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Ensayos sobre la relación entre el crecimiento económico y la energía : aplicaciones matemáticas y econométricas

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Ensayos sobre la relación entre el crecimiento económico y la energía. Aplicaciones matemáticas y econométricas.

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A mis hijas y mi marido por su apoyo incondicional

PREFACIO

Esta tesis investiga la relación existente entre el crecimiento económico y algunas variables tales como el consumo de energía o las emisiones de CO_2. El origen de esta contribución comienza en 2005 cuando empecé mi docencia en el Departamento de Economía de la Universidad de Huelva, una vez finalizada mi licenciatura de Matemáticas, en la Universidad de Sevilla. Gracias a esta oportunidad, inicié mis cursos de doctorado que me han llevado a realizar esta tesis y es ahora cuando se cierra un ciclo que inicié ya hace más de una década.

Son varias las personas que me han animado y ayudado en esta tarea, en especial, estoy muy agradecida a mis dos directores, Mónica Carmona y Emilio Congregado, los cuales han tenido una paciencia infinita y no han dudado en prestarme toda su ayuda y tiempo para llegar hasta donde estamos.

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Finalmente, no podría terminar sin agradecer a mis padres y mi abuela, mi marido y mis tres hijas, Laura, Adriana y María por su total apoyo durante todos estos años.

Julia Feria Gallardo
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Chapter 1: Introducción

1.1 Introducción

La relación entre el crecimiento económico y algunas variables energéticas tales como el consumo de energía o las emisiones de CO_2, han sido y continúan siendo uno de los ejes centrales dentro de la llamada "Economía de la energía", debido a la fuerte dependencia que las economías desarrolladas tienen del sector energético y éste en el consumo de energía. Satisfacer las necesidades para mantener el desarrollo de los países de una manera sostenible requiere una cartera de energía equilibrada que se adapte a las condiciones y los recursos económicos, sociales de los distintos países y regiones (Flavin y Aeck, 2005). Además, la Agencia Internacional de Energía (IEA, 2009) alerta de que las tendencias actuales en el suministro de energía y el uso siguen siendo económicamente, ambientalmente y socialmente insostenible.

Las políticas energéticas en el ámbito internacional están concentrando los esfuerzos de políticos, investigadores y académicos, con el objetivo de establecer un marco internacional que garantiza un desarrollo sostenible. Como prueba de ello, en España, atendiendo a la información del Ministerio de Industria, Tecnología y Turismo, se está desarrollando una política muy activa en los aspectos medioambientales de la energía, con la imbricación de la protección medioambiental en la Ley del Sector Eléctrico y en la Ley del Sector de Hidrocarburos; con la creación de Órganos específicos –Consejo Nacional del Clima- para analizar y definir la estrategia española frente a los compromisos asumidos por la firma del Protocolo de Kioto; con la aprobación de un Plan de Fomento de las Energías Renovables que pretende elevar en el año 2010 la participación de dichas energías al 12% del abastecimiento total, así como el próximo Plan de Eficiencia Energética, constituyendo ambos el núcleo del impulso que se pretende dar al pilar medioambiental de la política energética. Por su parte, el papel de la economía de los Estados Unidos en el consumo total de energía en el mundo y la producción es de vital importancia. Según la Enviromental Protection Agency, el dióxido de carbono (CO_2) en los Estados Unidos aumentaron en un 7% entre 1990 y 2013. Siendo los combustible fósiles como la mayor fuente de emisiones de gases de efecto invernadero en los Estados Unidos, los cambios en las emisiones de los combustibles fósiles han sido históricamente el factor dominante que afecta a las tendencias de las emisiones de Estados Unidos. Dichos cambios en las emisiones de CO_2 procedentes de la quema de combustibles fósiles están influenciados por muchos factores a largo plazo, incluyendo el crecimiento de la población, el crecimiento económico, cambios en los precios de la energía, las nuevas tecnologías, el comportamiento cambiante, y las temperaturas estacionales. Entre 1990 y 2013, el aumento de las emisiones de CO_2 se correspondía con el aumento del consumo de energía en una economía y una población en expansión y un crecimiento global de las emisiones vinculadas a la generación de electricidad. Las emisiones de transporte también contribuyeron al aumento del 7%, en gran parte debido a un aumento de millas recorridas por vehículos de motor.

En este sentido, conocer el tipo de relación existente dentro de las variables mencionadas anteriormente se revela como fundamental a la hora de determinar las distintas políticas energéticas llevadas a cabo por los "policy makers". El núcleo principal de esta tesis radica en aportar una mayor claridad sobre la interrelación existente entre el crecimiento económico y el consumo de energía o las emisiones de Co2.

La relación existente entre el crecimiento económico y el consumo de energía o las emisiones de CO2 han sido ampliamente estudiado durante los últimos años en la literatura de la economía ambiental. Como es bien sabido, esta literatura emergente se puede dividir en tres grandes bloques, dependiendo del foco de la investigación en el los contaminantes ambientales y PIB de crecimiento que terminan por probar la validez de la hipótesis de la Curva de Kuznets Ambiental (EKC por sus siglas en ingles), la causalidad que va desde el crecimiento económico a la energía, y un enfoque combinado, aunque quizás menos estudiado (Menegaki, 2013).

1.2 Hipótesis de Causalidad entre crecimiento y consumo de energía

Desafortunadamente tampoco existe consenso sobre la causalidad ni la dirección de causalidad de la relación que existe entre el crecimiento y el consumo energético. No obstante, la principal fuente de consenso se ha encontrado en sintetizar la relación entre crecimiento y consumo de energía en las hipótesis que se resumen en las que tal vez sean las obras más reconocidas en esta disciplina, éstas son las de Ozturk (2010), Payne (2010) o recientemente Omri (2014), y que establecen que la relación causal emerge de cuatro maneras posibles:

Neutral hypothesis. El PIB está incorrelado con el consumo de energía, lo que implica que las políticas energéticas (expansivas o contractivas) no tienen ningún efecto sobre el crecimiento económico. Por lo tanto que la escasez de energía y las políticas conservadoras en relación con el uso de energía no afectan el crecimiento económico.

Conservative hypothesis. Este enfoque reconoce la causalidad unidireccional de crecimiento del PIB hacia el consumo de energía y, en consecuencia, cualquier política de conservación en relación con el consumo de energía tendrá poco o ningún efecto adverso en el crecimiento económico. Por tanto, las políticas energéticas no tendrían efectos adversos en el crecimiento económico.

Growth hypothesis. Donde el PIB es causado por el consumo de energía, siendo esta fundamental para el desarrollo económico. El crecimiento económico, por tanto, depende (positiva o negativamente) en el consumo de energía. En definitive, la "hipótesis de crecimiento" sugiere que la disponibilidad de abundantes fuentes de energía baratas promueve el crecimiento económico. En ese sentido, mientras que los aumentos en el consumo de energía pueden contribuir a un mayor crecimiento económico, la reducción en el consumo de energía pueden tener efectos negativos sobre el crecimiento

Feedback hypothesis. Ambos, tanto el consumo de energía como el PIB dependen mutuamente.

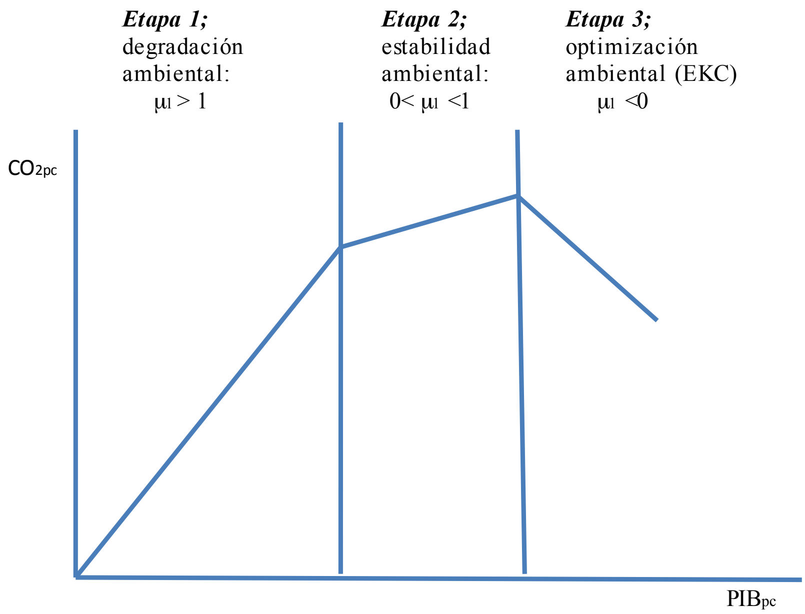
Varias son las respuestas proporcionadas por la literatura empírica, en función del ámbito geográfico utilizado, el ámbito temporal usado, el indicador utilizado para medir tanto el crecimiento económico (PIB, PNB, IPI, etc) como el consumo de energía (total, por sectores, por tipo, etc) o el total de emisiones (Co2, So2, etc.) o la técnica utilizada (datos de panel, sección cruzadas o series temporales). En la presente tesis, como ya se ha comentado previamente, se intentará dar respuesta y conciliar dichos resultados mediante distintas técnicas econométricas y matemáticas utilizadas, y ámbitos temporales y geográficos distintos.

1.3 Hipótesis EKC

En cuanto a la relación entre el crecimiento económico y las emisiones de CO2, al igual que anteriormente, varias son las hipótesis formuladas, destacando especialmente la llamada Curva Medioambiental de Kuznets (Environmental Kuznets Curve en inglés), donde se pone de manifiesto la relación primero positiva y luego negativa entre el crecimiento económico y dichas emisiones. En este contexto, la relación entre crecimiento económico y polución ha sido ampliamente contrastada en la literatura de economía ambiental (Grossman y Krueger, 1995; Martínez-Allier, 1995; Arrow et al., 1995; Carson y Maccubin, 1997; Suri y Chapman, 1998; Torras y Boyce, 1998; Stern, 2004; Payne, 2009; Aslanidis, 2009; o Jordan, 2010, entre otros). En el trabajo de Grossman y Krueger (1991) encontraron que esta relación presenta la forma de U-invertida, un comportamiento que ha sido interpretado en la línea de que las economías conducen a la degradación ambiental en su etapa inicial con niveles de renta pc bajos y, a partir de un nivel de renta pc son capaces de establecer industrias menos contaminantes a medida que ésta se incrementa. En otras palabras, la hipótesis EKC sostiene la idea de que la contaminación pasa de ser un bien normal a ser un bien inferior a medida que aumenta la renta.

Esta aportación supone el planteamiento más aceptado para sostener el modelo conocido como EKC (por sus siglas en inglés). A partir del trabajo de Grossman y Krueger, en las dos últimas décadas se han realizado importantes esfuerzos por proporcionar evidencia empírica sobre el modelo EKC, focalizándose el análisis desde planteamientos lineales, paramétricos, semi-paramétricos y no paramétricos, estudiando varios contaminantes (So2, CO2, Nh4, etc.) y usando varios tipos de datos y países (series temporales, sección cruzada y panel). Desgraciadamente, los resultados revelan conclusiones muy dispares no sólo sobre la forma de la curva, sino sobre la propia existencia de la misma, convirtiéndose en un tópico controvertido dentro del análisis en economía ambiental (véase Stern, 2004; Payne, 2009; Aslanidis, 2009; o Jordan, 2010). Gran parte de esta controversia se deriva de la falta de robustez de los diferentes contrastes, dada la alta sensibilidad de los resultados a la técnica econométrica de estimación o al sesgo que en las mismas introducen la no consideración de determinados fenómenos (Stern, 2004).

En la siguiente figura, se muestra un gráfico donde se puede observar con mayor claridad lo expuesto por la hipótesis EKC.



Haciendo uso de distintas metodologías, intentaremos contrastar la existencia de dicha curva.

1.4 Evidencia empírica disponible

Como se ha citado en líneas anteriores, la evidencia empírica relativa a los tópicos analizados en esta tesis es poco concluyente tanto para el caso de la hipótesis EKC, la relación de causalidad entre crecimiento y consumo de energía y en la contrastación de la persistencia en esta relación.

La relación que establece la EKC se ha convertido en una cuestión controvertida ya que la relación directa que se establece estrictamente en la hipótesis ha abierto un campo de análisis muy prolífero en economía ambiental (Grossman y Krueguer, 1995; Cole et al. 1997; List y Gallet, 1999; López y Mitra, 2000; Hettige, 2000; Andreoni y Levinson; 2001; Pffaf et al. 2004; o para un survey Borgeshi, 1999; Dinda, 2004 o recientemente Kijima et al. 2010; Bo, 2010 o Esteve y Tamarit, 2012 entre otros). Ekins, (1997) y de Bruyn y Heintz (1999) abrían la discusión sobre la aceptación de la hipótesis de la EKC ya que no encontraron evidencia sobre dicha hipótesis en varios contaminantes analizados. Alrededor de este debate, Dinda (2004) o Roca y Padilla (2003) argumentan que las interpretaciones sobre la EKC deben contemplar algunos factores que podría estar detrás de la falta de consenso sobre la aceptación de la hipótesis. Entre ellos caben citar el cambio tecnológico, el peso del sector industrial y el sector servicios, el aumento de renta (McConnell (1997), Selden y Song (1995) o López (1994), las políticas públicas (Carpentier, 2006) o la densidad de población (Dhakal, 2009) entre otros.

Por su parte, la evidencia empírica que emerge en la literatura con el objetivo de arrojar luz sobre la dirección de causalidad tampoco es concluyente. Gran parte de la investigación existente se han resumido recientemente por Omri (2014), revelando la citda ambigüedad en la literatura anterior. En ese sentido, se muestra una revisión de 48 artículos que por nexo consumo-crecimiento sustentan la hipótesis de crecimiento el 29% de los estudios observados, el 27% sostiene la hipótesis feedback, el 23% la hipótesis de la conservación, y el 21% la hipótesis de neutralidad. Anteriormente, Payne (2010) proporcionó resultados similares en su estudio, concluyendo un análisis que incluye 101 estudios durante el período 1.978 hasta 2008 no hay un claro consenso, debido a que el 23,1% mostró causalidad unidireccional desde el consumo de energía al crecimiento del PIB, el 19,5% se encontró la causalidad del crecimiento del PIB al consumo de energía, el 28,2% muestran una relación bidireccional, y el 29,2% no muestran ninguna relación. Entre los factores en juego en esta controversia acerca de la relación entre el crecimiento y el consumo de energía, podemos encontrar en la literatura algunas fuentes potenciales tales como los períodos de muestreo, las especificaciones del modelo, diferentes patrones de consumo, sesgo de variables omitidas, los acuerdos comerciales entre los países, los marcos estructurales y las políticas seguidas por los países, los impactos que varían según diferentes fuentes de energía, las importaciones de energía y el perfil de las exportaciones o las diferentes etapas de desarrollo y procesos de cada país (ver Kalimeris et al., 2014, o los recientes surveys de Payne, 2010, Ozturk, 2010 o Omri, 2014).

Por su parte, la persistencia puede definirse y medirse de varias maneras. Una posible definición nos llevaría a definir la persistencia (o histéresis) como la situación donde cualquier cambio transitorio se convierte en permanente. El enfoque más popular en la literatura empírica simplemente equipara la persistencia con la existencia de una raíz unitaria en una variable. La evidencia disponible sobre la persistencia en el consumo de energía, también es poco concluyente. Algunos autores sugieren que el consumo de energía es integrada de orden cero en el que las políticas de caso sólo tienen efectos a corto plazo (Chen y Lee, 2007; Narayan & Smith, 2007;. Apergis et al, 2010a-b), mientras que otros como Hsu y Lee (2008) (o Mishra et al (2009) proporciona evidencia en contra. Además, un número de trabajos han estudiado métodos para la comprobación de presencia de histéresis (persistencia y remanencia) en un marco no lineal, las pruebas de quiebres estructurales (ver Ozturk, 2010).

