i^2. Consequently, x_i denotes the expected business-as-usual emission level for sector *i*. To keep the exposition simple and to focus on the central parts of our problem, we abstract from uncertain abatement benefits. The aggregate MAC function amounts to

(3) $$MAC = \theta \left(x - e + \varepsilon \right),$$

where $\theta = \theta_1 \theta_2 / \left(\theta_1 + \theta_2 \right)$, $x = x_1 + x_2$, and $e = e_1 + e_2$. The aggregate cost shock ε (= ε_1 + ε_2) has the mean 0 and the variance $\sigma^2 = \sigma_1^2 + \sigma_2^2 + 2\sigma_{12}$, where σ_{12} denotes the covariance between ε_1 and ε_2.

The aggregate emission level that equates MAC and MAB is given by

(4) $$e^*(x, \varepsilon) = \frac{-f + \left(x + \varepsilon \right) \theta}{g + \theta}$$

At *e**, the economic value or environmental cost of an additional emission unit equals

$$v^*(e,\varepsilon)=\frac{\left(f+g\left(x+\varepsilon\right)\right)\theta}{g+\theta} \tag{5}$$

Setting (5) equal to (2) and solving for e_i gives the ex post cost-effective allocation of the emission volume e* between the two sectors.

$$e_1{}^*(x_1,\varepsilon_1)=\frac{\theta_1\left(g+\theta_2\right)\left(x_1+\varepsilon_1\right)-\theta_2\left(f+g\left(x_2+\varepsilon_2\right)\right)}{g\theta_2+\theta_1\left(g+\theta_2\right)} \tag{6}$$

$$e_2{}^*(x_2,\varepsilon_2)=\frac{\theta_2\left(g+\theta_1\right)\left(x_2+\varepsilon_2\right)-\theta_1\left(f+g\left(x_1+\varepsilon_1\right)\right)}{g\theta_2+\theta_1\left(g+\theta_2\right)} \tag{7}$$

Under a cap-and-trade (CnT) regime, the regulator sets the aggregate cap level (q) and distributes tradable emission permits to the firms up to that level. From Montgomery (1972) we know that competitive permit trade equalizes MACs over the two sectors irrespectively of the initial permit allocation. We may thus state expected social costs as

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{q}^{x+\varepsilon} MACdef(\varepsilon_1,\varepsilon_2)d\varepsilon_1 d\varepsilon_2+\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{q} MABdef(\varepsilon_1,\varepsilon_2)d\varepsilon_1 d\varepsilon_2 \tag{8}$$

It is straightforward to show that the cap that minimizes (8) equals the expectation of (4). Under this cap level (q^{opt}), expected social cost amounts to

$$SC_{CnT}=\frac{-f^2+2\theta fx+g\theta x^2}{2\left(g+\theta\right)}+\frac{\theta}{2}\sigma^2 \tag{9}$$

Under a uniform economy-wide emission tax (t), the expected social cost is given by

$$(10)\qquad \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{e(t,\varepsilon)}^{x+\varepsilon} MACdef(\varepsilon_1,\varepsilon_2)d\varepsilon_1 d\varepsilon_2 + \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{0}^{e(t,\varepsilon)} MABdef(\varepsilon_1,\varepsilon_2)d\varepsilon_1 d\varepsilon_2$$

where $e(t,\varepsilon)=\dfrac{-t+\theta x+\theta\varepsilon}{\theta}$ is obtained by setting *t* equal to (3) and solving for *e*. It is straightforward to show that the optimal tax (t^{opt}) equals the expectation of (5) and that, in optimum, the expected social cost amounts to

$$(11)\qquad SC_T=\frac{-f^2+2f\theta x+g\theta x^2}{2\left(g+\theta\right)}$$

The difference in expected social cost between the optimal tax policy and the optimal cap-and-trade system equals

$$(12)\qquad SC_{T\text{-}CnT}=\frac{g-\theta}{2}\sigma^2$$

This is the famous Weitzman’s formula for the optimal policy instrument choice, saying that the tax policy outperforms the cap-and-trade policy whenever the MAB function is flatter than the MAC function (i.e., $g<\theta$) and vice versa. According to this formula, the importance of the instrumental choice increases in the difference in slopes of the MAB and the MAC functions and the degree of uncertainty.

We now turn to derive the optimal mix of an emission tax and a cap-and-trade system. Mandell (2008) shows that the regulator by the means of such a policy mix may induce an expected aggregate emission volume closer to the ex post efficient one, and that this allocation gain may outweigh the cost-effectiveness loss arising because the emitters will not face the same “price” on emissions. Our model deviates from the one in Mandell (2008) in a couple of ways. First, we treat the frontier between the two sectors as exogenously given. Second, we assume that all firms within each sector are identical. Third, we allow for idiosyncratic cost shocks. Letting the emissions from Sector 1 be governed by an emission tax (t_1) and Sector 2 being subject to a cap-and-trade system (q_2), the regulator's problem is to choose the pair (t_1, q_2) that minimizes

(13)
$$\int_{-\infty}^{\infty}\int_{e_1(t_1,\varepsilon_1)}^{x_1+\varepsilon_1} MAC_1 de_1 f(\varepsilon_1) d\varepsilon_1 + \int_{-\infty}^{\infty}\int_{q_2}^{x_2+\varepsilon_2} MAC_2 de_2 f(\varepsilon_2) d\varepsilon_2 + \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_0^{e_1(t_1,\varepsilon_1)+q_2} MABde f(\varepsilon_1, \varepsilon_2) d\varepsilon_1 d\varepsilon_2$$

where $e_1(t_1, \varepsilon_1) = \dfrac{-t_1 + \theta_1 x_1 + \theta_1 \varepsilon_1}{\theta_1}$ is obtained by setting t_1 equal to (2) and solving for e_1. The optimal policy mix consists of t_1^{opt} (equal to the expectations of (5)) and q_2^{opt} (equal to the expectation of (7)), see Appendix 1 for details. It should be noted that the policy mix in focus here is only optimal if $\theta_1 > \theta_2$. Otherwise it would be better to switch the treatments of the two sectors. Given t_1^{opt} and q_2^{opt}, the expected social cost amounts to

$$(14) \quad SC_{Mix} = \frac{-f^2 + 2f\theta x + g\theta x^2}{2(g+\theta)} + \frac{g\sigma_1^2 + \theta_2\sigma_2^2}{2}$$