1.5 Tendencias en el consumo de energía

Las tendencias de consumo energético quedan sujetas al modelo de crecimiento económico y el diseño de eficiencia energética que las políticas de un país establezcan. En este sentido, los modelos de crecimiento basados en la industria, en la construcción, en la agricultura o en los servicios generarán el marco más favorable en términos de ahorro energético, y que duda cabe que los planes establecidos en materia de políticas energéticas están detrás del resultado que los países encuentran en relación a las fuentes de energía demandadas, los niveles de polución y las estrategias sobre energías renovables para el futuro. La Agencia Internacional de la Energía (organismo dependiente de la OCDE) en el World Energy Outlook 2009 (IEA, 2009), señala que la demanda de energía crecerá a un ritmo del 1,6% anual al año hasta 2030. En otras palabras, la demanda primaria de energía pasará de 11.730.000 ktep2 (miles de toneladas de petróleo equivalente) en 2006 a 17.014.000 Ktep en 2030 lo que supone una aumento acumulado del 45%. Este crecimiento de la demanda de energía primaria está fundamentado en un crecimiento anual del PIB mundial para el período 2006 – 2030 del 3,3%, frente a un crecimiento medio de 3,5% en el período 1980 – 2006. En definitiva, revisando las conclusiones que se aportan desde un marco descriptivo en el citado informe, no se esperan grandes cambios en el crecimiento tendencial del mundo. Sin embargo, un enfoque más optimista y en el largo plazo, en términos macroeconómicos y estudiando la eficiencia energética - consumo de energía por unidad de producto- la tendencia parece mostrar un consumo energético cada vez más eficiente-en 2007 se utilizaba un 40% menos de energía que en 1965 para producir una unidad de PIB-

En la tabla 1, se muestra el crecimiento medio del consumo de energía para el período 1980-2012. Es fácilmente comprobable que si bien en todos los casos el consumo energético ha aumentado, se observa como dicho crecimiento ha sido mucho más lento en Europa y Norteamérica (inferior al crecimiento energético global), justo las dos regiones con un mayor nivel de desarrollo económico, mientras que dicho consumo ha sido mucho más elevado (superior a la media) en zonas tradicionalmente menos desarrollados como centro y Sudamérica, África o especialmente en el medio oriente y el caso asiático.

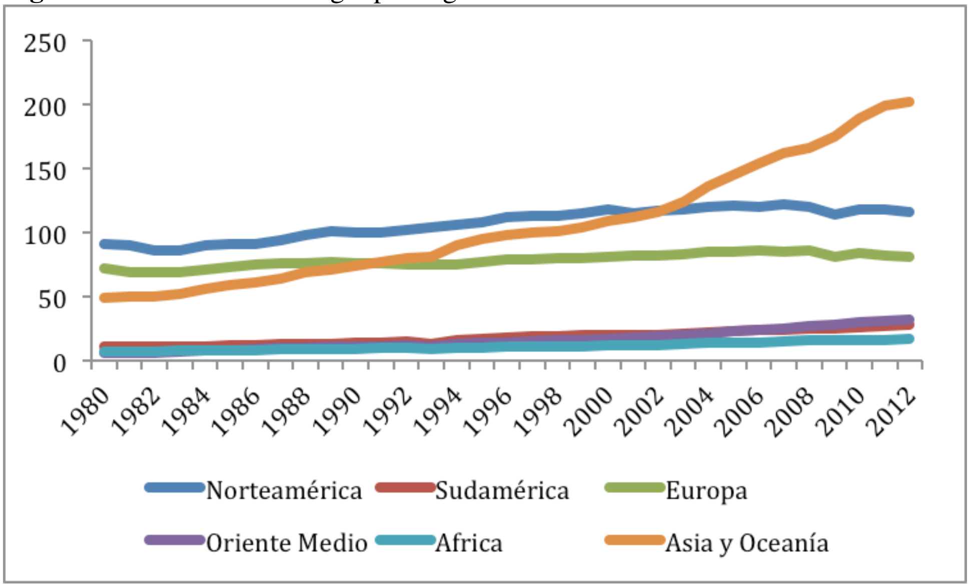
Tabla 1 Crecimiento medio del consumo de energía desde 1980 hasta 2012

Región	**Consumo de energía**	**Emisiones de CO2**
Norteamérica	23,78	2,90
Sudamérica	91,05	62,19
Europa	12,73	-15,55
Oriente Medio	170,81	133,14
África	93,55	86,33
Asia & Oceanía	141,87	89,86
Mundo	61,57	28,15

Fuente: U.S. Energy Information Administration

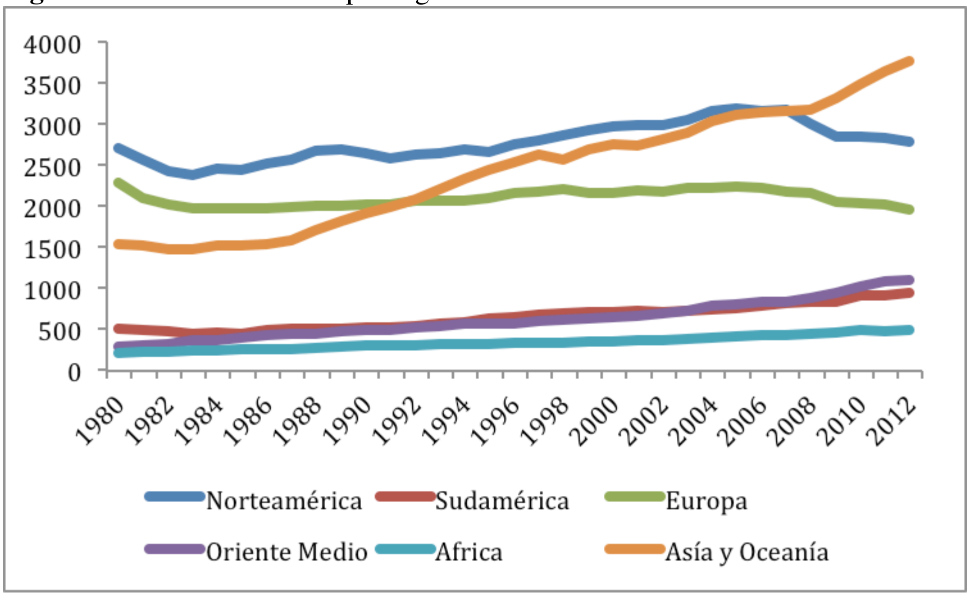
La figura 1 y 2 muestra la evolución temporal para dicho periodo para el consumo de energía y las emisiones de Co2 en las regiones anteriormente descritas.

Figura 1. Consumo de energía por regiones.



Fuente: U.S. Energy Information Administration

Figura 2. Emisiones de Co2 por regiones.



Fuente: U.S. Energy Information Administration

En ambos gráficos, se puede observar como a mediados de la pasada década, tanto el consumo de energía como las emisiones de CO2 de la región "Asia y Oceanía" ha pasado a ser en ambos casos las primeras y con un crecimiento mucho más elevado que el resto de regiones.

1.6 Datos y aproximaciones econométricas

Datos

En esta tesis, con el objetivo de facilitar la comprensión de las relaciones de causalidad entre crecimiento y consumo de energía, la persistencia de la relación y el comportamiento de las emisiones según la fase de crecimiento económico, se proponen el uso de series temporales desde fuentes de datos alternativas así como un catálogo de recursos econométricos recientes.

Los datos utilizados en el capítulo que mide la causalidad entre crecimiento y producción son observaciones trimestrales desde 1973: 1 a 2015: 2. El consumo de energía primaria -medida en quadrilium de unidades térmicas británicas (BTU) - se desagrega por total, los combustibles fósiles totales, totales renovables, carbón, gas natural, petróleo, nuclear y renovable- hidroeléctrica, geotermal y biomasa-. Estos datos se obtienen de la EEUU Administración infomration Energía (EIA). Los datos del PIB se toma de la Oficina de Análisis Económico (BEA) un medido en miles de millones de dólares de 2009 encadenados. Antes de la realización de los análisis de datos empíricos fueron ajustados estacionalmente y se convierten en logaritmos naturales. En segundo lugar, cuando se estudia la persitencia en la relación citada, los datos utilizados son observaciones trimestrales desde 1973: 1 a 2015:2. El consumo de energía queda medida en trillones de BTU, mientras que el PIB queda medido en miles de millones de dólares con base en 2009. Estos datos se extraen de la Administración de Información de Energía (EIA) y la Oficina de Análisis Económico (BEA), respectivamente. Por otra parte, para contrastar la hipótesis EKC, en el análisis empírico se utilizan los datos trimestrales de los Estados Unidos para el período 1973: 1 a 2.015: 2. El PIB se define como el producto interno bruto real (medida en miles de millones de encadenado 2.009 US $), los datos tomados desde US Bureau of Economic Analysis (BEA). La emisión total de CO2 se expresa en millones de toneladas métricas de dióxido de carbono, disponible en la Administración de Información de Energía (EIA). Por último, también se utilizan los datos consumo de energía primaria y PIB en el período 1980:1-2010:4 -datos trimestrales- procedentes de la Red Eléctrica Española (REE) y el Instituto Nacional de estadística (INE)

Aproximaciones econométricas

Por un lado, se analizan las pruebas de causalidad de Granger aplicando la metodología propuesta por Toda y Yamamoto (1995) y, en segundo lugar, la ampliación de dicha técnica propuesta por Hatemi-J (2012), la principal ventaja de ambas técnicas es que no necesitan de ningún apriorismo sobre las series a tratar o sobre su relación entre ellas (orden de integración, relaciones de cointegración, etc.). Dichas metodologías nos permiten analizar las asimetrías en la causalidad del consumo de energía hacia el crecimiento económico o viceversa. Por otro lado, la relación entre el crecimiento de la producción y el consumo de energía se analiza modelo de componentes no observable bivariante para investigar la interacción y persistencia entre la producción y el consumo de energía. Concretamente, se hace uso del modelo de Sinclair (2009) que permite la posible correlación entre los componentes de la matriz de covarianza. Este modelo puede ser utilizado para descomponer las dos series en sus componentes cíclicos y naturales. Además, en orden de contrastar la hipótesis EKC se aplica la especificación propuesta por Jaunky (2011), que permite testar la posible existencia de relaciones de cointegración entre las emisiones de $CO2$ y el crecimiento económico. Después de confirmar la existencia de correlaciones y la obtención de la elasticidad entre las dos variables, se estudia la posibilidad de cambios estructurales en la relación utilizando la metodología propuesta por Kejriwal-Perron (2010). Adicionalmente, se analizan las diferentes elasticidades obtenidas para cada período de prueba de la existencia de la EKC en los Estados Unidos. Finalmente, para analizar el caso español, se emplean las técnicas de cointegración lineal la propuesta de Johansen, (1988, 1991) y para el análisis de quiebres estructurales propuesto por Gregory and Hansen (1996).

1. 7 Esquema de capítulos y principales aportaciones de la tesis

La presente tesis trata de buscar nueva evidencia sobre las hipótesis mostradas anteriormente. Así, en el primer capítulo, se trata de dar respuesta a la relación entre el consumo de energía y el PIB, haciendo uso de datos trimestrales españoles, desde 1980 hasta 2010. Para ello, se ha utilizado una función de producción donde la producción real es explicada por el consumo de energía y la formación bruta de capital siguiendo la especificación propuesta por Stern (1993,2000):

$$Y_t = \alpha_t + \beta_t EC_t + \delta_t K_t + \varepsilon_t$$

Dicha función se ha estimado por mínimos cuadrados ordinarios dinámicos propuesto por Stock y Watson (1993), y posteriormente ampliado por Shin (1994). Los resultados muestran como la elasticidad del consumo de energía sobre la renta es positiva alcanzado un valor de 0.543, implicando que por cada punto porcentual de crecimiento del consumo de energía, el PIB crecería poco más de medio punto porcentual. Una vez determinada dicha relación, se ha contrastado si es estable a lo largo del tiempo, permitiendo la existencia de quiebres estructurales siguiendo la metodología propuesta por Gregory and Hansen (1996) y Hatemi-J (2008). Los resultados muestran la existencia de dos quiebres estructurales para el periodo 1987:2 y 1998:3, y, por tanto, tres regímenes (1980:1-1987:2, 1987:3-1998:3 y 1998:4-2010:4). La elasticidad en cada periodo sigue siendo positiva alcanzando su máximo en el segundo periodo. Finalmente, se contrasta las relaciones de causalidad en sentido de Granger tanto a corto como a largo plazo, encontrándose que solo existe causalidad (a largo plazo y el total) del consumo de energía hacia el PIB para el total y el primer y segundo periodo, y del PIB hacia el consumo de energía solo a corto plazo y en el último de los regímenes.

En los posteriores capítulos, el ámbito geográfico ha pasado de España a Estados Unidos, básicamente por la existencia de una mayor disponibilidad de datos, tanto en frecuencia como en amplitud temporal, como a un nivel de desagregación mayor que en el caso español.

Así, el segundo capitulo de la tesis, realiza un análisis para el contraste de la relación de causalidad anteriormente descrita, pero contrastando a la vez, si dicho consumo de energía es persistente, es decir, si los cambios transitorios en dicho consumo se convierten en permanentes[1]. La metodología utilizada es la propuesta por Sinclair (2010) utilizando métodos de componentes no observables con observaciones trimestrales desde el primer trimestre de 1973 hasta el segundo trimestre de 2015. Los resultados avalan la existencia de persistencia (histéresis) en el consumo de energía. La estimación permite estimar el componente cíclico de ambas variables, pudiendo realizar un contraste de causalidad en sentido de Granger. Los resultados muestran causalidad bidireccional, cumpliéndose, por tanto, la hipótesis feedback (recordemos que el análisis es realizado a los componentes cíclicos). Finalmente, la posible existencia de quiebres estructurales, es contrastada mediante la técnica de Bai-Perron[2] (1998,2003). Esta, indica la existencia de un quiebre estructural a principios del año 2009 (al comienzo de la reciente crisis económica), y, donde se confirma la existencia de dicha relación bidireccional pero solo para el último periodo, es decir, solo a partir de la crisis económica actual, manteniéndose durante todo el periodo la causalidad desde el ciclo económico al consumo de energía.

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[1] El concepto de persistencia en economía se asemeja al de histéresis utilizado principalmente en la rama de física.

[2] Al contrario que en la metodología de Kerjiwal-Perron, es necesario que las series sean estacionarias, condicionante que se cumple en los componentes cíclicos y que es confirmado mediante un contraste de raíces unitarias.

El tercer trabajo, versa sobre las relaciones de causalidad del PIB con el consumo de energía, desagregando esta última por su origen (fósil, carbón, petróleo, gas natural, nuclear, renovable, biomasa y geotermal). El marco econométrico es distinto, porque estamos interesados en ver las relaciones de causalidad, pero no solo desde el punto de vista lineal, sino también teniendo en cuenta si dichas relaciones presentan asimetría. Para dicho estudio, con datos trimestrales para el periodo 1973:1 -2015:2 utilizamos la metodología de Toda-Yamamoto (1996) y su ampliación propuesta por Hatemi-J (2012) en el caso de las asimetrías. La principal ventaja de estas metodologías, es que no hace falta hacer ningún supuesto acerca de las características de las series a utilizar (su orden de integración o si están cointegradas o no). Los resultados obtenidos son muy distintos si se suponen linealidad o asimetría en la relación. Básicamente, los resultados muestran la existencia de "neutral hypothesis" para el caso de las energías renovables y de "conservation hypothesis" para el caso de las energías fósiles. Sin embargo, cuando se permite asimetría, se observa como emerge la "growth hypothesis" para el caso del petróleo, resultado este importante, dada la importancia relativa del petróleo sobre el total del consumo energético.

Finalmente, el último capítulo de la presente tesis, amplia el campo de estudio, interesándose por la relación existente entre el PIB y ya no el consumo de energía, sino las emisiones de CO_2. Como se puede suponer, el consumo de energía lleva emparejado unas emisiones de CO_2 , estas están siendo objeto de debate debido, principalmente al cambio climático. Es por ello, que las políticas energéticas gubernamentales actuales están orientadas a como reducir dichas emisiones, principalmente mediante la eficiencia y la sustitución de las energías fósiles por las energías renovables. El presente capítulo, intenta demostrar si estas medidas se están llevando a cabo en Estados Unidos, intentando contrastar si se cumple la anteriormente mencionada "Curva medioambiental de Kuznets". Ha de tenerse en cuenta, que la existencia de dicha curva, implica que dichas políticas son exitosas, reduciendo, por tanto las emisiones de CO_2, sin afectar al crecimiento económico.

Para testar dicha curva, mediante la especificación propuesta por Jaunky (2011), se estima la elasticidad existente entre el CO_2 y el PIB, en el caso de que esta fuera negativa, implicaría, que la EKC se cumpliría en el caso norteamericano. Utilizando datos trimestrales desde Los resultados iniciales no muestran que dicha curva se cumpla, siendo la elasticidad positiva, y, por tanto, poniendo de manifiesto que a mayor crecimiento económico mayor será las emisiones de CO_2. Sin embargo, teniendo en cuenta la existencia de quiebres estructurales, usando para ello la metodología de Kerjiwal-Perron (2008, 2010) para la detención de dichos quiebres y las técnicas de cointegración de Arai-Kurozumi (2009) que permiten quiebres en la relaciones de cointegración. Tres son los quiebres encontrados, en 1980:1 (coincidente con la segunda crisis del petróleo), en 1986:2 (crisis de los precios en la OPEP) y 2007:4 (justo al inicio de la presente crisis económica). El contraste de Arai-Kurozumi confirma dichos quiebres, y por tanto, la relación a largo plazo entre ambas variables. Al estimar la elasticidad para cada periodo resultante (cuatro) se observa como esta es positiva para los tres primeros periodos y negativa para el último (justo a partir de la actual crisis económica). Por tanto, se observa que la relación es dependiente en el tiempo, y, lo que es más importante, como teniendo en cuenta la existencia de dichos quiebres, si se cumple la hipótesis de la EKC para el caso de Estados Unidos.

Con la presente tesis hemos intentado dar nuevas evidencias de las relaciones entre el consumo energético, las emisiones de CO_2 y el PIB. Se observa como dichas relaciones son diferentes en los distintos periodos de tiempo, según el origen de la fuente de energía y según las fases de expansión y recesión. Finalmente, se confirma la existencia de la EKC en Estados Unidos, pero señalando la necesidad de tener en cuenta que las relaciones a largo plazo entre las variables son cambiantes con el tiempo

Tabla 1: Síntesis de los capítulos de la Tesis

Capítulo	Objetivos	País	Datos	Marco Econométrico
2	Estimación de la elasticidad del consumo de energía hacia el PIB. Contraste de causalidad a corto y largo plazo.	España	Consumo de energía y PIB 1980:1-2010:4 (datos trimestrales) Red Eléctrica Española (REE) and Instituto Nacional de estadística (INE)	Linear cointegration (Johansen, 1988, 1991) Structural breaks (Gregory and Hansen, 1996)
3	Midiendo la relación de causalidad (lineales y asimétricas) entre consumo de energía por fuente (total, total fossil, coal, natural gas, petroleum, nuclear, renewable, biomass, geothermal and hydroelectric) y PIB.	USA	Total primary energy consumption by source and GDP 1973:1-2015:2 (quarterly data) US Energy Information Administration (EIA), US Bureau of Economic Analysis (BEA).	Linear Granger Causality (Toda-Yamamoto, 1995) Asymmetric Granger Causality (Hatemi-J, 2012)
4	Testando la hysteresis (persistencia) en el consumo de energía de los estados Unidos, y la relación de causalidad entre consumo de energía y PIB a lo largo de los ciclos así como los quiebres estructurales.	USA	Total primary energy consumption and GDP 1973:1-2015:2 (quarterly data) US Energy Information Administration (EIA), US Bureau of Economic Analysis (BEA)	Unobserved component models, Kalman Filter (Sinclair, 2010) Structural Breaks (Bai-Perron, 1998,2003) Granger Causality
5	Testar la existencia de la Environmental Kuznets Curve midiendo la relación entre emisiones de Co2 y PIB	USA	Total CO2 emissions and GDP 1973:1-2015:2 (quarterly data) US Energy Information Administration (EIA) and US Bureau of Economic Analysis (BEA)	Linear Cointegration (Johansen, 1989) Structural Breaks (Kerjiwall-Perron, 2000) Dynamic OLS (Vahid y Engle, 1993)

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PART II: Energy consumption in Spain

Chapter 2: Structural Breaks, energy consumption and GDP: Evidence from Spain

This paper examines the long-run relationship (cointegration) between capital formation, energy consumption and real GDP in the Spanish economy over the period 1980:1-2010:4. In order to achieve this goal, we allow for structural breaks in the series using the procedures suggested by Gregory and Hansen (1996a, 1996b) and Hatemi-J (2008). The results show the existence of cointegration between these variables although this relationship has changed over time. Our empirical results show that the cointegrating relationship is unstable and would suggest a model of three regimes with the date of the breaks estimated at 1987:2 and 1998:2. Accounting for structural changes, the initial estimated elasticities for energy consumption and capital stock with respect to real GDP are seen to be substantially biased. The results suggest that the evolution of these elasticities are very different, while the elasticity for energy consumption increases from the first regime to the second regime and then falls in the third period, the elasticity for capital stock have an opposite direction. Finally, according to the causalities tests, results reveal that the GDP is weak exogeneity in relation to energy consumption and capital stock in the whole sample and in the two first regimes. Results show that neutral hypothesis exists in the first two regime, but in the last regime, conservative hypothesis if found. This has important policy consequences, as it suggests that energy restrictions do not seem to harm economic growth in Spain.

2.1. Introduction

Since 1970s, the topic about the relationship between energy consumption and economic growth has been well-studied in the energy economics literature. The overall findings show that there is a strong relationship between both variables.

The direction, magnitude, and stability of the relationship of the GDP and energy consumption have occupied central importance in the conduct of energy policy. In particular, in the one hand, many consumption and production activities involve energy as a required input, making it a key source of economic growth. In the other hand, economic growth may induce the use of more energy. The policy implications of these relationships can be significant depending upon what kind of relationship exists.

Four are the hypothesis about the (causal) relationship between energy consumption and GDP:

- *Neutral hypothesis*. GDP is uncorrelated with energy consumption which means that energy policies (expansive or conservative) have any effect on economic growth.
- *Conservative hypothesis*. An increase in GDP causes an increase in energy consumption. It implies that conserva-

tive energy policies have no adverse effect on economic growth.

- *Growth hypothesis*. GDP is caused by energy consumption. It implies that energy consumption have an important role on economic growth. Economic growth depends positively (or negatively) on energy consumption.
- *Feedback hypothesis*. Which means that energy consumption and economic growth depends mutually.

Several studies have focused on different countries (developed or developing countries), time periods (since 1947 till now), proxy variables or new variables, and different econometric techniques (cointegration, panel unit roots, threshold cointegration, etc.) have been used to test this relationship[1]. However, the evidence is mixed. The empirical results are not conclusive about direction, stability or magnitude.

Using time series data, different studies have examined the relationship between energy consumption and economic growth in different countries and sample periods (the most recent, Belloumy (2009) for Tunisia, Bowden and Payne (2009) for USA, Lee and Chang (2005) for Tai-

[1] For an exhaustive survey, see Ozturk (2010)

wan, Zamani (2007) for Iran, Belke et al (2011) for OECD, or Wang et al. (2011) for 26 chinese provinces among others). However, the conclusions reached are mixed. Moreover, even for studies over the same country, conclusions are different (see Altinay and Karagol (2004), Erdal et al (2008), Jorbert and Karanfil (2007), Lise and Van Monfort (2007) or Soytas and Sari (2009) for the case of Turkey). The origin of the diversity of results could be originated by the instability of the relationship over the time.

In this way, several empirical studies have found that the series presents structural break such as Altinay and Karagol (2004), Schäfer (2005), Lee and Chang (2007), Narayan and Smyth (2008), Vaona (2012) or Kumar and Shabhaz (2012). From this perspective, seems clear the existence of structural breaks and it´s necessary to perform new techniques that account for the existence of this phenomenon.

In our work, we explore the empirical relationship between energy consumption and GDP allow structural break in the series using data from Spanish economy for the period 1980:1-2010:4. To the best of our knowledge, this is the first study of this kind using Spanish data[2] and al-

[2] The only other empirical contributions on spanish economy that we are aware of are the work of Ciarreta et al (2009) and Congregado et al (2011). In contrast to the present article, the work of these authors uses the electricity consumption and not the energy consumption and the cycles instead of series in levels, respectively.

lowing for structural breaks in the energy-growth nexus using the Gregory and Hansen (1996a, 1996b) and Hatemi-J (2008) procedures.

The paper is relevant for Spain, as Spain have shown a recent and quick development during the last 30 years, conclusions for Spain may be relevant for a number of countries, which have to go through a similar initial development state or are developing fast.

Furthermore is possible to perform granger causality test across regimes because of the big numbers of observations in each regime. Also, we can observe the relationship (and elasticities) between them.

The purpose of this paper is, first, to examine the long-run relationship between energy consumption, real GDP and real capital stock, second, test the stability of this relationship, third, the elasticities between them and, finally testing the granger causality between the variables in the whole sample and across regimes.

The paper is structured as follows. Section 2 describes the empirical specification and data. Section 3 discusses the econometric method and presents the empirical findings of the study. Section 4 concludes.

2.2. Data and theoretical framework

We use a multivariate model to test the relationship between real GDP and energy consumption through incorporating a capital stock variable. This production function approach follows the specification employed by Stern (1993, 2000) for time series, and Lee (2005) and Narayan et al. (2008) using panel techniques, can be formulated as this form:

$$Y_t = \alpha_t + \beta_t EC_t + \delta_t K_t + \epsilon_t \qquad (1)$$

In this equation Y refers to real GDP, EC is the energy consumption, and finally, K is the real gross fixed capital formation. All variables are measured in per capita and transformed in natural logarithms.

We use seasonally adjusted quarterly data for the Spanish economy for the period 1980:1-2010:4 (the choice of the starting period was constrained by the availability of data on GDP and real gross fixed capital formation). The variables GDP and gross fixed capital formation (both series in logs) are drawn from the Instituto Nacional de Estadística (INE). The variable energy consumption (also in logs) is measured in terms of Gigawatt hour (GWh) and is compiled from Red Eléctrica de España (REE).

2.3. Methodology and empirical results

Estimating the long-run relationship between Y, EC and K requires two steps. First, we test for unit roots in order to determine the order of integration of the three series. Second, we estimate the cointegration relationship between the variables, and we discuss the possibility of structural changes in this relationship. Once this has been done, we can continue checking the causality between the variables.

Unit root rests

As a first step of the analysis, we test for the order of integration of the series using the tests of Ng and Perron (2001). The results are shown in Table 1, and the null hypothesis of nonstationary cannot be rejected, independently of the test, for the three series in levels. Accordingly the results, the series would be I(1).

Table 1. Unit root tests Ng-Perron (series in logs)

Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{\alpha}^{GLS}$	*Lags*
GDP	0.682	0.548	0.804	44.771	3
EC	1.396	2.498	1.803	228.750	3
K	-0.170	-0.123	0.725	31.464	2

Note: *,** and *** Rejects null hypothesis at 1%, 5% and 10% significance level.

The long run relationship, cointegration and causality tests

Once analyzed the order of integration of the series, we perform a cointegration analysis of equation 1 over the whole sample, with no breaks included. Given the relatively sample size, we will estimate and test the coefficients of cointegration equation by means of the Dynamic Ordinary Least Squares (DOLS) method of Stock and Watson (1993), and following the methodology proposed by Shin (1994). The DOLS estimator of the cointegrating regression equation includes all variables in equation (1) in levels, leads and lags of values of the change in the explanatory variables[3]:

$$Y_t = \alpha_t + \beta_t EC_t + \delta_t K_t + \sum_{j=-p}^{p} \gamma_j \, \Delta EC_{t-j} + \sum_{j=-p}^{p} \theta_j \, \Delta K_{t-j} \; + \upsilon_t \tag{2}$$

Where υ_t is an error term, and then perform Shin`s (1994) test from the calculation of C_μ , a LM statistic form DOLS residuals, which tests for deterministic cointegration.

[3] The usefulness of this approach is that it allows for simultaneity bias and introduces dynamics in the specification of the model.

Table 2. Stock-Watson DOLS estimation of long-run relationship

$\hat{\alpha}$	$\hat{\beta}$	$\hat{\delta}$	R^2
4.436*** (0.076)	0.543*** (0.052)	0.214*** (0.043)	0.999
Shin cointegration test			
		Critical values	
C_μ	10%	5%	1%
0.152	0.163	0.221	0.380

Notes: Standars errors in brackets. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to $l=11=INT(T^{1/2})$ as proposed in Newey-West (1987). We choose $p=5=INT(T^{1/3})$,as proposed in Stock and Watson (1993). ***,** and * denote significance at the 1, 5 and 10% levels, respectively. The critical values test are taken from Shin (1994 Table 1), for m=2.

The coefficients from the DOLS regression and the results of the Shin test are reported in Table 2 and show that the null hypothesis of cointegration between Y, EC and K is not rejected at the 1% level of significance. We may conclude that there is a strong evidence of cointegration between Y, EC and K, with a long-run coefficient estimated of 0.543 between Y and EC and 0.214 between Y and K. Because the variables are expressed in natural logs, the coefficients on the energy consumption and capital stock can be interpreted as elasticities. We find that a 1% increase in energy consumption increases real GDP 0.543%, while a 1% increase in capital stock increases real GDP 0.214% (Narayan et al, 2008, for a panel of G7 countries, obtain a range from 0.12-0.39% for energy consumption and 0.01 to 0.28 for capital stock, also Ciarreta et al, 2010, using a panel of

European countries -employing electricity consumption instead energy consumption- find an elasticity of 0.3%).

Evidence of cointegration implies the existence of causality, at least, in one direction, for this reason, we are interest to discover the direction of causality between economic growth, capital stock and energy consumption. Agreeing to Engle and Granger (1987) cointegrated variables must have an error correction model incorporating an error correction term (ECT). Accordingly, a ECM (Error correction model) is formulated to reintroduce the information lost in the differencing process, thereby allowing for long-run equilibrium as well as short-run dynamics. The Engle and Granger (1987) two step procedure is undertaken by first estimating the long-run model specified in equation 2 (the results are shown in table 2) in order to obtain the estimated residuals. Next, defining the lagged residuals from equation 2 as the ECT, the following trivariate dynamic error correction model can be expressed and estimated as follows:

$$\Delta y_t = \alpha_1 + \alpha_2 \sum_{j=1}^{p} \Delta EC_{t-j} + \alpha_3 \sum_{j=1}^{p} \Delta K_{t-j} + \alpha_4 \sum_{j=1}^{p} \Delta y_{t-1} + \delta_1 ECT_{t-1} + u_{1t} \quad (3)$$

$$\Delta EC_t = \beta_1 + \beta_2 \sum_{j=1}^{p} \Delta EC_{t-1} + \beta_3 \sum_{j=1}^{p} \Delta K_{t-1} + \beta_4 \sum_{j=1}^{p} \Delta y_{t-1} + \delta_2 ECT_{t-1} + u_{2t} \quad (4)$$

$$\Delta K_t = \gamma_1 + \gamma_2 \sum_{j=1}^{p} \Delta EC_{t-1} + \gamma_3 \sum_{j=1}^{p} \Delta K_{t-1} + \gamma_4 \sum_{j=1}^{p} \Delta y_{t-1} + \delta_3 ECT_{t-1} + u_{3t} \quad (5)$$

Where Δ is the first difference operator, p is the lag length set, ECT is the error correction term, and u_t are the serially uncorrelated error term..

The t-statistic of estimate of lagged error correction term, i.e., ECT_{t-1} is used to test the long-run causal relation (which is the weak exogeneity test) and the joint χ^2 statistical significance of the estimates of first difference lagged independent variables is used to investigate short run causality. Finally, we can test strong exogeneity test which imposes stronger restrictions by testing the joint significance of both the lagged dynamic terms and the error correction term (Charemza and Deadman, 1992 and Engel, Hendry and Richard 1983).

For example, energy consumption granger causes economic growth if α_3 found statistically significant. On contrary, if β_4 is statistically significant then causality runs from economic growth to energy consumption. If δ_1=0. The rest of causality hypotheses can be inferred similarly.