Subtracting (14) from (11) gives the difference in expected social cost between the optimal tax policy and the optimal policy mix,

$$(15) \quad SC_{T-Mix} = \frac{g-\theta}{2}\sigma_2^2 + g\sigma_{12} - \frac{\theta}{2}\frac{\theta_2}{\theta_1}\sigma_2^2$$

where we have made use of the fact that $\sigma^2 = \sigma_1^2 + \sigma_2^2 + 2\sigma_{12}$. The first two terms of (15) captures the expected allocation gain of governing the emissions from Sector 2 by the means of a cap-and-trade system instead of an economy wide tax, i.e., of letting the aggregate emissions be $e_1(t_1^{opt}) + q_2^{opt}$ instead of $e\left(t^{opt}\right)$. Since $\theta \geq g$, the first term is negative. (If this were not the case it would not be relevant to compare the policy mix with the tax regime since the cap-and-trade regime then would be the preferred uniform alternative.) The second term may be positive or negative, depending on the sign of the covariance. A positive covariance implies that the variance of the aggregate MAC schedule is larger than the sum of the variances of the two sectors' MAC functions, and thus a greater allocation gain of the policy mix. The third term is negative and reflects the cost-effectiveness loss arising because the mixed policy induces different emission prices in the two sectors. Since the first term is non-positive and the third term is negative, we must have a positive covariance for eq. (15) to be positive, i.e., for the policy mix to outperform the tax policy. More precisely, it must satisfy

$$(16) \qquad \rho_{12} > .5\left(\frac{\theta - g}{g} + \frac{\theta_2}{\theta_1}\frac{\theta}{g}\right)/\psi \geq 0 \text{ for } \theta \geq g$$

where $\psi = \sigma_1/\sigma_2$ and ρ_{12} is the correlation coefficient between ε_1 and ε_2. Thus, unless σ_1 is zero or σ_2 equals infinity, a positive correlation is required for the mixed policy to lower expected social costs relative the uniform tax policy.

The difference in expected social cost between the optimal CnT policy and the optimal policy mix is obtained by subtracting (14) from (9),

$$(17) \qquad SC_{CnT-Mix} = -\frac{g-\theta}{2}\sigma_1^2 + \theta\sigma_{12} - \frac{\theta}{2}\frac{\theta_2}{\theta_1}\sigma_2^2$$

This expression is similar to (15). However, the deviation in aggregate emissions now stems from the fact that the emissions from Sector 1 are taxed instead of being covered by an economy wide cap-and-trade system. For the CnT system to be the relevant comparison we must have ($g \geq \theta$). Consequently, the first term of (17) is non-positive. So, also here we find that a positive covariance is a necessary condition for the policy mix to outperform the uniform policy. More precisely the correlation coefficient must satisfy

$$(18) \qquad \rho_{12} > .5\left(\frac{g-\theta}{\theta}\psi^2 + \frac{\theta_2}{\theta_1}\right)/\psi \geq 0 \text{ for } g \geq \theta$$

Even though a positive correlation is a necessary condition for the policy mix to outperform the uniform alternative, the correlation may be far from perfect. To see this, consider the case where $g = \theta$ and $\sigma_1 = \sigma_2$. Then, the regulator is indifferent between the T and the CnT policies and the first term of (15) and (18) equals zero, whereby the two expressions coincide. Now the policy mix outperforms the uniform polices when

$$(19) \qquad \rho_{12} > .5\frac{\theta_2}{\theta_1}$$

Since $\theta_1 \geq \theta_2$, the right-hand-side is smaller than .5. We have thus shown that the optimal policy mix outperforms the uniform policies for a wider range of parameter values than those studied in Mandell (2008), who assumed that the two sectors we subjected to one and the same cost-shock.

4.3. Indexed Carbon Tax

We are now in the position to study a policy where the emission tax in Sector 1 is indexed to the permit price in Sector 2. First we give, by the means of a diagrammatic exposition, the intuition for how such a policy may reduce social cost as compared to the policy mix studied above. Thereafter, we derive the optimal linear indexation scheme and study its determinants and relative performance.

Figure 4.1 illustrates an economy where abatement costs are uncertain. The solid lines indicate expected locations of the MAC functions. The departure for the analysis is the optimal policy mix consisting of a tax t_1' (= $E\{v^*\}$) in Sector 1 and a cap q_2' (= $E\{e_2^*\}$) for Sector 2. The expected permit price p_2' equals t_1'. It is easily seen that the expected aggregate emissions volume $E\{e_1*\} + q_2'$ equals $E\{e*\}$. Assume now that the realized MAC-functions deviate from their expected locations as illustrated by the dashed lines. Under this cost realization, the policy mix yields an aggregate emission volume equal to $e_1^H + q_2'$ *which* exceeds the efficient level, $e*_{ex\ post}$. Since Sector 2 emissions are fixed at the cap level, the marginal benefit of abatements in Sector 1 ($\text{MAB}_{\text{Residual}}$) corresponds to the segment of the MAB function lying to the right of q_2' in Figure 1c. Inserting the $\text{MAB}_{\text{Residual}}$ function in Figure 1a reveals that the tax level t_1' is too low for this cost realization. The resulting efficiency loss equals the shaded area in Figure 1a. Ex post we would like to have set the tax at t_1^H.[42] An indexation scheme that in a balanced way increases (reduces) the tax level relative t_1' when the MAC_2 function turns out to lie above (below) it's expected level, could have accomplished this.

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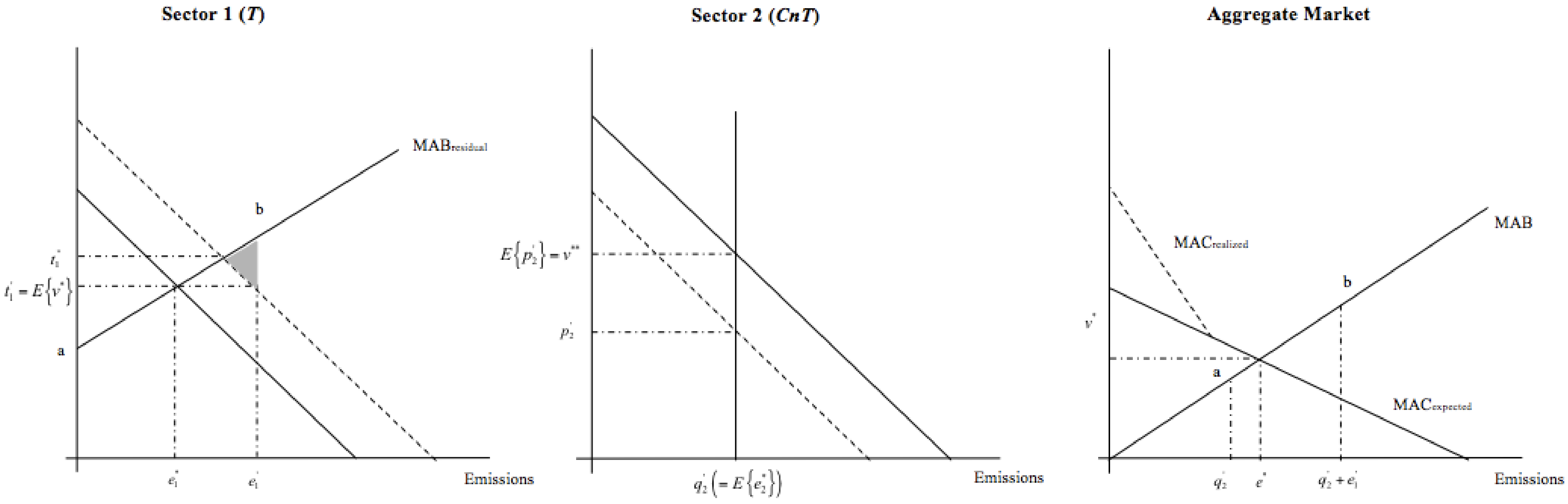
[42] To be sure, we would also like to adjust the cap for Sector 2. However, by assumption this is not a valid policy adjustment.

Figure 4.1. The value of ex post adjustment of the tax level in Sector 1.



Sector 1 (*T*)

Sector 2 (*CnT*)

Aggregate Market

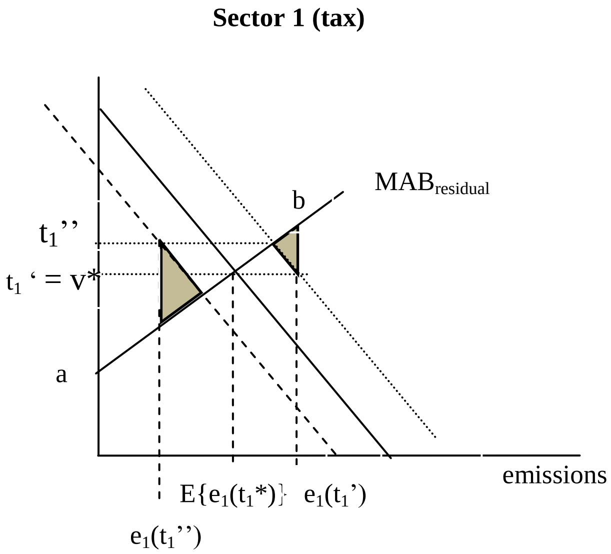
Figure 1a

Figure 1b

Figure 1c

Of course, a high (low) permit price need not be a signal of high (low) costs in sector 1. It is possible that this kind of indexation scheme may lead to a higher efficiency loss than under the optimal policy mix. To see this, assume that the regulator presumes a positive correlation between the two sectors' MACs and therefore follows a rule saying that a higher (lower) permit price than expected gives a higher (lower) tax level in Sector 1, so that the permit price p_2^H yields the tax level t_1^H. As indicated in Figure 4.2, no distortion would arise in Sector 1. However, even with a rather strong positive correlation a higher than expected permit price may be accompanied by a lower than expected MAC_1 function. If so, the tax level t_1^H, could give rise to a substantial efficiency loss, as indicated by the larger shaded area in Figure 4.2.

Figure 4.2. Pros and cons of ex post adjustment of the tax level in Sector 1



We now turn to a formal analysis of linear indexation schemes, i.e., rules of the following form, $t_1 = \alpha + \beta[E\{p_2\} - p_2]$. Given competitive permit trading, we have that $p_2 = MAC_2(q_2;\varepsilon_2) = \theta_2(x_2 + \varepsilon_2 - q_2)$. Using this to eliminate p_2 and $E\{p_2\}$ in the expression for t_1, we get

(20) $t_1 = \alpha - \beta\theta_2\varepsilon_2$

Set MAC$_1$ = t$_1$ and solve for e$_1$, and insert (20) in the expression obtained to get $e_1 = \frac{-(\alpha - \beta\theta_2\varepsilon_2) + \theta_1 x_1 + \theta_1\varepsilon_1}{\theta_1}$. The regulator’s problem can now be stated as choosing the triple (α, β and q_2) that minimizes

(21)

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{e_1(t_1(\alpha,\beta,\varepsilon_2,\varepsilon_2))}^{x_1+\varepsilon_1} MAC_1 de_1 f(\varepsilon_1,\varepsilon_2) d\varepsilon_1 d\varepsilon_2 + \int_{-\infty}^{\infty}\int_{q_2}^{x_2+\varepsilon_2} MAC_2 de_2 f(\varepsilon_2) d\varepsilon_2 + \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_0^{e_1(t_1(\alpha,\beta,\varepsilon_1,\varepsilon_2)+q_2} MABde f(\varepsilon_1,\varepsilon_2) d\varepsilon_1 d\varepsilon_2$$

From the FOCs of this problem we have. (For derivations, see Appendix 2.)

(22) $\alpha^{opt} = \frac{\theta}{g+\theta}\left(f + gx\right)$

(23) $\beta^{opt} = -\frac{g}{g+\theta_1}\frac{\theta_1}{\theta_2}\frac{\sigma_{12}}{\sigma_2^2}$

(24) $q_2^{Index} = -\frac{f\theta_1 + gx_1\theta_1 - gx_2\theta_2 - x_2\theta_1\theta_2}{g\left(\theta_1 + \theta_2\right) + \theta_1\theta_2}$

It should be noted that the sign of β^{opt} is determined by the sign of the covariance. A negative (positive) covariance gives a positive (negative) β^{opt}, implying that the tax level is adjusted in the opposite (same) direction as the permit price deviates from its expected level. The formula for the optimal indexed emission tax is given by

(25) $$t_1^{Ind} = \frac{\theta}{g+\theta}(f+gx) + \frac{g}{g+\theta_1}\theta_1\frac{\sigma_{12}}{\sigma_2^2}\varepsilon_2$$

The extent to which a given cost shock influences the tax level increases in the information value of the permit price (σ_{12}/σ_2^2), g, and θ_1 while it shrinks in θ_2. It should also be noted that the expected tax level under the optimal index policy equals the expectation of (5) and that the optimal cap for Sector 2 is the same as in the optimal policy mix.

Expected social cost under the optimal index policy amounts to

(26) $$\mathrm{SC}_{\mathrm{Ind}} = \frac{-f^2+2f\theta x+g\theta x^2}{2(g+\theta)} + \frac{g\sigma_1^2+\theta_2\sigma_2^2}{2} - \frac{g^2}{2(g+\theta_1)}\rho_{12}^2\sigma_1^2$$

Subtracting (26) from (14) yields

(27) $$SC_{Mix-Ind} = \frac{g^2}{2(g+\theta_1)}\rho_{12}^2\sigma_1^2$$

Our first main result is thus that the optimal index policy strictly outperforms the optimal policy mix as long as the covariance between the cost shocks differs from zero, i.e., as long as the permit price convey some information about the likely location of the MAC_1 function. This should come as no surprise. After all, we have assumed that the regulator knows the covariance *and* is equipped with an instrument (an easily adjusted emission tax) to utilize this information.

Now, we compare our index-policy scheme with the CnT and the T policies. Subtracting (26) from (9) and (11), respectively, gives.

$$(28) \quad SC_{\text{CnT-Ind}} = -\frac{g-\theta}{2}\sigma_1^2 + \theta\sigma_{12} - \frac{\theta_2}{\theta_1}\frac{\theta}{2}\sigma_2^2 + \frac{g^2}{2(g+\theta_1)}\rho_{12}^2\sigma_1^2 \quad \frac{\theta_1\theta_2}{\theta_1+\theta_2} - \frac{g^2\sigma_{12}}{(g+2\theta_1)\sigma_2^2},$$

$g \geq \theta$

$$(29) \quad SC_{\text{T-Ind}} = \frac{g-\theta}{2}\sigma_2^2 + g\sigma_{12} - \frac{\theta_2}{\theta_1}\frac{\theta}{2}\sigma_2^2 + \frac{g^2}{2(g+\theta_1)}\rho_{12}^2\sigma_1^2 \quad , \ g \leq \theta$$

The first three terms of (28) and (29) are familiar from eqs. (15) and (17), respectively. They reflect the net-gain if going from the uniform economy-wide policy to the optimal policy mix. The forth term captures the additional gain of letting the tax level in Sector 1 depend on the permit price level in Sector 2, and is identical to (27). Since this term is positive, the optimal index policy outperforms the uniform policies over a wider range of parameters than the optimal policy mix does. However, for a wide range of parameter values the index policy is outperformed by the uniform policy alternatives. This is easily seen by assuming a covariance/correlation equal to zero. Then (28) and (29) become negative.