Table 3. Causality tests

Hypothesis	Short-run Granger causality	Long-run weak exogeneity test	Overall strong exogeneity test
$\Delta y_t \nrightarrow \Delta EC_t$	1.109	0.058	1.109
$\Delta EC_t \nrightarrow \Delta y_t$	0.252	3.469*	3.620
$\Delta y_t \nrightarrow \Delta k_t$	1.158	0.060	1.158
$\Delta k_t \nrightarrow \Delta y_t$	43.937***	3.469*	51.407***
$\Delta k_t \nrightarrow \Delta EC_t$	4.250**	0.060	1.109
$\Delta EC_t \nrightarrow \Delta k_t$	1.124	0.060	1.157

Notes: *, ** and *** indicate rejection of the null hypothesis of non-causality at 10%, 5% and 1% level of significance, respectively; and all statistical tests are performed using Wald test.

Our results reported in table 3 show strong evidence of capital stock growth causing economic growth. Focusing in energy consumption growth, we find short-run granger causality from capital stock growth to energy consumption growth. The significance of the error correction term (long-run weak exogeneity test) in the GDP equation implies that there is a long-run permanent relationship between GDP, capital stock and energy consumption.

In resume, we find a weak causal relationship between the three variables. As we explain in previous section, the possible existence of structural breaks in the relationship could be an answer about the poor results showed.

Structural breaks

Next, we will study whether the long-run relationship estimated between GDP, EC and Y is stable over time, or it exhibits some structural breaks, allowing the instability to occur at a unknown date. To do this task, we use the tests of multiple structural breaks proposed by Gregory and Hansen (1996a,1996b) for and Hatemi-J (2008) allowing for one and two structural breaks respectively.

Both tests are based on the study of the errors from the long-run regression model of Engle and Granger (1987), in which we include one (two) break in the model with an a priori unknown date, which would be endogenously determined by the data.

Exists different alternatives to account for structural breaks in the standard Engle and Granger`s cointegration model, although the null hypothesis in all these alternatives is that the series are not cointegrated.

Gregory and Hansen (1996a,1996b) and Hatemi-J (2008) allow to detect the existence of cointegration under the presence of time discontinuities, of different nature, in the long run regression series and to efficiently test for the breakpoint(s) date(s). The test´s statistics consist in three tests:

the modified versions of the Zα and Zt statistics of Phillips (1987) test, and the augmented Dickey-Fuller test (ADF)[4].

The results of applying the Gregory-Hansen and Hatemi-J test to the relationship between Y, EC and K are shown in table 4.

Table 4. Tests of multiple structural changes in the long-run re-

Model	*ADF*	T_b	Z_t^*	T_b	Z_α^*	T_b
G-H	-	2002:	-7.917***	1987:	-	1987:
Hatemi	-	1992:	-	1987:	-	1987:
		1998:		1998:		1998:

Notes: ***,** and * denote significance at the 1, 5 and 10% levels, respectively. The critical values have been obtained from Gregory and Hansen (1996a,1996b), Table 1, m=2, and Hatemi-J (2008), Table 1, m=2.

Our results indicate that we can only reject, at 1% significance level, the null of no cointegration only in ADF* statistics. According with the rest of the tests the break points are located in 1987:2 and 1998:2. Hence, we conclude in favor of the presence of three regimes (two breaks), with the dates of the breaks estimated at 1987:2 and 1998:2.

The economic interpretation of these result, would be as follows. The first regime occurs from 1980:1 to 1987:2, i.e., just after the Spanish integration in the European Economic Community (EEC). The second regime occurs since 1987:3 to 1998:2, just the end of socialist government

[4] See Appendix for technical details.

and the beginning of the conservative government. Finally, the third regime starts in 1998:3 till now.

Lastly, as we can see, the new estimates of the long-run elasticities for the three regimes are different than those coefficients estimated without structural breaks in table 2. As we can see all of the parameters values are statistically significant. These results reveal a bias in the estimation of a unique long-run relationship in the presence of instability in the series.

Table 5: Elasticities across regimes

	Regime 1 1980:1-1987:2	**Regime 2 1987:3-1998:2**	**Regime 3 1998:3-2010:4**
$\hat{\alpha}$	4.744*** (0.223)	4.384*** (0.127)	5.050*** (0.181)
$\hat{\beta}$	0.427*** (0.030)	0.681*** (0.020)	0.488*** (0.074)
$\hat{\delta}$	0.289*** (0.020)	0.093*** (0.024)	0.207*** (0.061)
R^2	0.997	0.995	0.998
C_μ	0.103	0.080	0.095
		Critical values	
	10%	5%	1%
	0.163	0.221	0.380

Notes: Standars errors in brackets. ***,** and * denote significance at the 1, 5 and 10% levels, respectively. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to $l=11=INT(T^{1/2})$ as proposed in Newey-West (1987). We choose $p=5=INT(T^{1/3})$,as proposed in Stock and Watson (1993). ***,** and * denote significance at the 1, 5 and 10% levels, respectively. The critical values test are taken from Shin (1994 Table 1), for m=2.

Before allowing for structural breaks, the elasticity of energy consumption on GDP over the entire period (1980:1-2010:4) was 0.543; when we allow for structural changes, the new estimates of the coefficient increase after 1987:2 from 0.427 to 0.681, and decrease after 1998 from 0.681 to 0.488. In relation to the elasticity of capital stock on GDP, there is a substantial decrease across the regime, in the first period from elasticity of 0.289 to 0.093 and finally a strong increase in the last period from 0.093 to 0.207.

Focusing in the last regime, the elasticity of energy consumption on GDP decrease and the elasticity of capital stock on GDP increase, one of the reasons, especially in the second result could be the construction's boom of the Spanish economy. As we can see in table 6, during the last regime, the relative wage of the construction sector over the whole economy have showed an important increment.

Table 6. Change in sectors composition of GDP in breaks dates

Sector	**1980:1**	**1987:2**	**1998:2**	**2010:4**
Agriculture	7.62%	6.64%	4.83%	2.84%
Indus+Energ	31.97%	28.99%	22.62%	16.03%
Construction	8.62%	7.03%	7.42%	10.21%
Services	51.79%	57.34%	65.13%	70.91%

Source: Ministerio de Economía y Hacienda (BDMacro)

Once determined the elasticities across regimes, we are interesting to discover the causal relations between the variables in each regime. For this purpose, we estimate, as a previous section, an ECM to test the existence of different types of causalities. The results are shown in table 7.

Table 7. Causality tests across regimes

Hypothesis	Short-run Granger causality	Long-run weak exogeneity test	Overall strong exogeneity test
Regime I (1980:1 - 1987:2)			
$\Delta y_t \nrightarrow \Delta EC_t$	0.057	0.055	0.261
$\Delta EC_t \nrightarrow \Delta y_t$	2.629	4.213**	4.962*
$\Delta y_t \nrightarrow \Delta k_t$	0.000	0.004	0.004
$\Delta k_t \nrightarrow \Delta y_t$	1.631	4.213**	9.562***
$\Delta k_t \nrightarrow \Delta EC_t$	0.008	0.055	0.056
$\Delta EC_t \nrightarrow \Delta k_t$	3.361*	0.004	4.133
Regime II (1987:3 – 1998:2)			
$\Delta y_t \nrightarrow \Delta EC_t$	0.566	0.322	0.566
$\Delta EC_t \nrightarrow \Delta y_t$	0.828	9.470***	9.680***
$\Delta y_t \nrightarrow \Delta k_t$	0.026	0.015	0.026
$\Delta k_t \nrightarrow \Delta y_t$	7.698***	9.470***	31.399***
$\Delta k_t \nrightarrow \Delta EC_t$	0.518	0.322	1.523
$\Delta EC_t \nrightarrow \Delta k_t$	1.698	0.015	1.703
Regime III (1998:3 – 2010:4)			
$\Delta y_t \nrightarrow \Delta EC_t$	3.739*	0.150	3.739
$\Delta EC_t \nrightarrow \Delta y_t$	0.382	0.035	0.403
$\Delta y_t \nrightarrow \Delta k_t$	22.440***	0.902	22.240***
$\Delta k_t \nrightarrow \Delta y_t$	0.171	0.035	0.238
$\Delta k_t \nrightarrow \Delta EC_t$	0.089	0.150	0.284
$\Delta EC_t \nrightarrow \Delta k_t$	0.017	0.902	0.907

Notes: *, ** and *** indicate rejection of the null hypothesis of non-causality at 10%, 5% and 1% level of significance,
respectively; and all statistical tests are performed using Wald test.

The results show a clearly different scenario comparing with the whole sample. For example, GDP during the first two regimes show a long run relationship (weak exogeneity) with energy consumption and capital stock, nevertheless, this relation disappear in the last regime. Furthermore, turning specifically in energy consumption, while in the first regime, energy consumption granger cause to capital stock, in the middle regime, no short run causality relationship (neutral hypothesis) is found but a long run relationship with economic growth and capital stock is defined, and finally, in the last regime, energy consumption is granger caused from economic growth (conservative hypothesis). About capital stock, results show a long run relationship across the three regimes from energy consumption and economic growth to capital stock.

2.4. Conclusions and policy implications

There are a big number of papers on energy-growth nexus using cointegration techniques to investigate the long-run relationship between energy consumption and GDP. This paper contributes to this empirical literature by checking whether these two variables are cointegrated over the period 1980:1-2010:4. As a novelty we test for structural breaks in the series allowing the instability to occur at an unknown date. Moreover, we incorporate the important episodes (structural breaks) in our cointegration estimations to check whether the long-run between variables is stable over time using the multiple structural change approach of Gregory and Hansen

(1996a, 1996b) and Hatemi-j (2008). Furthermore we test the existence of causality relationship between the variables in the whole sample and across regimes. Finally, the Spanish economy can represent an interesting case of study, since she has been a quick degree of developing in a "relative" short time period. Conclusions for Spain may be relevant for a number of countries, which have to go through a similar development path, increasing the pressure of the already scarce energy resources.

Our results are consistent with the existence of a cointegration relationship between GDP, EC and K, with an estimate long-run energy consumption elasticity of growth spending of 0.543. Also we provide evidence against the stability of this relationship, finding two breaks in 1987:2 and 1998:2. The first break occurred in 1987:2 around the time of the Spanish integration in the EEC. In turn, the second structural change occurred in 1998:2 just in the beginning of the construction and real estate Spanish boom. On the other hand, up to three regimes were detected over the whole sample with an estimated long-run energy consumption elasticity of 0.427 for 1980:1 to 1987:2, 0.681 for 1987:2 to 1998:2 and 0.481 for 1998:2-2010:4. Focusing our results in the estimate long-run stock capital elasticity of growth, the initial elasticity was 0.214, however across the regimes, there was a decrease in there long-run elasticity of capital stock on

GDP, from 0.289 in the first regime to 0.207 in the third regime (0.093 in the second regime).

Focusing in the causality relationships, we discover different patterns between the whole sample and each regime. In the whole sample, the results show the existence of short run granger causality from capital stock growth to economic growth and energy consumption growth. Also, result reveals a weak exogeneity relationship from capital stock and energy consumption growth to economic growth.

Across regimes, results are quite different, on the one hand, focusing in energy consumption, results reveals a different pattern across regimes, in the first two regimes, we observe that the economic growth present a weak exogeneity relationship from energy consumption, but in the last regime, this situation change, and this type of relationship disappear and appear a short run causality from energy consumption growth to economic growth. It is important to note that during the first two regimes, economic growth show no short granger causality from or to any other variable, however, in the last regime, economic growth granger cause both variables.

Finally, these empirical findings have important implications. First, the granger cause of economic growth to energy consumption, in the third period, could be interpreted like a signal of a way to the conservative hypothesis, i.e., Spain have reach a high degree of development and conservative energy policies have no adverse effect on economic growth. For this reason, energy restrictions could have not (or weak) effect in Spanish economic growth. Second, Spanish economy could be an example for countries whose has a quick economic growth or are in a preliminary (in 1980 Spain was an almost developing country) stage of development. Third and finally, the non-stable relationship could be interpreted like the relationship between energy consumption (capital stock) and GDP depends the degree of development, i.e., while Spain was a developing country (till the end of the 80s), the results showed that energy consumption (capital stock) had a high (low) correlation with economic growth. Once reached the degree of "developed country", the relationship is decreasing.

Areas for future research are to undertake similar analysis to verify in which countries the results of this paper takes over.

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APPENDIX A. Gregory and Hansen methodology

The test proposed by Gregory and Hansen consider an alternative hypothesis in which the cointegrating vector may be subject to a regime shift at an unknown time. They analyzed models that accommodate, under the alternative hypothesis of cointegration, the possibility of changes in parameters and then shifting to a new long run relationship. The structural break would be reflected in changes in the intercept and/or changes to the slope.

To model structural change, a dummy variable is defined:

$$\varphi_t = \begin{Bmatrix} 0 & if\ \ t \leq [n\tau] \\ 1 & if\ \ t > [n\tau] \end{Bmatrix}$$

Where the unknown parameter φ ∈ (0,1) denote the timing of the change point, and [ ] denotes integer part.

Gregory and Hansen proposed three alternative types of regression models to implement the tests:

MODEL C: a model with a level shift,

MODEL C/T: a model with a linear trend including a level shift,

MODEL C/S: a model encompassing both a change in the level and in the slope of the coefficients of the long term relationship variables.

(In this paper, we use this last type of model)

The model C, C/T and C/S are estimated for each possible break date (for each τ), and the residuals $\hat{\varepsilon}_t$ are obtained. Next, a unit root test is perfomed on the estimated residuals. The authors consider the following test statistics:

$$ADF^* = \inf_{\tau \in T} ADF(\tau)$$

$$Z_t^* = \inf_{\tau \in T} Z_t(\tau)$$

$$Z_\alpha^* = \inf_{\tau \in T} Z_\alpha(\tau)$$

APPENDIX B. Hatemi-J metohology

Cointegration test with two structural breaks suggested by Hatemi-J. This methodology uses the Gregory and Hansen procedure including two breaks in the long run relationship. To test the null hypothesis of no cointegration, author uses three statistics: Zα and Zt tests developed by Phillips and augmented Dickey- Fuller (ADF) test. The test statistics are based of the calculation of the bias corrected first-order serial correlation coefficient estimate ($\hat{p}^{\cdot}$) Hatemi-J defines $\hat{p}^{\cdot}$ as:

$$\hat{p}^{\cdot} = \frac{\sum_{t=1}^{T-1}\left(\hat{e}_t\hat{e}_{t+1} - \sum_{j=1}^{B} w(j/B)\hat{\gamma}(j)\right)}{\sum_{t=1}^{T-1}\hat{e}_t^2}$$

Where $\hat{e}_t$ is the estimated value of at time t for the estimated model with T observations. $w(.)$ Is a function providing kernel weights meeting the standard conditions for spectral density estimators. B is the bandwidth number satisfying the conditions $B \rightarrow \infty$ and $B/T^5 = O(1)$. $\hat{\gamma}(j)$ is an autocovariance function. The autocovariance function is defined as:

$$\hat{\gamma}(j) = \frac{1}{T}\sum_{t=j+1}^{T}\left(\hat{e}_{t-j} - \hat{p}\hat{e}_{t-j-1}\right)\left(\hat{e}_t - \hat{p}\hat{e}_{t-1}\right)$$

Here $\hat{p}$ indicates the estimated values of the effect of $\hat{e}_{t-1}$on. The Zα test statistic is defined as

$$Z_{\propto} = T(\hat{p} - 1)$$

The Zt test statistic is defined as follows:

$$\frac{Z_t(\hat{p}^{\cdot} - 1)}{\left(\hat{\gamma}(0) + 2\sum_{j=1}^{B} w(j/B)\hat{\gamma}(j)\right)/\sum_{1}^{T-1}\hat{e}_t^2}$$