More generally, for $SC_{\text{T-Ind}}$ to be positive we must have

$$(30) \qquad \rho_{12} \geq \frac{g+\theta_1}{g}\left(-1+\sqrt{\frac{\theta_1+\theta_2}{g+\theta_1}}\right)/\psi \quad \text{for } g \leq \theta$$

Since we have $g \leq \theta < \theta_2 < \theta_1$ the square-root exceeds one, and the right-hand side of (30) is positive. In other words, a strictly positive correlation is required for the index policy to perform better than a uniform tax.

A positive $SC_{\text{CnT-Ind}}$ requires

$$(31) \quad \rho_{12} \geq \frac{g+\theta_1}{g}\left(-\frac{\theta}{g}+\sqrt{\frac{g-\theta}{g+\theta_1}\psi^2+\left(\frac{\theta}{g}\right)^2+\frac{\theta}{g+\theta_1}\frac{\theta_2}{\theta_1}}\right)/\psi \quad \text{for } g \geq \theta$$

By inspection we see that the square root exceeds θ/g. So again we find that a positive correlation is required. (The derivations of (30) and (31) are presented in Appendix 3. There we also explain why the negative roots are irrelevant.)

The expressions (30) and (31) are rather messy. However, we see directly that the more uncertain we are about the location of the MAC_2-function (i.e., the lower the ψ is) the higher must the correlation be for the index policy to outperform the uniform alternatives. To gain some further insights assume that $\theta = g$, whereby (30) and (31) coincide to

$$\rho_{12} \geq \frac{\theta + \theta_1}{\theta}\left(-1 + \sqrt{\frac{(\theta_1 + \theta_2)^2}{(\theta_1 + \theta_2)^2 - \theta_2^2}}\right)/\psi \tag{32}$$

Then, under the assumption of $\sigma_1 = \sigma_2$ and $\theta_1 = \theta_2$ we have that ρ_{12} cannot be lower than .46 if the index policy is to outperform the uniform policy alternatives. Thus, in some cases the may need to exceed zero by far. Still, there seems to exist a window of opportunity for lowering expected social cost by the means of our index policy.

We now turn to a numerical analysis in order to (a) clarify the role of the different parameters and (b) to indicate the size of the potential efficiency gains of using the index policy. We use parameter values from the EU context. This makes particular sense since the EU for some time now have had a policy mix of the kind in focus here and for which it has been suggested that the future tax level should be indexed to the permit price. The values are presented in Table 4.1.

Table 4.1. Parameter Values

Parameter	σ_1^2	σ_2^2	θ_1	θ_2	θ
	4	4	1.5	.8	.52

The parameter values in Table 4.1 are collected from different sources. The slope parameters for the MAC$_1$ schedule (θ_1) and the MAC$_2$ schedule (θ_2) are obtained by the means of linear approximations of the MAC curves for the non-trading sector in the EU and the EU ETS. The approximations are made around the point €100/ton CO$_2$. Considering that the EU ETS price currently are below €20/ton and many member states tax fossil fuel use in the non-trading sector by an amount exceeding €100/ton CO$_2$, it may seem odd to make the approximations at the same price level. However, what we here are analysing is an optimal policy mix, not the current mix. Time series data of the EU ETS price are used to estimate σ_2^2.[43] Since the consumption of fossil fuels in Sector 1 is not held constant we cannot use the crude oil price or the gasoline price data to estimate σ_1^2 in the proper manner. Therefore, we assume equal variances. This is of minor importance for the qualitative results since σ_1 only enters as a scale variable. More important for the results is the slope of the MAB function, *g*. We therefore consider a wide interval of values for g.

Consider Figure 4.3. The shaded area therein illustrates the combinations of ρ_{12} and *g* values for which the index policy outperforms the tax policy, given the parameter values stated above. We measure ρ_{12} on the x-axis and *g* on the y-axis. Since θ is held fixed at .52, we allow g/θ to vary from around zero to 3.85. As mentioned above, the comparison between a uniform tax and the index policy is

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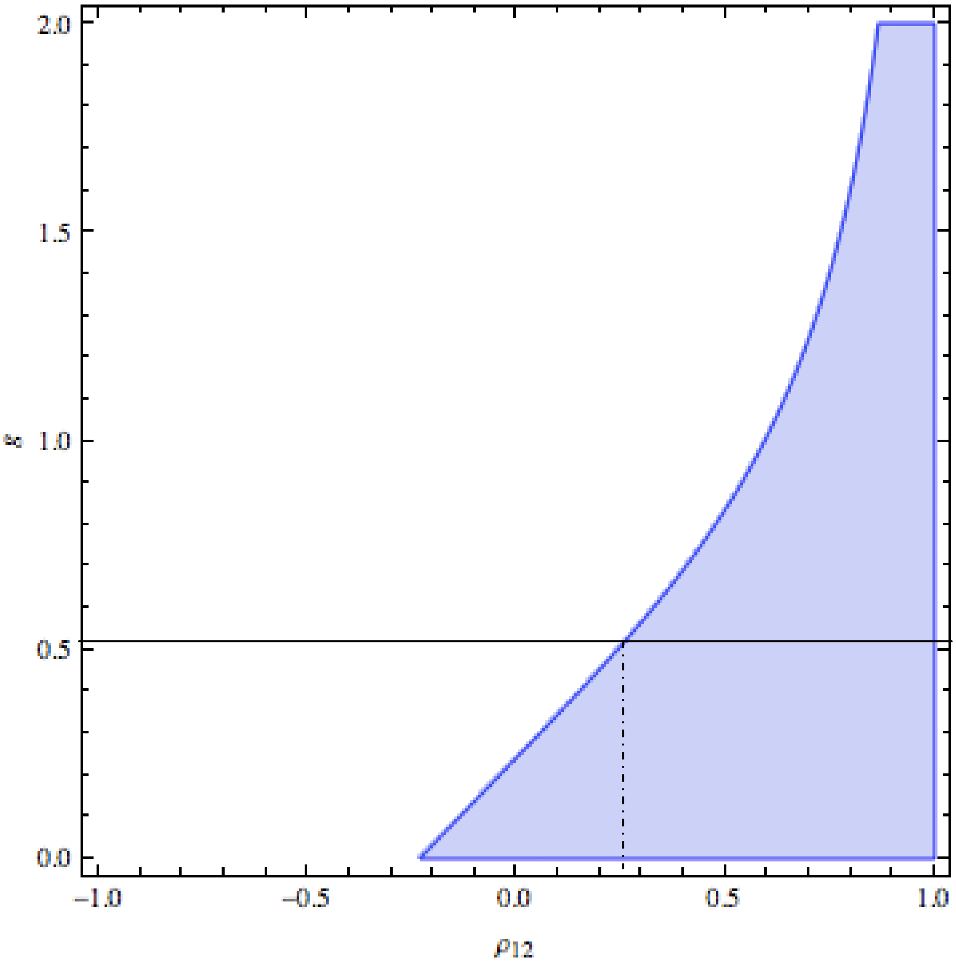
[43] The variance has been computed on the EU ETS spot price for the period 2010-2012 available at www.carbonmarketdata.com.

only relevant if $g/\theta \leq 1$.[44] In other words, we focus on the area below the straight horizontal line in the Figure. As indicated by the dashed vertical line, the correlation between the two sectors' cost shocks must be .29 or higher for the index policy to yield lower expected social costs than the tax policy. We also see that the lower is g (i.e. the higher the relative steepness of the MAC function is) the higher must the correlation be. Interesting to note is that for a sufficiently flat MAB function (g equal to or below .25) the index policy cannot outperform the uniform tax no matter how high the correlation is.