Where $\left(\hat{\gamma}(0) + 2\sum_{j=1}^{B} w(j/B)\hat{\gamma}(j)\right)/\sum_{1}^{T-1}\hat{e}_t^2$ denotes the long-run variance of the residuals of a regression $\hat{e}_t$ on $\hat{e}_{t-1}$ The distribution of these tests does not follow standard asymptotic distributions and using Monte-Carlo simulations new critical values are generated by Hatemi-J. The test statistics are the smallest values of these three across all values for $\tau_1$and τ_2, with $\tau_1 \in T_1 = (0.15{,}0.70)$ and $\tau_2 \in T_2 = (0.15 + \tau_1, 0.70)$. These test statistics are as follows:

$$ADF^* = \inf_{(\tau_1/\tau_2)\in T} ADF(\tau_1, \tau_2)$$

$$Z_t^* = \inf_{(\tau_1/\tau_2)\in T} Z_t(\tau_1, \tau_2)$$

$$Z_\alpha^* = \inf_{(\tau_1/\tau_2)\in T} Z_\alpha(\tau_1, \tau_2)$$

Figures: series in levels

Figure I GDP

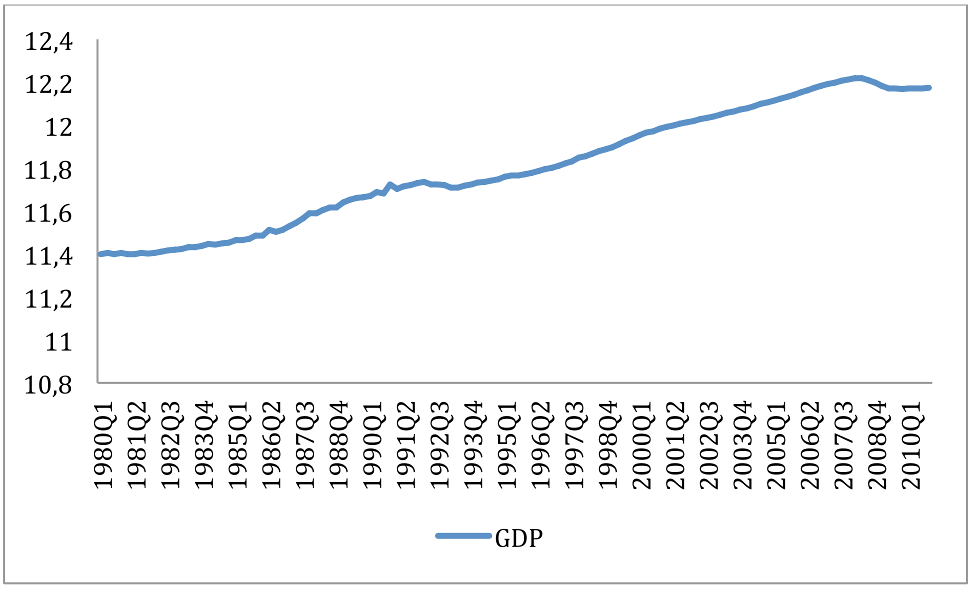


Figure II Capital Stock

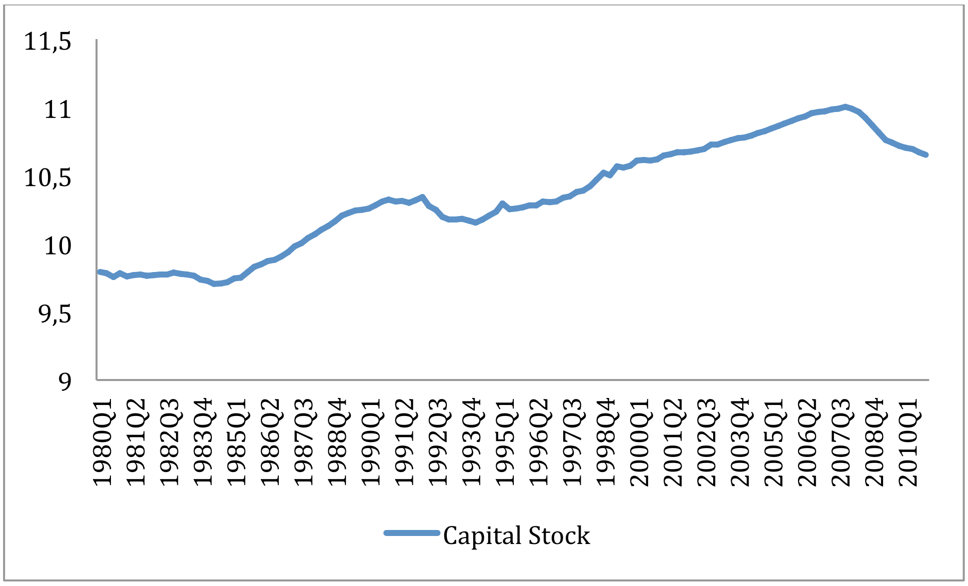
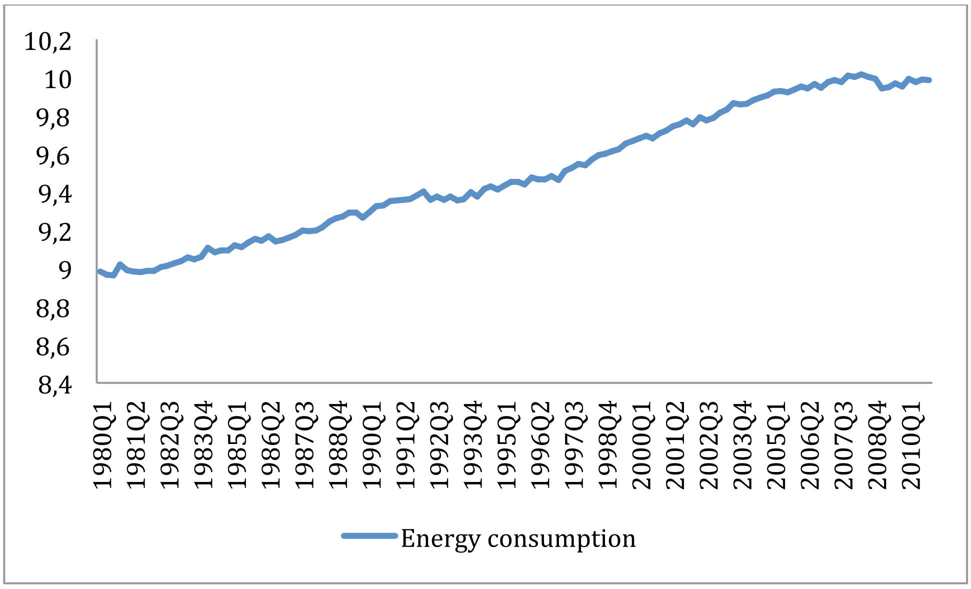


Figure III Energy Consumption



Figures: series first differences

Figure IV GDP (first difference)

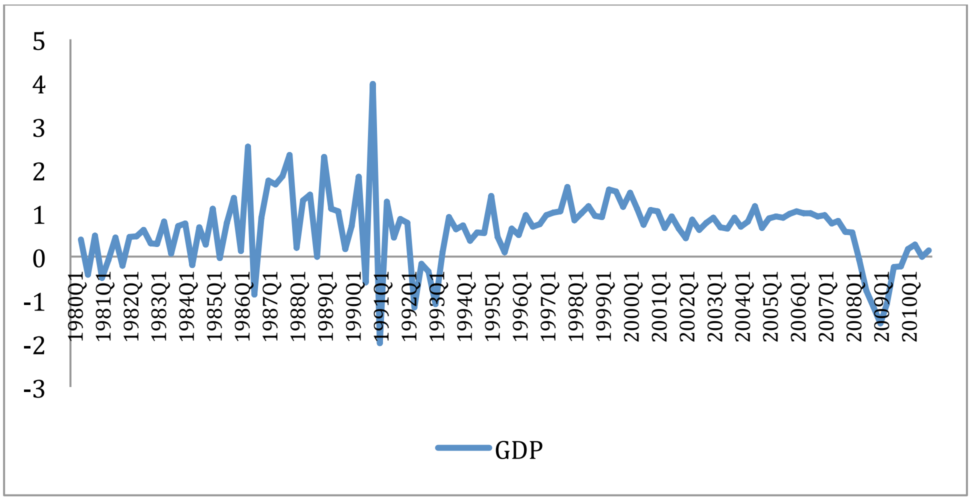


Figure V Capital stock (first difference)

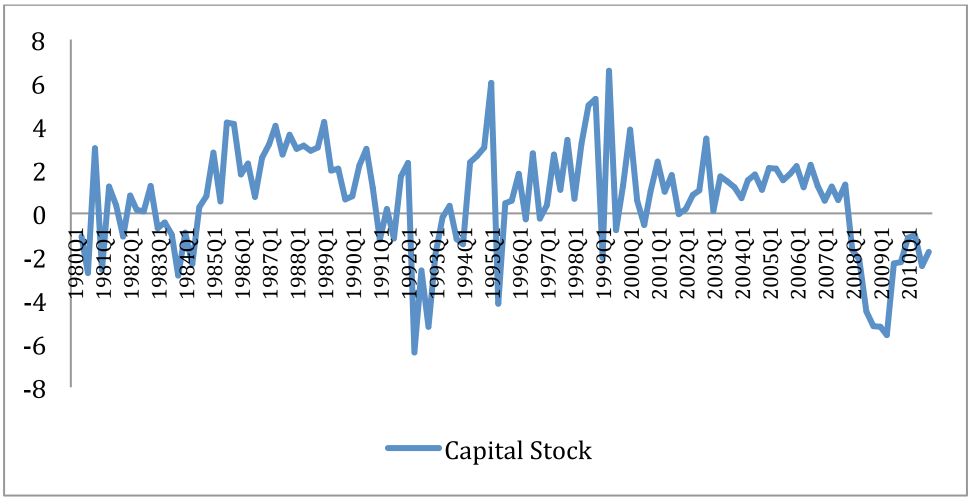
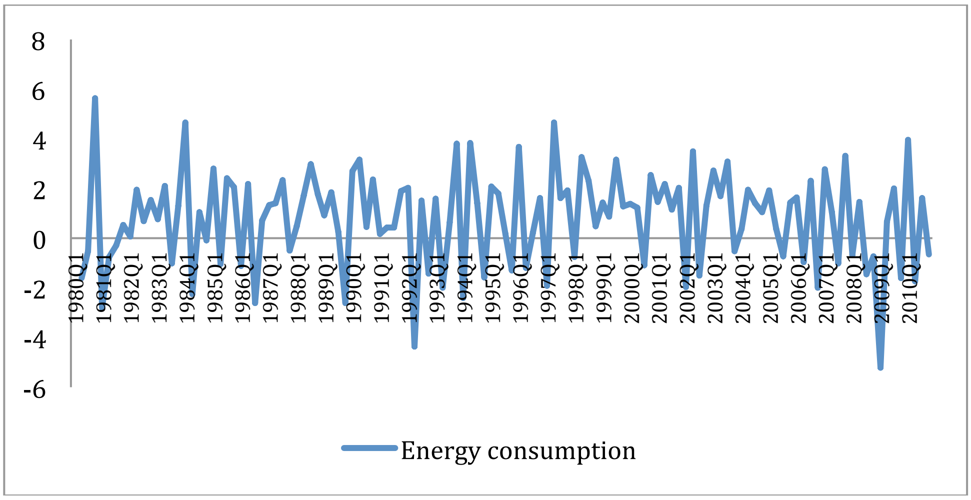


Figure VI Energy consumption (first difference)



PART III: Energy consumption in USA

Chapter 3: The energy-growth nexus reconsidered: persistence and causality

This article applies a recent econometric framework to the analysis of the relationship between energy consumption and economic growth in the US, which allow a joint study of causality and persistence. We provide evidence suggesting a nonlinear relationship with two structural breaks. In the most recent regime we find that GDP causes energy consumption (and vice versa). Furthermore, both series show persistence, i.e. cyclical and natural components do not evolve independently. Thus, policies oriented to the reduction of energy consumption could constrain economic growth and policy shocks can have permanent effects

3.1 Introduction

The relationship between energy consumption and economic growth has been at the heart of the debate on energy policy. In particular, the existence and direction of causality should be considered as a key element for the formulation of energy policies, whereas testing for persistence is a crucial element for analysing the long-run effects of the energy policy.

For example, if causality does not exist in both directions or if causality is only in one direction such as from GDP to energy, then a policy of energy conservation may be appropriate since it will not have a negative effect on economic growth and will have a positive effect on the environment –conservation hypothesis-. By contrast, if there is a bi-directional causality or a causality relation from energy to GDP, the reduction in energy consumption may harm economic recovery or constrain economic growth –feedback hypothesis-.[1]

This causal relationship between energy consumption and economic growth has been extensively explored in different countries or groups of countries, time periods, and proxy variables using different strategies, as

[1] The other two options are no causality or neutrality hypothesis the uni-directional causality from energy consumption to economic growth or growth hypothesis (see Ozturk, 2010).

recently surveys Ozturk (2010), Payne (2010) or Pirlogea and Cicea (2012) or Omri (2014) or the meta-analysis of Menegaki (2014) and Kalimeris et al. (2013). As it is well-known, the relation between energy consumption and economic growth has become a source of controversy in Energy Economics, since evidence has not provided unambiguous results. Leaving aside proxy and times periods, and as Ozturk (2010) states one of the most likely reasons for explaining the lack of consensus on the causality relationship between energy consumption and economic growth may be arise due to different econometric approaches have been used. In this article we put the focus on the importance of the econometric approach undertaken, as one of the most important cause of this wide range of results.

In country specific studies, the most popular approach has consisted of testing for Granger causality. As it is well-known, these tests should be undertaken with stationary time series. For this reason unit roots tests with or without structural breaks are used before looking for Granger causality in order to yield valid inferences. However, when time series are non-stationary, the alternative way for analyzing the causality relationship is the cointegration approach, procedures valid irrespective whether time series are stationary or not. In that case, either by using the Johansen-Juselius (1990), Pesaran Shin (1999) and Pesaran et al. (2001) cointegration approach (for cointegrated time series) or procedures such as Toda

Yamamoto (1995) or Dolado and Lütkepol (1996) (when the time series are not cointegrated), researchers avoid the potential biases of pre-testing when undertaking causality tests. (Payne (2010), p. 729)

However, there is another way to avoid the pre-testing. In this article, we propose the use of a multivariate unobserved component model, recently developed by Sinclair (2009) to decompose energy consumption and the real GDP into the sum of its two (unobservable) components: the non-stationary natural component, and the stationary (transitory) cyclical components. In doing so, and given that a cyclical component is stationary, we can test directly the causality by using this component. To the best of our knowledge its application to Energy Economics is novel.

We also ask whether energy consumption exhibits persistence[2], defined as a macro dynamic structure in which the cyclical component of energy consumption has persistent effects on its natural rate, as Jaeger & Parkinson suggests (1990, 1994). Persistence can be defined and measured in various ways. The most popular approach in the empirical literature

[2] Persistence is another important topic in Energy Economics, since it concerns to the long-term effects of energy policies: if energy consumption is non-stationary, policy shocks can be regarded as permanent; by contrast, if energy consumption is trend-stationary, economic and policy shocks can be regarded as transitory: the level eventually reverts to its trend. Therefore, at the heart of this question is whether energy consumption evolves as a trend-stationary or as a non-stationary time-series process.

simply equates persistence with the existence of a unit root in a variable[3]. The available evidence on persistence in energy consumption, is also mixed. Some authors suggests that energy consumption is integrated of order zero in which case policies only have short-term effects (Chen & Lee (2007); Narayan & Smith, (2007); Apergis et al., (2010a-b), while others as Hsu and Lee (2008) (or Mishra et al (2009) provides evidence on the contrary[4].

Furthermore a number of papers have studied methods for checking for presence of hysteresis (persistence and remanence[5]) in a nonlinear framework, testing for structural breaks (see Ozturk, 2010). However, though these models incorporate nonlinearities they have the same weak point as the linear models described above: natural and cyclical shocks are summarized in the innovation with no distinction.

However, persistence in a time series arises when a change in the cyclical component induces a permanent change in the natural component. Therefore, the presence of a unit root in the time series is a necessary con-

[3] See, Røed (1997), for a survey.

[4] See Payne (2010) or Smyth (2013) for a survey.