Figure 4.3. Tax vs. the Index Policy (SC_T - SC_{Ind})



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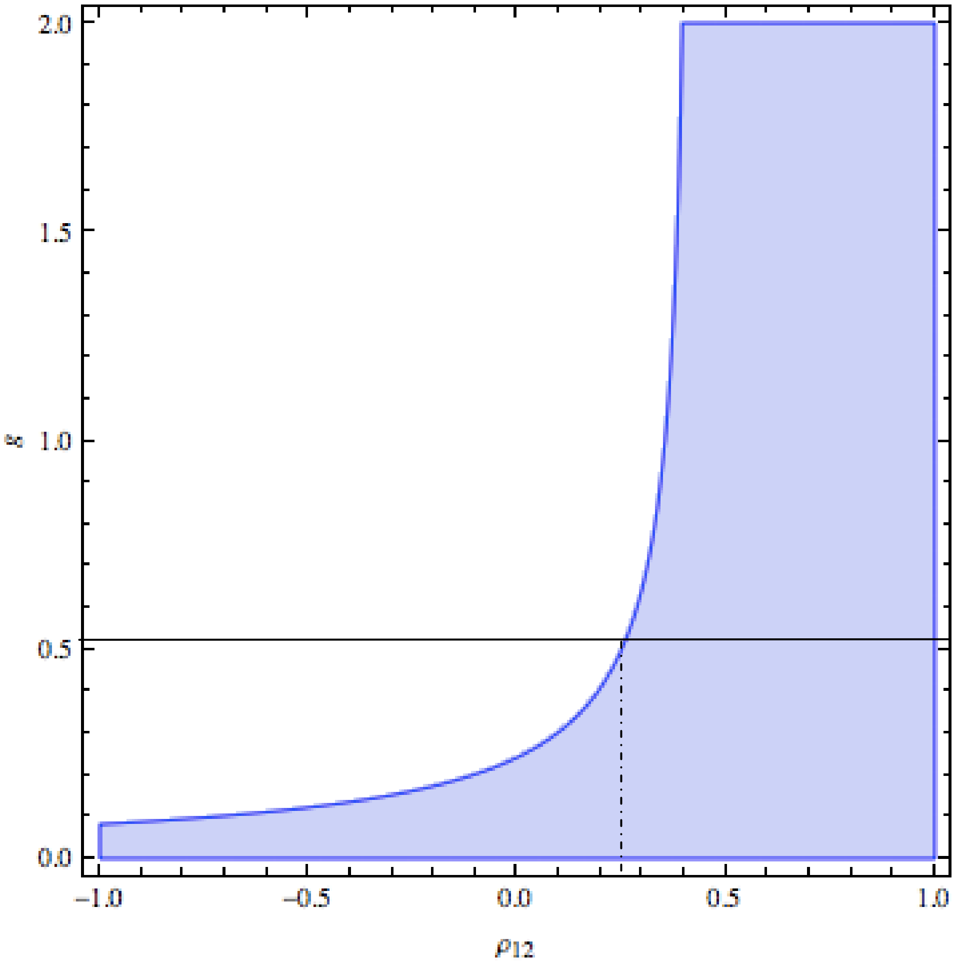
[44] That the optimal index policy performs better than a uniform emission tax when this instrument is a sub-optimal choice is of minor interest here.

Figure 4.3 shows the combinations of ρ_{12} and g values for which the index policy outperforms the economy-wide cap-and-trade system. This comparison is relevant for $g \geq \theta$ (=.52), i.e. for the area above the straight horizontal line. As indicated by the dashed vertical line, the correlation coefficient must be around .6 or higher for the index policy to perform better that the cap-and-trade system. In line with our expectations, we see that the larger is the ratio g/θ, the larger must the correlation coefficient be for the index policy to be preferred alternative. In contrast to Figure 4.4, we see that, for the g interval studied here, there always exists correlation coefficient allowing for the index policy to be the better alternative.

Figure 4.4. Cap-and-trade vs. the Index Policy (SC_{CnT} - SC_{Ind})



The graphical representation and the previous mathematical analysis show us that there is a wide range of parameters values for which the index policy is the most efficient instrument to regulate the emission of pollutants in the context as the one we described. Below, we present some calculations of the expected relative net-gains of using the index policy instead of (i) the policy mix, (ii) a uniform emission tax, and (iii) an economy-wide cap-and-trade system, given the parameter set in Table 4.1. Figure 4.5 shows the expected relative gain of using the index policy instead of the optimal policy mix. More precisely we graph $(SC_{Mix}\text{-}SC_{Ind})/SC_{Mix}$ over the correlation coefficient for various g values.

Figure 4.5. Expected relative gain of using the indexing the tax to the permit price.

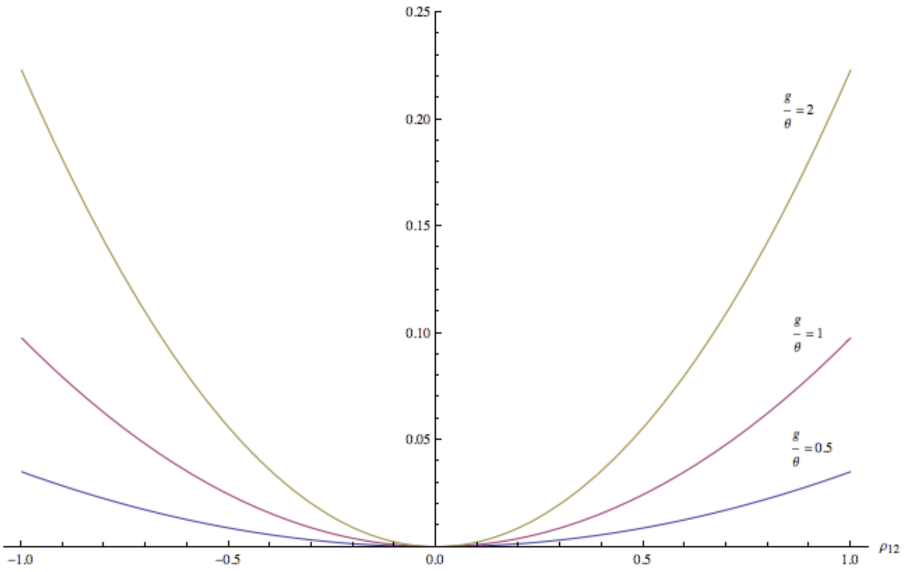


Figure 4.5 reveals that although the index policy strictly outperforms the policy mix as long as the correlation between the two sectors' cost shocks differs from zero, the expected relative gains for most cases are rather small.