[5] We prevent the use of persistence and hysteresis as synonymous. A formal definition of a hysteretic process requires the properties of persistence and remanence, and this last one is lacking in a linear model (Amable et al., (1995)). At this point, we want to thank an anonymous referee suggestion about the use of this term.

dition for the existence of persistence but not a sufficient one since the unit root could be generated by accumulation of natural shocks and be completely independent of whether there is persistence (Pérez and di Sanzo (2011) or Congregado et al. (2011)).

Hence, separating the respective effects of transitory and permanent shocks on the natural component is the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both. For this reason, we adopt an unobserved components model in order to put this idea in perspective and for testing the validity of the persistence hypothesis for energy consumption. In particular, we use the unobserved component model recently proposed by Sinclair (2009) which decomposed the actual values of a series into two components, a natural and cyclical component. This framework allows: i) on the one hand, to check the presence of hysteresis in energy consumption from an analysis of the cross correlation between the natural and cyclical component of the energy consumption series; and, ii) an analysis of causality between energy consumption and GDP using the cyclical components of both series, extracted by using this UC model, which allow to avoid problems related to the stationarity properties of our series in levels.

Hence, separating the respective effects of transitory and permanent shocks on the natural component of energy consumption the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both.

For this reason, the second novelty of our approach is the study of the persistence by means of the analysis of the cross-correlation between the two unobserved components of each time series, described above, which allow us to know whether temporary shocks in energy consumption have permanent effects while the energy cycle does not evolve independently of the natural component.

In that sense, this paper explore a new empirical approach in order to understand and interpret the why and wherefore of the lack of uniformity shown by the previous empirical evidence on the relationship between energy consumption and growth and on the permanent or transitory character of shocks in energy consumption.

Leaving aside issues of data quality, the key question is to identify the correct model specification so as to ensure a consistent estimating procedure. In this context, this article provide the results of applying an unobserved component model, recently proposed by Sinclair (2009) which allows for a simultaneous study of causality and persistence in a single framework.

In particular, the method consists of decomposing the two time-series in two unobservable components: a non-stationary "natural" component, and a stationary "cyclical" component. The use of these cyclical components would allow to avoid potential biases associated to the stationarity properties of time series necessary for the causality analysis. On the other hand, separating the respective effects of transitory and permanent shocks on the natural component is the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both.

In sum, this article jointly estimates the permanent and transitory movements in U.S. output and energy consumption as well as the relationships between them. The estimated components, suggest that movements in their permanent components look similar to the series themselves. In addition, the innovations to the permanent component and the transitory component are highly correlated for both output and energy consumption. This suggests that it would be inappropriate to treat these components as independent. Finally, the positive correlation between the permanent and transitory innovations to real GDP and energy consumption indicates that real GDP and the energy consumption are strongly linked not only through their transitory movements but also through their permanent movements.

The rest of the article is organized as follows. The next section presents the econometric framework. The empirical results are discussed in section 3. Finally, section 4 presents the concluding remarks.

3.2. Econometric framework and data

The starting point of our estimation strategy call for, decompose the series Xt into the sum of its two (unobservable) components: the non-stationary natural component, X_t^N , and the stationary cyclical component, X_t^C

The relationship between output growth and energy consumption is analyzed estimating a bivariate correlated unobserved components model to investigate the interplay between output and energy consumption. We use Sinclair's (2009) model which allows for possible correlation between the components of the covariance matrix. This model can be used to decompose the two series into their cyclical and natural components:

$$C_t = C_t^C + C_t^N \tag{1}$$

$$Y_t = Y_t^C + Y_t^N \tag{2}$$

Each cyclical component is modeled as an AR(2) process[6]:

$$C_t^C = \varphi_{1c} C_{t-1}^C + \varphi_{2c} C_{t-2}^C + \varepsilon_{st} \qquad \varepsilon_{ct} \sim NID\left(0, \sigma_{\varepsilon_c}^2\right) \tag{3}$$

$$Y_t^C = \varphi_{1y} Y_{t-1}^C + \varphi_{2y} Y_{t-2}^C + \varepsilon_{yt} \qquad \varepsilon_{yt} \sim NID\left(0, \sigma_{\varepsilon_y}^2\right) \tag{4}$$

Each natural component is assumed to be given by a random walk[7], although we also allow for a drift μ in the GDP equation:

$$C_t^N = C_{t-1}^N + \eta_{ct} \quad \eta_{ct} \sim NID\left(0, \sigma_{\eta_c}^2\right) \tag{5}$$

$$Y_t^N = \mu_{yt} + Y_{t-1}^N + \eta_{yt} \quad \eta_{yt} \sim NID\left(0, \sigma_{\eta_y}^2\right) \tag{6}$$

The state-space form of this model can be estimated using the Kalman Filter with maximum likelihood estimation of the parameters and the cyclical and natural components.[8] We also estimate all the correlations

[6] We find that an AR(2) process for the cyclical component fits the data well for all the time series under study.

[7] Ng-Perron (2001) tests cannot reject a unit root for either of the series used (see appendix). Zivot & Andrews (1992) tests are also used for testing unit roots allowing for structural breaks (available upon request).

[8] As Sinclair (2009) explains, this model is identified without the imposition of any restriction on the covariance matrix.

between the unobserved components of the two series. The correlation coefficient between the cyclical components of the two series reveals pro- or counter-cyclical variation depending on whether the coefficient is positive or negative. At the same time, the correlation between the natural components of energy consumption and output reveals the nature of the relationship between these variables in the long-run. Once the previous strategy has been used as a way to separate cyclical and natural components in the two series, our next objective will be looking for Granger-causality in the relationship by using the estimates of the two cyclical components.

The data used are quarterly observations from 1973:1 to 2015:2. The energy consumption (measured in quadrillion Btu.) and GDP data (measured in seasonally adjusted billions of chained 2009 dollars) are extracted from the US Energy Information Administration (EIA) and the US Bureau of Economics Analysis (BEA), respectively. Before conducting the empirical analysis data were seasonally adjusted.

3.3 Results

The estimates are presented in Table 1. These estimates come from joint estimation produced using a Kalman filter. Append 1presents the estimated components of output and energy consumption, respectively along with the observed series.

The estimates in Table 1 and the estimated permanent component of energy consumption indicate that movements are highly variable. Second, innovations to the permanent component are significantly negatively correlated with innovations to the transitory component, rejecting the restriction of independent components.

The estimate of the permanent component, shown in append 1 looks very similar to the energy consumption series. The transitory movements are the difference between the series and the permanent component.

Let's focus now on the cross-series correlations, that is, on the relationship between the transitory components of output and energy consumption. As discussed in the previous section, the correlation between the transitory and natural components of GDP and energy consumption points to a pro-cyclical nature of this relationship .This correlation suggests that the transitory components of output and energy consumption are positively correlated. (see the last two rows in table 1).

Regarding to the relationship between the permanent components the estimates presented in Table 1 indicate a positive relationship, similar to that of transitory output and energy consumption.

Finally, the size of the correlation between the cyclical and natural component for either series suggests that a substantial amount of the transitory component arises from adjustment to permanent shocks (rows 1 and 5, in table 1).

Table 1. Estimates of the bivariate unobserved component model

GDP		
Correlation between GDP innovations	$\rho_{ny\varepsilon y}$	-0.976*** (0.013)
GDP drift	μ_y	0.054*** (0.007)
GDP 1st AR parameter	φ_{1y}	0.769*** (0.063)
GDP 2nd AR parameter	φ_{2y}	-0.023 (0.031)
ENERGY CONSUMPTION (EC)		
Correlation between EC innovations	$\rho_{nc\varepsilon c}$	-0.796*** (0.098)
EC 1st AR parameter	φ_{1c}	1.363*** (0.078)
EC 2ND AR parameter	φ_{2c}	-0.649*** (0.083)
CROSS SERIES CORRELATIONS		
Natural GDP/Natural EC	ρ_{nync}	0.892*** (0.043)
Cyclical GDP/ Cyclical EC	$\rho_{\varepsilon y\varepsilon c}$	0.951*** (0.079)

Notes: Standard errors are in parentheses. ***,**,*, rejects null hypothesis at 1%, 5% and 10% significance level, respectively.

Table 2 report the result of the Granger causality test, where the null is the hypothesis of no causation. The null hypothesis of no causation is rejected in both directions, implying then that the direction of causality is bilateral. The Granger causality tests show that there is bidirectional causality between cyclical energy consumption variation and cyclical output for U.S.

Therefore, the Granger-causality tests show that there is bidirectional causality between GDP and energy consumption.

Table 2. Granger Causality tests between cyclical GDP and cyclical Energy Consumption

Null hypothesis	P-value
$C_t^c \nrightarrow Y_t^c$	**0.005**
$Y_t^c \nrightarrow C_t^c$	**0.005**

Note: In bold p-values smaller than 10%.

Our results are in line with Lee 82006) since we find a bi-directional causality at the 10% level of significance. However, if we establish a more demanding statistical criterion with regard the significance level, our results agrees well with the previous works of Stern (1993, 2000) using a multivariate VAR model and cointegration and Granger causality test, respectively, Soytas & Sari (2006) and Bowden and Payne (2009) using the Toda-Yamamoto approach, given that at the 5% only a causality running from C to GDP is found.

Finally, and since we are considering a long period of time (1973-2015), it is possible that the relationship under consideration underwent some structural shifts. Because the existence of structural shifts would bias our results, leading to incorrect inference about cyclicality, we checked for (possibly multiple) structural breaks in the relationship estimated, using a methodology proposed by Bai and Perron (1998, 2003a-b)[9]. In the absence of structural breaks, the inferences made earlier remain valid. In presence of structural breaks, on the other hand, the causal relationships estimated in the previous subsection need to be re-estimated for each sub-period determined by the breaks. That way, we can avoid drawing spurious conclusions from an inappropriately conjoined set of sub-periods.

As Table A5 (in the appendix) shows, the energy-growth relationship is subject to structural breaks, with a break point in 2009(I), clearly at the beginning recent economic crisis. This implies two sub-periods over which the causality relationship can exhibit different performance.

Given the existence of structural breaks, we reexamine the causality relationships for each sub-period separately. The results are summarized in Table 3. Looking at table, the first sub-period, exhibit causality running from output cycles to energy consumption cycles or vice-versa. In contrast,

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[9] The Bai-Perron only can be used for stationary variables. We have checked and confirm the stationary of the cycles obtained. Results are in table A4 in the appendix

the second period exhibit causality running from output cycles to energy consumption cycle.

Table 3. Granger causality tests between self-employment and output in different sub-periods.

Null hypothesis	Sub-period 1 1973(I)-2009(I)	Sub-period 2 2009(II)-2015(II)
$C_t^c \nrightarrow Y_t^c$	0.152	**0.028**
$Y_t^c \nrightarrow C_t^c$	**0.045**	**0.006**

Note: In bold p-values smaller than 10%.

3.4. Concluding remarks

Our results shed new light on the important issue of the relationship between energy consumption and economic growth. In particular, this paper applies a new approach in order to clarify in some extent the literature's puzzle on this relationship. In line with some previous results our findings point to, the existence of a bi-directional causality between energy consumption and economic growth or by applying a more demanding statistical significance level the existence of a unidirectional causality running from energy consumption to economic growth. However, and once the possibility of structural breaks has been taken into account, our findings suggest that the causality relationships have changed between periods. In particular, in the most recent regime, a bi-directional relationship is found.

The Granger causality tests reveal that energy consumption cycles cause output cycles and vice versa. Therefore, energy conservative policies may harm economic recovery.

Second, this paper contributes to the debate about the variability in the natural rate of energy consumption. In that sense, our results show that movements in U.S. energy consumption are largely permanent.

We also provide estimates of the different relationships between the unobserved components of output and energy consumption. On the one hand we find negative and statistically significant correlations within-series, that is, those between the innovations to the permanent and transitory components of the same series. The innovations to the permanent and transitory components of the two series are negatively correlated.

Finally we also report cross-series correlations, that is, the correlation between the transitory components of output and energy consumption and, between their two permanent components being both of them negatives.

However, we cannot rule out the possibility that it might also simply reflect data limitations including the possibility that self-employment is an unsatisfactory practical measure of entrepreneurship.

Further research is needed to determine whether it is different national (e.g. institutional) and economic conditions, or merely different data definitions of self-employment, which explain the diverse findings. Future work could also fruitfully apply the methodology used in this article to a broader range of countries, and should seek to lengthen the length of the data series that are utilized. Future work might fruitfully apply the methodology used in this article to a broader range of countries, and should also seek to use alternative data series.

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APPENDIX

Unit root test

Table A1. Unit root tests

	PP	Ng-Perron				
		I(1) vs. I(0)				
Variable	**Test**	$\overline{M}Z_{\alpha}^{GLS}$	$\overline{M}Z_{t}^{GLS}$	$\overline{M}SB^{GLS}$	$\overline{M}PT^{GLS}$	**Lags**
ly	-1.080	-4.642	-1.354	0.292	18.533	1
lc	-2.151	-7.153	-1.836	0.257	12.553	1
		I(2) vs. I(1)				
Variable	**Test**	$\overline{M}Z_{\alpha}^{GLS}$	$\overline{M}Z_{t}^{GLS}$	$\overline{M}SB^{GLS}$	$\overline{M}PT^{GLS}$	**Lags**
Δly	-8.740***	-15.677***	-2.753***	0.176**	1.740***	1
Δlc	-16.042***	-19.560***	-3.120***	0.160***	1.279***	1

Notes:
The critical values for the Ng-Perron test are tabulated in Ng & Perron (2001). The M*BIC* information criteria is used to select the autoregressive truncation lag, *k*, as proposed in Perron and Ng (1996)
***, ** and * denote significance at 1%, 5% and 10% level respectively

Cointegration

Cointegration analysis requires the model to have a common lag length. To select the lag length of the VAR we have used the Akaike information criterion (AIC), the Schwarz information criterion (SC), and the Hannan-Quinn (HQ) criterion. Although the SC and HQ criteria suggest that *k=2,* the choice of *k* based on the Akaike information criterion suggests that *k=3* is to be preferred.

Table A2. Results for choosing the lag length of the VAR model based on the AIC, SC and HQ criteria[a].

Lags	AIC	SC	HQ
1	-12,164	-12,051	-12,118
2	-12,406	-12,216*	-12,329*
3	-12,422*	-12,155	-12,314
4	-12,412	-12,069	-12,273
5	-12,375	-11,956	-12,205
6	-12,368	-11,873	-12,167
7	-12,370	-11,798	-12,138
8	-12,351	-11,703	-12,088

[*] denotes lag order selection by the criterion

Testing for cointegration

The results obtained from applying the Johansen reduced rank regression approach to our model are given in table A3. The two hypothesis tested, from no cointegration *r*=0 (alternatively *n*-*r*=2) to the presence of one cointegration vector (*r*=1) are presented in the two first columns. The eigenvalues associated with the combinations of the *I(1)* levels of x_t are in column 3. Next come the $\lambda_{\max}$ statistics that test whether *r*=0 against *r*=1. That is, a test of the significance of the largest λ_r is performed. The results suggest that the hypothesis of no cointegration (*r*=0) can be rejected.

Table A3. Johansen Cointegration test [a]

$H_o : r$	$n - r$	λ	$\lambda_{\max}$ test	$\lambda_{\max}$ (0,95)	λ_{trace} test	λ_{trace} (0,95)	Lags
0	2	0.035	5.790	14.265	7.313	15.495	2
1	1	0.009	1.522	3.841	1.522	3.841	

* denotes rejection at the 5% significance level.

Unit root test (cycles)

To confirm the stationary propierties of the cycles obtained in the article. We have checked the stationary of the variables (cyclesI using the Philip-Perron and Ng-Perron unit root test.

Table A4. Unit root tests (cycles)

	I(1) vs. I(0)					
	PP	**Ng-Perron**				
Variable	**Test**	$\overline{M}Z_{\alpha}^{GLS}$	$\overline{M}Z_{t}^{GLS}$	$\overline{M}SB^{GL}$	$\overline{M}PT^{GL}$	**Lags**
Y_t^c	-5.949***	-22.117***	-3.316***	0.150***	1.141***	0
C_t^c	-3.124**	-135.185***	-8.217***	0.061***	0.188***	1

Notes:
The critical values for the Ng-Perron test are tabulated in Ng & Perron (2001). The M*BIC* information criteria is used to select the autoregressive truncation lag, k, as proposed in Perron and Ng (1996)
***, ** and * denote significance at 1%, 5% and 10% level respectively

Bai-Perron tests of multiple structural changes in the relationship between the cyclical components of Energy Consumption and GDP

We give a brief description of the Bai-Perron methodology before reporting the results. The Bai-Perron methodology comprises a sequence of tests, of the following form. First, the null hypothesis of no structural breaks is tested against the alternative of an unknown number of breaks. If the null is rejected, one proceeds to the second step which contains a set of tests of no breaks against an integer number *l* of breaks. If these tests show evidence of at least one break, at the third step a further set of hypotheses of *l* breaks is tested against the alternative of *l* +1 breaks. This identifies the precise number of structural breaks, as well as break points, in the data. The energy-growth relationship is subject to one structural break, with a break point in 2009(I). This implies two sub-periods over which the relationship can exhibit different patterns: 1973(I)–2009 (I); and 2009(II)–2015(II). As Table A4 shows, the energy-growth relationship is subject to structural breaks. This implies that the inferences made earlier are not valid.

Table A5. Bai-Perron tests of multiple structural changes in the relationship between the energy consumption and economic growth.[a]

Statistics						
$y_t=\{Y_t^C\}$	$z_t=\{C_t^C\}$	$q=1$	$p=0$	$h=15$	$M=5$	
UD-max	*WDmax*	$SupF_t(1)$	$SupF_t(2$	$SupF_t$	$SupF_t$	$SupF_t$
11.483***	184.802***	11.483***	11.273***	7.697***	6.922***	4.853***
$SupF_t(2$	$SupF_t(3$	$SupF_t(4$	$SupF_t(5$		BIC	LWZ
9.568	0.503	0.003	0.000		0	0

[a]y_t,z_t,q,p,h, and M denote the dependent variable, the explanatory variable allowed to change, the number of regressors, the number of corrections included in the variance-covariance matrix, the minimum number of observations in each segment, and the maximum number of breaks, respectively.

*,**,and *** denote significance at the 10%,5% and 1% levels, respectively. The critical values are taken from Bai and Perron [28], Tables 1 and 2; and from Bai and Perron [29], Tables 1 and 2.

The number of breaks (in our case, one) has been determined according to the sequential procedure of Bai and Perron [28] ,at the 1% size for the sequential test $SupF_t(\ell + 1/\ell)$.

Figure 1. US Gross Domestic Product (in logs)

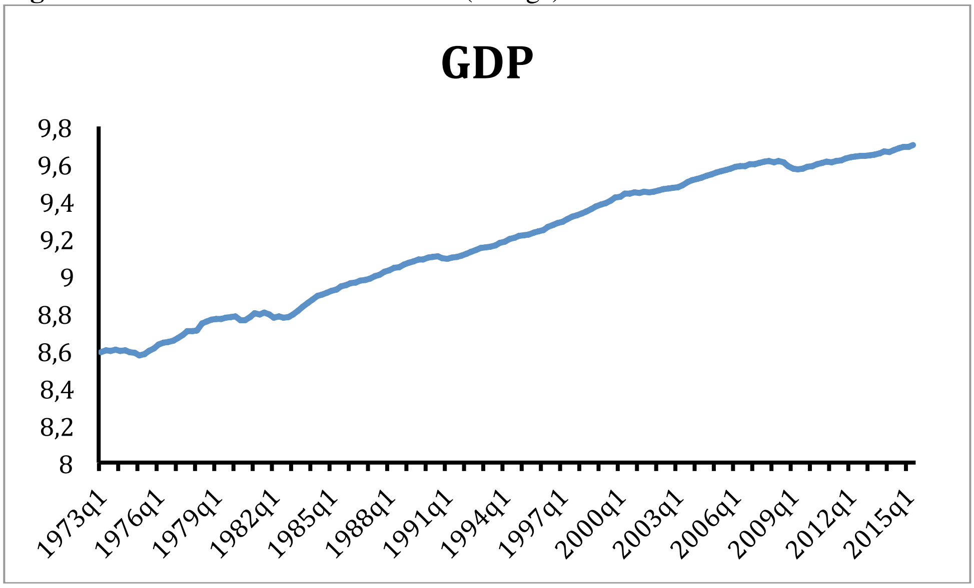


Figure 2. US Energy consumption (in logs)

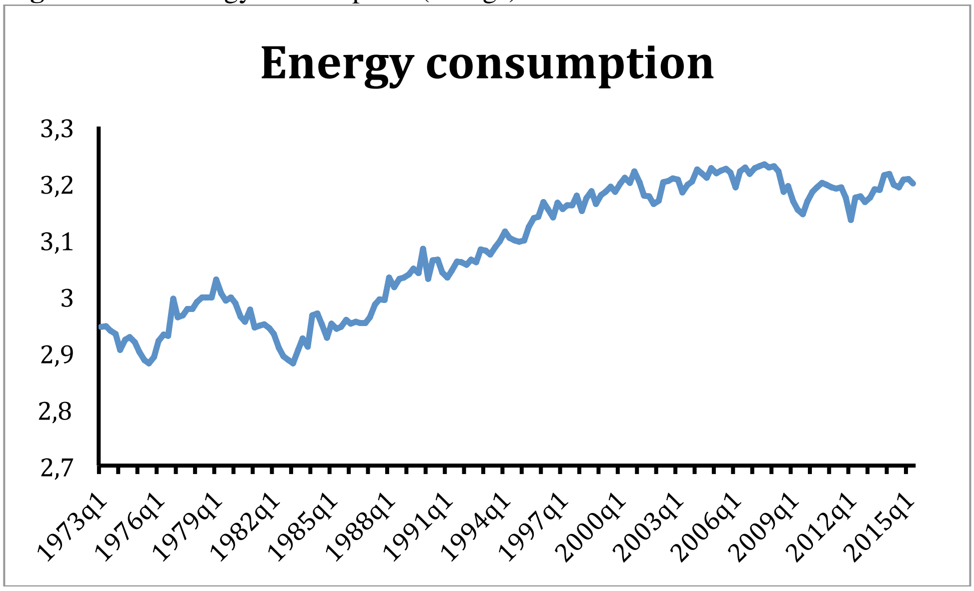


Figure 3. GDP and “Natural GDP”

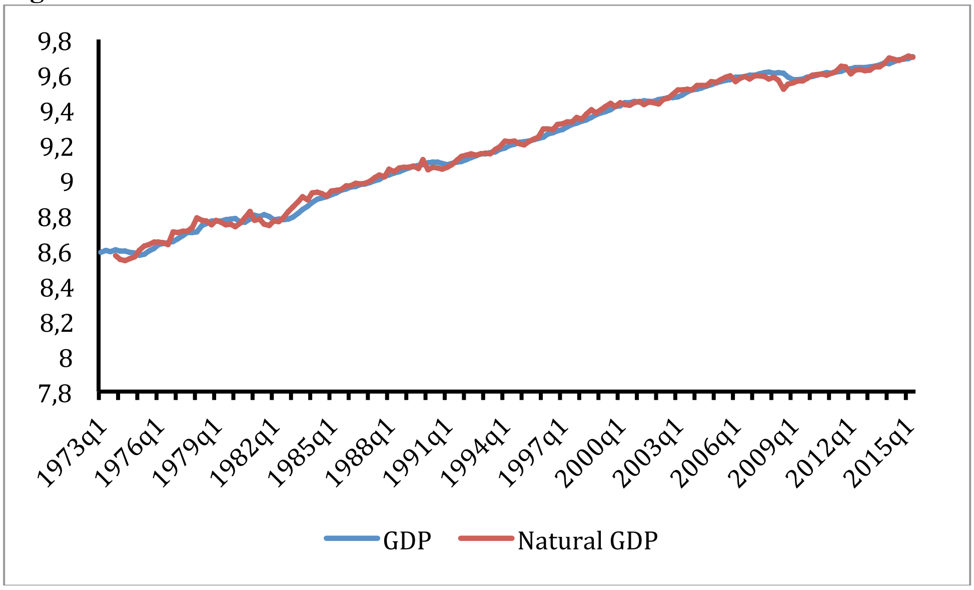


Figure 4. Energy consumption and “Natural energy consumption”

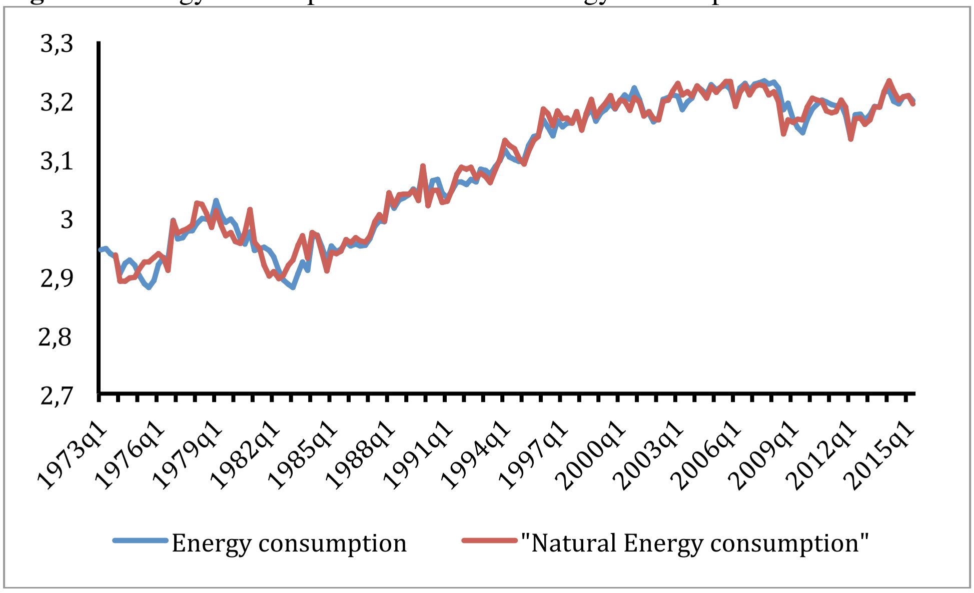


Figure 5. Cyclical GDP

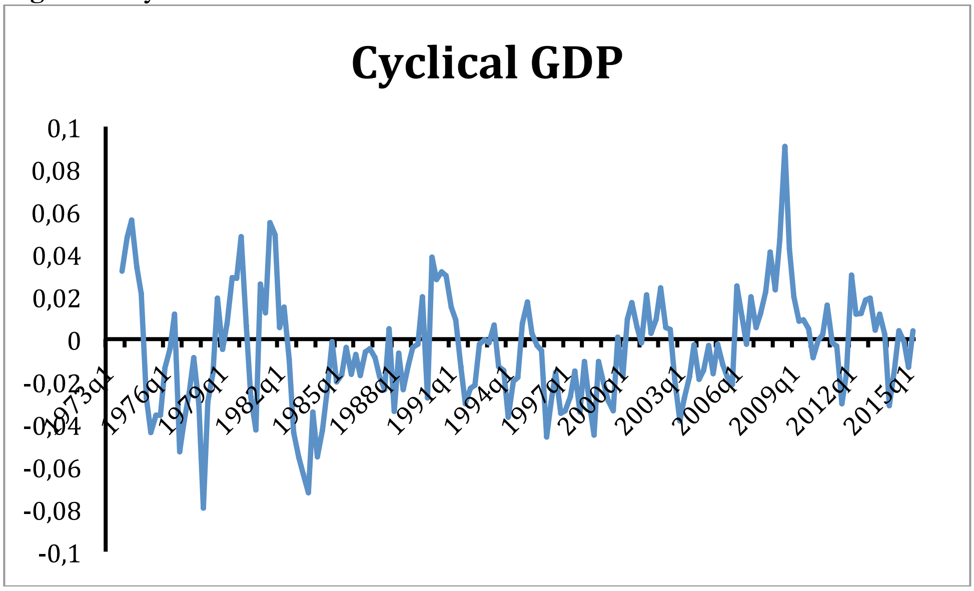
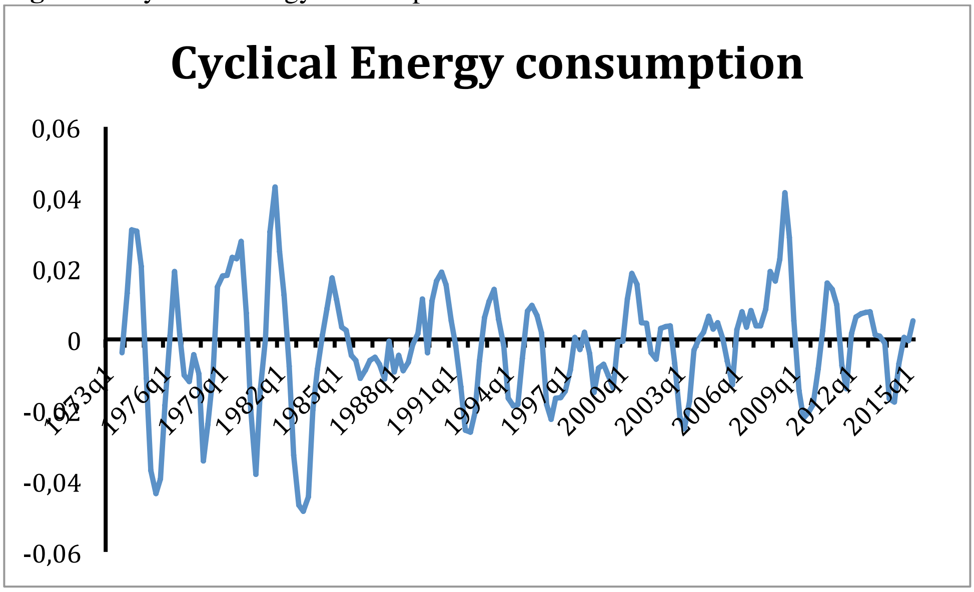


Figure 6. Cyclical Energy consumption



Chapter 4: Exploring the granger causality among primary energy sources in USA

This work analyze the reaction of income shocks in USA on primary energy consumption and the reverse impact, distinguishing by total fossil -coal, natural gas and petroleum- nuclear, and renewable –Hydroelectric, geotermal and biomass for the period 1973:1 to 2015:2. To this end, we apply the nature of Granger causality trough the Toda and Yamamoto (1995) and Hatemi-J. (2012) approaches for a Granger causality analysis from a time series perspective in order to evaluate the existence of assymetries on this bidirectional relationaship. Empirical results suggest that the impact of GDP on primary energy consumption is heterogeneous and energy source-specific and an asymetric behaviour appear among cycles. Moreover, it seems clear that the conservation hypothesis is very clear to all, overall fossil and coal. The relationship established by the feedback hypothesis is not supported by our empirical findings and the neutrallity hypothesis is confirmed for renewables. In sum, recessions stop using coal, while in expansions the most demanding energy are natural gas, nuclear and geothermal.

4.1 Introduction

Meeting the essential energy needs economically and sustainably requires a balanced energy portfolio that is suited to the economic, social, and resource conditions of individual countries and regions (Flavin and Aeck, 2005). Furthermore, the International Energy Agency (IEA, 2009) alert that current trends in energy supply and use are still economically, environmentally and socially unsustainable. In this context, renewable energy sources such as wind, solar, hydro, geo-thermal, and bioenergy have have partially replaced the fossil- fuels and nuclear power them in four distinct markets: power generation, thermal applications, transport fuels energy and non-networked services in rural areas in developing countries. Overall, investment in renewable energy has grown exponentially in recent years - in 2004 was 22,000 million dollars to 211,000 in 2010, while the involvement of the States in promoting the use of alternative energy sources has also been evident - 118 countries had some kinds of policies to support renewable energy, well above the 55 countries that had in 2005 (See REN21, 2011). In 2012, 18% of world total primary energy consumption correspond to the USA. In this country, Petroleum is the main source of energy while the prevalence of fossil fuels in the U.S. energy mix. Nevertheless renewable energies have experienced a remarkable popularity in recent years, when the use of renewable energy increased from about 16.8 million metric tons of oil equivalent in 2001 to nearly 60 million metric tons of oil equivalent in 2013, 13 percent of the nation’s total electricity generation derived from biomass, hydro and wind sources.