Figure 4.6 presents graphs of $(SC_T\text{-}SC_{Ind})/SC_T$ over the correlation coefficient for various g values.

Figure 4.6. Expected relative gains of using the index policy instead of a uniform tax policy

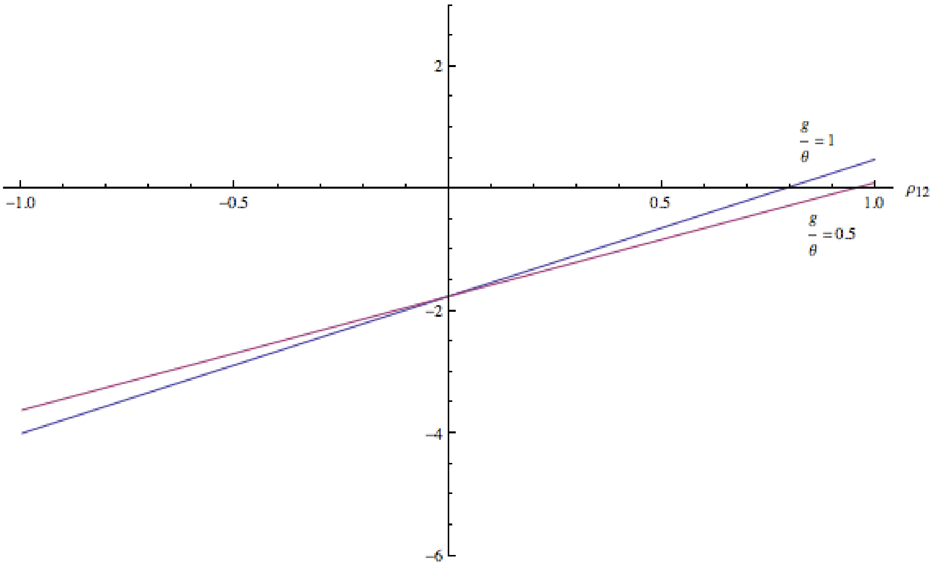
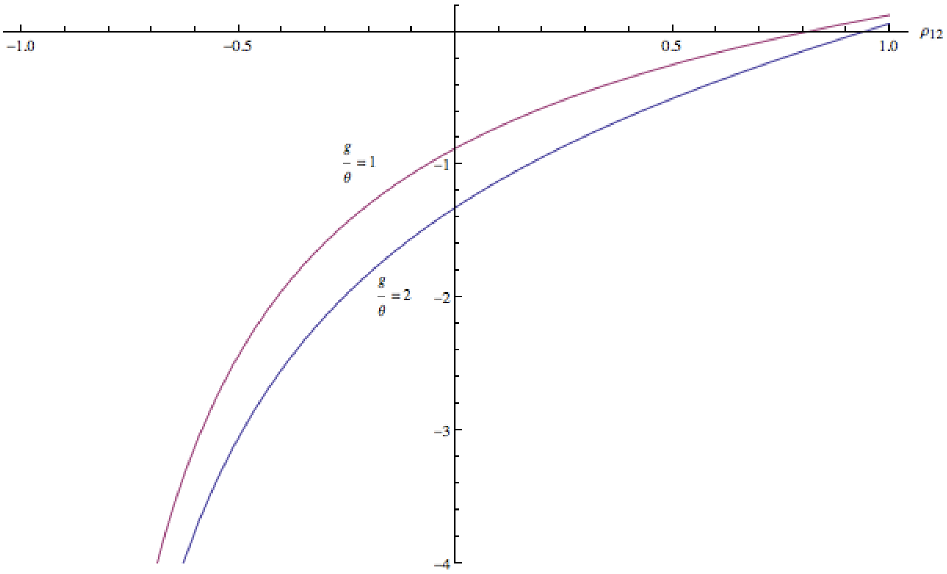


Figure 4.7 presents graphs of $(SC_{CnT}-SC_{Ind})/SC_{CnT}$ over the correlation coefficient for various g values.

Figure 4.7. Expected relative gains of the index policy instead of a cap-and-trade system.



Considering figures 4.6 and 4.7, we observe that the index policy outperforms the uniform policies only for rather high values on the correlation coefficient. Concretely, the comparison between the index policy versus the uniform tax policy (figure 4.6) is only relevant when $g/\theta \leq 1$. Under this scenario, the expected gains are rather small and only reachable for high correlations while potential losses are large.

Figure 4.7 shows a similar situation. The expected relative gain of the indexed policy with respect to a uniform CnT, only relevant if $g/\theta \leq 1$, appears when the positive correlation is high, at least 0.8. For any lower values, potential losses are rather large.

4.4. Conclusions.

We have here studied the properties of a policy mix where one group of emitters is subject to an emission tax and the other emitters are covered by a cap-and-trade system and where the tax level is indexed to the permit price. With such a policy the tax level may be updated with respect to the realized marginal abatement cost function of the capped sector. We find that the optimal linear index policy outperforms the policy mix studied in Mandell (2010) as long as the two groups' cost shocks are correlated, i.e., as long as the permit price variation convey any information about the expected location of the other sector's marginal abatement cost schedule. Consequently, we also find that the index policy outperforms an economy wide tax or a cap-and-trade system over a wider set of parameter values than the policy mix does. Thus, in economies that mix emission taxes and cap-and-trade systems, such as the EU, the regulator may lower expected social costs by indexing the emission tax to the permit price level. However, the expected net-gains are small (at least for the case of linear marginal abatement cost and benefit functions) and for a wide range of parameters both the optimal policy mix and the optimal index policy are outperformed by an economy wide emission tax or a cap-and-trade system.

Our analysis abstracts from several real-world conditions of potential importance, such as implementation costs and that the regulator may only have a fuzzy picture about the covariance between the cost shocks of different sectors. Taking into account this and other real-world aspects of emissions controls, such as the possibility to adjust the level of an economy wide emission tax or adding an explicit or implicit safety valve to an economy wide cap-and-trade system, may further strengthen the argument for the uniform policy alternatives.

Appendix 1. Derivation of the optimal policy mix (t_1^{opt}, q_2^{opt}).

Insert MAC_1, MAC_2, obtained from (2), and $e_1\left(t_1,\varepsilon_1\right)=\frac{-t_1}{\theta_1}+x_1+\varepsilon_1$ in (13) and take expectations. Then after some manipulation we have

(A1.1)

$$\frac{t_1^2}{2\theta_1}+\frac{\theta_2}{2}\left(q_2^2-2q_2x_2+x_2^2+\sigma_2^2\right)+\frac{gt_1^2-2t_1(f+gq_2+gx_1)\theta_1+\theta_1^2(gq_2^2+2fx_1+gx_1^2+2q_2(f+gx_1)+g\sigma_1^2)}{2\theta_1^2}$$

This is the expected social cost of the policy mix t_1 and q_2. Let $h\left(t_1,q_2\right)$ denote (A1.1). The first order conditions for the problem of minimizing $h\left(t_1,q_2\right)$ with respect to t_1 and q_2, are:

(A1.2) $$\frac{\partial h\left(t_1,q_2\right)}{\partial t_1}=\frac{t_1}{\theta_1}+\frac{2gt_1-2\left(f+gq_2+gx_1\right)}{2\theta_1^2}=0$$

(A1.3) $$\frac{\partial h\left(t_1,q_2\right)}{\partial q_2}=\frac{-2gt_1+\left(2gq_2+2\left(f+gx_1\right)\right)\theta_1}{2\theta_1}+\left(q_2-x_2\right)\theta_2=0$$

Solving for t_1 and q_2, gives the optimal control levels.

(A1.4) $$t_1^{opt}=\frac{f+gx}{g+\theta}\theta$$

(A1.5) $$q_2^{opt}=\frac{\left(g\theta_2+\theta_1\theta_2\right)x_2-\left(f+gx_1\right)\theta_1}{\left(g+\theta\right)\left(\theta_1+\theta_2\right)}$$

Inserting (A1.4) and (A1.5) in (A1.1), yields after some manipulation (14). The second partial derivatives of (A1.1) amounts to

(A1.6) $$\begin{bmatrix}\dfrac{\partial^2 h\left(t_1,q_2\right)}{\partial^2 t_1} & \dfrac{\partial^2 h\left(t_1,q_2\right)}{\partial t_1\partial q_2}\\[2ex] \dfrac{\partial^2 h\left(t_1,q_2\right)}{\partial q_2\partial t_1} & \dfrac{\partial^2 h\left(t_1,q_2\right)}{\partial^2 q_2}\end{bmatrix}=\begin{bmatrix}\dfrac{g}{\theta_1^2}+\dfrac{1}{\theta_1} & -\dfrac{g}{\theta_1}\\[2ex] -\dfrac{g}{\theta_1} & g+\theta_2\end{bmatrix}$$

Since the leading principal minors are positive, the SOCs of our minimization problem are satisfied.

Appendix 2. Derivation of the optimal linear index policy (α^{opt}, β^{opt}, q_2^{opt}).

Let t_1 be given by (20). Insert MAC_1, MAC_2, $e_1\left(t_1,\varepsilon_1\right)=\frac{-t_1}{\theta_1}+x_1+\varepsilon_1$ and (20) in (13) and take expectations. After some manipulation we have

(A2.1)

$$\frac{\alpha^2}{2\theta_1}+\frac{\beta^2\theta_2^2}{2\theta_1}\sigma_2^2+\frac{\theta_2}{2}\left(q_2^2-2q_2x_2+x_2^2+\sigma_2^2\right)+$$
$$\frac{\theta_1^2((q_2+x_1)(2f+g(q_2+x_1))+g\sigma_1^2)+g(\alpha^2+\beta^2\theta_2^2\sigma_2^2)-2\theta_1(\alpha(f+g(q_2+x_1))-g\beta\theta_2\sigma_{12})}{2\theta_1^2}$$

This is the expected social cost under the index policy. Let $h\left(\alpha,\beta,q_2\right)$ denote (A2.1). The first order conditions for the problem of minimizing (A2.1= with respect to α, β and q_2, are:

(A2.2) $$\frac{\partial h\left(\alpha,\beta,q_2\right)}{\partial\alpha}=\frac{\alpha}{\theta_1}+\frac{2g\alpha-2\left(f+g\left(q_2+x_1\right)\right)\theta_1}{2\theta_1^2}=0$$

(A2.3) $$\frac{\partial h\left(\alpha,\beta,q_2\right)}{\partial\beta}=\frac{\beta\theta_2^2\sigma_2^2}{\theta_1}+\frac{2g\theta_2\left(\beta\theta_2\sigma_2^2+\theta_1\sigma_{12}\right)}{2\theta_1^2}=0$$

(A2.4) $$\frac{\partial h\left(\alpha,\beta,q_2\right)}{\partial q_2}=\frac{-g\alpha+\left(f+g\left(q_2+x_1\right)\right)\theta_1}{\theta_1}+\left(q_2-x_2\right)\theta_2=0$$

Solving for α^{opt}, β^{opt}, q_2^{Index} gives (22), (23) and (24). The second partials of (A2.1) are

(A2.5)

$$\begin{bmatrix}\frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial^2\alpha} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial\alpha\partial\beta} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial\alpha\partial q_2}\\ \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial\beta\partial\alpha} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial^2\beta} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial\beta\partial q_2}\\ \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial q_2\partial\alpha} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial q_2\partial\beta} & \frac{\partial^2h\left(\alpha,\beta,q_2\right)}{\partial^2q_2}\end{bmatrix}=\begin{bmatrix}\frac{g}{\theta_1^2}+\frac{1}{\theta_1} & 0 & -\frac{g}{\theta_1}\\ 0 & \frac{g\theta_2^2\sigma_2^2}{\theta_1^2}+\frac{\theta_2^2\sigma_2^2}{\theta_1} & 0\\ -\frac{g}{\theta_1} & 0 & g+\theta_2\end{bmatrix}$$

Since all the leading minors are positive , the SOCs of our minimization problem is fulfilled.

Appendix 3. Analytical expression to derive the covariance for indexed policy to outperform the alternatives.

Equations (28) and (29) indicate the expected social cost of our index policy scheme with the uniform policies, *CnT* and *T* respectively. The goal is to determine the range of covariance for which index policy outperforms.

When $\theta = g$, (28) and (29) coincide and, we get a second order expression with respect to the covariance. Setting this expression to zero and solving for $\frac{\sigma_{12}}{\sigma_2^2}$ gives the range of covariance values under which the optimal index policy outperforms the uniform policies, such that

$$\text{(A3.1)} \qquad \begin{aligned} \frac{\sigma_{12}}{\sigma_2^2} &\leq -2 - \frac{\theta_1}{\theta_2} - \frac{\left(\theta_1\left(\theta_1 + 2\theta_2\right)\right)^{1/2}}{\theta} \\ \frac{\sigma_{12}}{\sigma_2^2} &\geq -2 - \frac{\theta_1}{\theta_2} + \frac{\left(\theta_1\left(\theta_1 + 2\theta_2\right)\right)^{1/2}}{\theta} \end{aligned}$$

In case of covariance equals to zero, uniform policies are more efficient than the proposed policy. However, $\theta = g$ is a limited case and our discussion should be wider. More precisely and after some manipulation (28) gives (A3.2) and (29) (A3.3).

$$\text{(A3.2)} \qquad \left.\begin{aligned} \frac{\sigma_{12}}{\sigma_2^2} &\leq \frac{1}{2}\left(-\theta\left(g+\theta_1\right) - \left(\left(g+\theta_1\right)\left(\theta^2\theta_1 + g\left(g-\theta\right)\psi^2 + \frac{g\theta_2^2}{\theta_1+\theta_2}\right)\right)^{1/2}\right) \\ \frac{\sigma_{12}}{\sigma_2^2} &\geq \frac{1}{2}\left(-\theta\left(g+\theta_1\right) + \left(\left(g+\theta_1\right)\left(\theta^2\theta_1 + g\left(g-\theta\right)\psi^2 + \frac{g\theta_2^2}{\theta_1+\theta_2}\right)\right)^{1/2}\right) \end{aligned}\right., \quad g \geq \theta$$

$$\text{(A3.3)} \qquad \left.\begin{aligned} \frac{\sigma_{12}}{\sigma_2^2} &\leq \frac{-(g+\theta_1) - \sqrt{\left(g+\theta_1\right)\left(\theta_1+\theta_2\right)}}{g} \\ \frac{\sigma_{12}}{\sigma_2^2} &\geq \frac{-(g+\theta_1) + \sqrt{\left(g+\theta_1\right)\left(\theta_1+\theta_2\right)}}{g} \end{aligned}\right., \quad \theta \geq g$$

Both (A3.2) and (A3.3) are symmetric expressions around a negative value. The IND policy may therefore outperform the *T* or the *CnT* regimes also when we have a negative covariance but it would never be the case when $\sigma_{12} = 0$.

Chapter 5. Conclusions.

The main objective is this dissertation is to get public policy conclusions that allow policy makers to apply the findings in a context of transport and environment policy.

Regarding to the literature review, we highlight the need for improvements in the treatment of the data because of the lack of comparable and easily measured data and the methodological problems largely unsolved. Therefore, it is remarkable the need for further research in the wider economic benefits and the impacts of the infrastructure to achieve transferable results that allow to incorporate them into a transport infrastructure appraisal.

We may conclude of the literature review that, unfortunately, there is no a rule of thumb to include the wider economic benefits in the project appraisal. Most of cases it is really tough to compute those effects so it is only useful to make that effort if and only if there are some doubts with respect to its social convenience, otherwise it does not seem obvious that wider economic benefits may justify it.

In the second chapter, we focus on the high-speed rail impacts on employment density and indirectly on agglomeration economies. The empirical approach provides us quantifiable results and conclusions about the infrastructure capability to generate these forces of agglomeration. The chapter compares two areas of influence with different sizes; also we treat two different databases considering the pool of municipalities or only those, which are similar to the ones affected by the infrastructure (statistical matching).

Thus, the conclusions are carried out from two different dimensions, comparing databases, with and without statistical matching, for a given distance, or comparing the same database for different distances. Comparing the same database for different influence areas, we found a decrease in the impact of high-speed rail has on the surrounding regions as we move away. That is, the construction of a high-speed infrastructure increases employment density around the station of high speed, but its impact diminishes as we move away from the infrastructure.

These impacts reduce, though there exists, once we compare municipalities similar to those that have the infrastructure. That is, high-speed rail provides lower impacts but still significant when we isolate some unobservable characteristics.

If we contextualize the results in relation to the literature, we note that increases in employment density are only significant if they translate into increases of production and productivity. In this paper, the estimates show that the existence of the Spanish high-speed rail provides an increase in the employment intensity of 3.6-4.7% for an influence area with a radius of 10 km and 1.8-3.7%, with a radius of 20 kilometres.

This impact seems to be significant but it is not possible to disentangle if the shown impact is due to the relocation of economic activity between affected and non-affected regions, or due to net increases of employment density. Thus, the fact that the analysed hinterlands or epicenters (i.e., the high speed rail stations) receive social benefits of building infrastructure may affect the development of other regions if there is relocation behind the shown figures.

This has important implications for public policy, but we should first discuss the exact meaning of our impacts and differences with the existing literature. On the one hand, one could argue that the estimated coefficients may arise from Keynesian multiplier that, in principle, arises without mattering the characteristics of the investment. If this were the case, these effects should not be considered an additional benefit of the transport infrastructure. However, it should be noted that high-speed rail variable takes the value 1 only in the period of operation of the new mode of transport, avoiding the possibility that these effects could come from prior periods.

On the other hand, estimates may be affected by the economic trend of the municipalities, which could lead to errors of magnitude in the results. In other words, the existence of two municipalities with divergent trends, that the introduction of new infrastructure could boost, could lead to an overestimation of the effects on employment density. However, the use of fixed effects or intra-group estimator and the comparison between municipalities with similar characteristics mitigate these drawbacks.

Therefore, the most controversial point is to discuss whether the effects are captured in net gains related to the density of employment and economic activity or due to the relocation of economic activity.

Our explanation is as follows; the econometric estimates presented cannot distinguish between the two possibilities. So assuming, for simplicity that in a country there are only two identical regions whose employment densities are constant before the introduction of the high-speed rail. Its construction should be considered exogenous and random, as the station could have been constructed in any of the two cities.

The problem, therefore, is that the estimates cannot distinguish the net effect and relocation. As a result of the new high-speed infrastructure, the region has grown in terms of employment density, while the other region has remained unchanged, a difference that determines the net effect of the high-speed rail. However, the construction of this new transport infrastructure could lead to the relocation of economic activity such that the total effect includes the relocation of activity.

Thus, the estimated effect on employment arising from agglomeration economies by building infrastructure provides no information relevant to the final creation of the net effects. The problem that arises, therefore, is that increases in the density of employment and productivity cannot be transferred directly to the benefits of the infrastructure. However, in our paper, the comparison between different influence areas for the same database suggests that there are relocation effects between the epicentre and the concentric circle in favour of the former.

Regarding to chapter 3, we focus, as mentioned above, on the effect of the high-speed rail on the levels of congestion and accidents. The results are useful to be included in an infrastructure appraisal given that the estimation of these social benefits may be, in some cases, crucial to determine the social desirability of the investment.

Most of project appraisals do not include them because previous evaluation is not directly observable. The uncertainty associated with the cross-elasticity of demand between modes and, consequently, the volume of diverted traffic from the new infrastructure for alternative modes makes difficult to know exactly the social benefits of the accidents and congestion reduction.

However, the possibility to compare the corridor before and after the introduction of a new infrastructure, controlling for some observable and exogenous variables us to estimate the impact that infrastructure has on high-speed rail and road traffic in terms of congestion and accident reduction.

Therefore, this indirect mechanism gives us the opportunity to calculate the benefits listed above.

Accidents reduction represent about 5% of the total costs of high-speed train and the congestion reduction seems not in any case be significant in quantitative terms. However, in the latter case, we should consider that most of the congestion is intraday nature so the use of temporal analysis that considers this condition could be estimated coefficient slightly higher than those presented in the dissertation. Another aspect to consider is that the results are subject to uncertainty about the future relationship between the variables, such as growth in the value of time and the value of statistical life. However, all assumptions have been made considering the most favourable situation for the project.

In chapter 4, we have studied the properties of a regulatory policy in which a group of issuers are subject to a tax regulation while others are protected by a cap-and-trade, moreover the tax regulation is indexed to the permit price subject to the cap-and-trade. With such a policy, the tax level is updated with respect to the role of marginal cost reduction sector subject to a cap-and-trade regulation. The chapter concludes that a linear indexation policy provides better results than the regulatory policy studied in Mandell (2010) given the covariance between the cost function shocks of the two groups is different from zero. Moreover our proposal offers better results than an economy subject to quantity or price regulation for a broader set of parameters than the mix policy.

Therefore, in those economies, such as the European Union, which combines mixed systems based regulation of prices and quantities, the regulator can reduce expected inefficiency indexing taxes on emissions at the price set in regulating quantity markets. However, the expected net gains are small, at least for the case in which the cost functions and benefits of emissions reduction are positive. It should also be noted that our analysis does not include assumptions or conditions on the potential importance of implementation or a priori beliefs about the relationship of covariance and costs shocks on different sectors.

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