Comprehending the actual direction of causality between energy consumption and economic growth has substantial implications for policymakers as well as for the natural environments at least for reduce the consumption of non-renewable energies and consequently the use of contributing to the enviroment trough reduce the carbon dioxide (CO2) emissions (Aslan et al. 2014). A unidirectional causal relationship from energy consumption to growth reflects an unsustainable energy security situation even with high energy resources present in one country (Menegaki, 2013), while from an optimistic point of view, the continuous technological advance and the possibility of substitution of natural inputs with man-made capital sostaine the growth trends (Solow, 1997, or Baumol, 1986). However, attending on the empirical researches, academics they are far from establishing a clear consensus about the direction of causality either.

Although there are a lots of works that investigated the relation between energy consumption and economic growth, there are fewer who have paid attention to this relationship breaking down the different energy sources. To shed more light on this relationship, in this paper we carry out the reaction to income shocks in USA on primary energy consumption and reverse applying a Granger causalyty approach. Indeed, from a novel approach in previous literature, we investigate the posible existence of assymetries on the bidirectional relationaship distinguishing by total fossil -coal, natural gas and petroleum- nuclear, and renewable– hydroelectric, geotermal and biomass. For that, we analyse a sample of these energy sources for USA during the period 1973:Q1 to 2015:Q2, using the real gdp as the economic gwowth indicator. Our econometric strategy consist in a set of techniques developed by Toda and Yamamoto (1995) and Hatemi-J. (2012) for a Granger causality analysis in a time series perspective. Our results support heterogeneus evidence on the impact of GDP on primary energy consumption and an asymetric behaviour appear among cycles.

The remainder of this paper is organised following the next escheme. In Section 2 ilustrate a theoretical and empirical background on energy consumption and growth. Section 3 provides the data and methods description used in the empirical analysis. Section 4 outlined the main results, and section 5 comprises the main conclusions and some usefull recomendations for policy makers.

4.2. The relationship between energy and GDP growth

Since the seminal work of Kraft and Kraft (1978) where the relationship between energy consumption and GDP growth was established for the U.S.A. with causality running from income to energy, many literature concerning on this relationship has sought to know the causality direction. Nonetheless, a commom alternative is studied it in an supply side, in a production function approach, and the demand side perspective that investigates the relationship between energy consumption, economic growth and energy prices. Nonetheless, as it is well known, this emerging literature can be divided into three strands depending on the focus of research into the the environmental pollutants and GDP growth which end up testing the validity of the Environmental Kuznet's Curve (EKC) hypothesis, the causality running from income to energy, and a combined approach, perhaps the less studied (Menegaki, 2013).

In order to stablish a comprehensive framework on the energy consumption and growth relationship, following the main surveys founded in the literature, perhaps these are the works of Ozturk (2010), Payne (2010) or recently Omri (2014), several hypothesis have been developed on this regard, summarizing the causal relationship in four ways. Firstly, Growth hypothesis sostaine by the idea that energy consumption causes

GDP growth. The “growth hypothesis” suggests that the availability of abundant cheap energy sources promotes economic growth. In that sense, while increases in energy consumption may contribute to further economic growth, reductions in energy consumption may have negative effects on growth. Secondly, the Conservation hypothesis recognise the unidirectional causality from GDP growth to energy consumption and consequently any conservation policies concerning energy consumption will have little or no adverse effect on economic growth. Thisltly, the Feedback hypothesis determines a bi-directional causality flows between GDP and energy consumption. Finally, the Neutrality hypothesis or no causality indicates that energy consumption is not correlated with GDP growth and consequently that energy scarcity and conservative policies in relation to energy use do not affect economic growth.

Great part of the extant researh have been summarized recently by Omri (2014), revealing a great ambiguity in the previous literature. In that sense, he shows for an review of 48 articles that for energy consumption-growth nexus the 29% sostaine the growth hypothesis, 27% the feedback hypothesis, 23% the conservation hypothesis, and 21% the neutrality hypothesis. Previously, Payne (2010) provided similar results in his survey, concluding for an analysis including 101 studies over the period 1978 to 2008 no clear consensus, so 23.1% showed unidirectional causality from energy consumption to GDP growth, 19.5% found causality from GDP growth to energy consumption, 28.2% show a bidirectional relationship, and 29.2% show no relationship.

Despite all these hypothesis may be equally valid, it is only posible to discriminate between them empirically, unfortunatelly the empirical findings do not provide conclusive results. There are various reasons to sostaine the lack of consensus in the literature. Great part of the extant research have been done for developed countries, due the availability of data are avalaible only in these countries. Among the factors at play on this controversy about the link between growth and energy consumption, we can found in the literature some potential sources such us the sample periods, model specifications, different consumption patterns, omitted variable bias, trade agreements among countries, structural frameworks and the policies followed by countries, the varying impacts from different sources of energy, their energy imports and exports profile, the different development stages and processes in each country or the cross-section dependence between countries which is usually overseen and this leads to biased results (see Kalimeris et al., 2014, or Payne, 2010, Ozturk, 2010 or Omri, 2014, for a surveys).1 In that sense, Menegaki (2014) support that the long

[1] Payne (2010) summarize four primary econometric approaches to analyze the causal

run elasticity of GDP growth with respect to energy consumption is not independent of the method employed for cointegration, the data type and the inclusion of variables such as the price level or capital in the cointegration equation. Hence, he propose that 1% increase in capital, increases the elasticity of GDP with respect to energy consumption by 0.85%. On the other hand, the recent meta-analysis proposed by Kalimeris et al. (2014) neither support the existence of a fundamental "macro" direction, nor the so-called neutrality hypothesis in the causal relationship between energy consumption and economic growth.

Nonetheless, another factor that arise in the mentioned empirical controversy is the kind of energy that is included in the analysis that address the correlation between energy consumption and growth. While most studies have used electricity as a source of energy consumption has appeared in recent years a growing interest in knowing the relationship between the different sources of energy and economic growth, i.e. the fossil fuels, nuclear energy and renewable energy. Attending on the recent sur-

relationship: Granger–Sims causality testing, Engle–Granger/Johanssen–Juselius cointegration and error-correction modeling, Toda–Yamamoto long-run causality testing, and panel cointegration error correction modeling. For its part, Belke et al. (2011) summarize the main econometric aproaches used in the literature in the vector autoregression method (VAR) with the assumption of stationarity of the underlying variables, Eagle and Granger procedure which also contemplates for non-stationarity, Johansen's multivariate approach which includes more variables in the cointegration relationship and the panel estimation techniques.

vey of Omri (2014), we can observe the empirical evidence supporting each type of hypothesis by several energy sources. On this regard for the electricity consumption-growth nexus: 40% sostained the growth hypothesis, 33% the feedback hypothesis, and 27% conservation hypothesis; (iii) for the nuclear consumption-growth nexus: 60% supported the neutrality hypothesis, and 40% the growth hypothesis; and (iv) for the renewable consumption-growth nexus: 40% supported the neutrality hypothesis, 40% the conservation hypothesis, and 20% the growth hypothesis. For its part, Ohlen and Fetters (2014) contribute with the empirical researches concerning on differents energy sources across 20 OECD countries over 1990 to 2008, showing four set of results from a commonly used panel error correction model. A bidirectional relationship between aggregate renewable generation and real GDP exist, while biomass, hydroelectricity, waste, and wind energy exhibit a positive long-run relationship with GDP. On the other hand, hydroelectricity and waste generation exhibit a short-run positive bidirectional relationship with GDP growth, and finally biomass, hydroelectric, and waste electricity generation have the largest impact on real GDP in the long-run. They also analyse the existence of structural breaks and cross-sectional dependence and find that in the short-run, increases in biomass and waste generation negatively affect GDP, while aggregate renewable and hydroelectricity increase GDP.

In order to explore the causal relationaship between energy consumption and growth, it is important distinguish between energy sources. Such us Ohler and Fetters (2014) argue biomass and waste generation are important drivers in the renewable energy–GDP relationship, but the environmental impacts between sources vary.2 The next subsection is devoted to explain the relationship stablished between growth and each specific source of energy, total fossil- coal, natural and petroleum-, nuclear and renewable energies-Hydroelectric, geo-thermal and bio-mass-. To explore the mentioned puzzle about the causal relationship and the direction, we provide in table 1 a summary of selected papers after the exhaustive survey of Omri (2014), in which we can observe this mixed results supported in the recent literature too, classified by author, country, period, energy source and its measure, data source, methodology, the Main result and Confirmed hypothesis.

Empirical evidence in US

The novel paper analizying the causal relationship among energy consumption and growth in USA were Kraft & Kraft (2012), were they found GDP cause Energy Consumption. Later, and Stern (1993) support

[2] Omri et al. (2015) provides an extense Summary of empirical studies on the causality between nuclear and renewable energy consumption and growth (see table 1).

this result and reveal that the opossite causality also appear. At the moment, the evidence is still mixed in the US. The causes of this lack of consensus can be found in the arguments above. Among the results that emerge in literature, is more common analysis of the causal link between growth and energy consumption without discriminating power source. Perhaps the main attention in recent years is focusing on the distinction of renewable and non renewables energies. In fact, Sari et al. (2008) analyzed the two-way causality between renewable energy consumption and industrial in the USA over the period of 1969-2009, and they supported the conservation hypothesis. Payne (2009) also investigate the relationship between renewable and non-renewable energy consumption and economic growth for the period of 1949–2006, and the results supported the neutrality hypothesis.

In order to a better understanding of the behavior of the use of energy sources and their role in the growth, the empirical evidence available in the case of the US has produced some interesting results. Kum et al. (2012) found evidence of bidirectional Granger-causality between natural gas and growth. For its part Payne (2011a) found evidence of unidirectional Granger-causality running from biomass energy consumption to real GDP and hence provided support of the growth hypothesis. In other work of Payne (2011b) analizyng the case of coal consumption neglect the Granger-causality between coal consumption and real GDP, however he sostaine a positive unidirectional Granger-causality running from real GDP to natural gas consumption and positive unidirectional Granger-causality running from petroleum consumption to real GDP.

Attending on the USA renewable energies evidence, the Conservation Hypothesis has been supported by Sari et al. (2008) or Menyah and Wolde-Rufael (2010) who sostaine unidirectional causality from growth to renewable energy. Other contributions have appeared in favor of the Growth Hypothesis, for instance Payne (2011b) and Bowden and Payne (2010). Finally also appear evidence in line of the Neutrality Hypothesis in the case of renewable energies in the work of Payne (2009) . Particularly, the biomass energy has been investigated in Payne (2011a) trough the causal relationship between biomass energy consumption and real GDP, where the empirical findings revealed the growth hypothesis.

Table 1

Selected papers on the energy consumption and growth hypothesis after 2014

Study	Country or countries	Period	Energy source and measure*	Data source or data sources	Methodology	Main result: Confirmed hypothesis
Apergis & Daniletiu (2014)	80 countries	1990 - 2012	Renewable energy: enewable energy consumption (RE) -million of kilowatt hours; stock of capital (K) -real gross fixed capital formation in billions of constant 2000 U.S. dollars, and labor (L) in total labor force in millions were used.	U.S. Energy Information Administration and World Bank Development Indicators (WDI)	Canning and Pedroni (2008) long-run causality test	$\leftrightarrows$ ***Feedback Hypothesis*:** Strong evidence that the interdependence between renewable energy consumption and economic growth indicates that renewable energy is important for economic growth and likewise economic growth encourages the use of more renewable energy source.
Aslan et al. (2014)	U.S.	1973q1-2012q1	Primary energy consumption (Million Kilowatt-hours)	U.S. Energy Information Administration and the Bureau of Economic Analysis of the U.S. Department of Commerce	Granger causality tests	$\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis}$. Energy consumption causes economic growth, while the reverse is not true
Wolde-Rufael (2014)	15 developing countries: Belarus, Bulgaria, Czech Republic, Latvia, Lithuania, Russian Federation;, Ukraine Albania, Macedonia, Moldova, Poland, Romania, Serbia, Slovak Republic and Slovenia.	1975–2010	Electricity consumption per capita	WDI (2013)	Panel causality approach developed by Kónya (2006)	$EC \mapsto \boldsymbol{GDP - Growth\ Hypothesis}$. Unidirectional causality running from **electricity consumption to economic growth** only in Belarus and Bulgaria; from $\boldsymbol{EC \leftarrow Growth - Conservationh\ hypothesis}$ economic growth to electricity consumption in the Czech Republic, Latvia, Lithuania and the Russian Federation; $\leftrightarrows$ ***Feedback Hypothesis***. bidirectional causality only in Ukraine while no Granger causality in any direction in Albania, Macedonia, Moldova, Poland, Romania, Serbia, Slovak Republic and Slovenia.
Yıldırım et al. (2014)	Bangladesh, Bangladesh Egypt, Indonesia, Iran, Korea Mexico, Pakistan, Philippines, Turkey (N-11 countries except for Nigeria and Vietnam)	1971-2007/10/11*see table 3	Energy use per capita (kg of oil equivalent)	WDI (2013)	Toda & Yamamoto (1995) bootstrapped AR metric causality approach	$\nLeftrightarrow$ ***Neutrality hypothesis*** Neutrality hypothesis is valid for all of the countries except for Turkey. In the case of key $\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis}$. a unidirectional causal nexus was found from energy consumption to economic growth.
***Ohler* & Fetters (2014)**	20 OECD countries: Australia, Austria, Belgium, Canada, Denmark, France, Germany, Iceland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and United States.	1990-2008	Gross electricity production (GWh). Coal (bit.) Coal (lig.) Coal Coal–biomass Biomass Biomass Biomass Biomass (wood Geothermal Natural (subbit.) (bit.) (black liquor) (landfill gas) (municipal solid) and wood gas waste)	International Energy Agency's dataset on world renewable and waste energy statistics & OECD.	Several panel cointegration tests, panel error correction models and analysis for structural breaks and cross-sectional dependence	$\leftrightarrows$ ***Feedback Hypothesis***. Bidirectional relationship between aggregate renewable generation and real GDP, (b) biomass, hydroelectricity, waste, and wind energy exhibit a positive long-run relationship with GDP, (c) hydroelectricity and waste generation exhibit a short-run positive bidirectional relationship with GDP growth, and (d) biomass, hydroelectric, and waste electricity generation have the largest impact on real GDP in the long-run.

Study	Country or countries	Period	Energy source and measure*	Data source or data sources	Methodology	Main result: Confirmed hypothesis
Bildirici & Bakirtas (2014)	Brazil, Russian, India, China, Turkey and South Africa	1980-2011	OEC (oil energy consumption), CEC (coal energy consumption), NGC (natural gas energy consumption)	BP Statistical Review of World Energy 2011, WDI and International Financial Statistics of the IMF (International Monetary Fund).	ARDL (autoregressive distributed lag bounds)	⇆**Feedback hypothesis: Bi-directional causality** between oil energy consumption and Y for all countries. The long-run causality and strong causality results between coal consumption and economic growth indicated that there is bi-directional causality for China and India. According to long-run causality results and a strong causality result, there are bi-directional causality relationships between NGC (natural gas energy consumption) and Y for Brazil, Russia and Turkey.
Tiwari (2014)	U.S.	January 1973–October 2011.	Natural Gas Consumption (Billion Cubic Feet), Primary Energy Consumption Total (Trillion Btu), Coal Consumption (Thousand Short Tons), Total Electricity End Use (Billion Kilowatt hours), Total Renewable Energy Consumption (Trillion Btu) and real GDP. (All measured in growth rates).	U.S. Energy Information Admin- istration (June 2012 Monthly Energy Review) and http://www.bea.doc.gov/.3	Asymmetric Granger-causality developed by Hatemi-J	**Asymmetric Granger-causality** (i.e., Coal Consumption (CC), Natural Gas Consumption (NG), Primary Energy Consumption (PE), and Total Renewable Energy Consumption (TRE)) and GDP (all measured in growth rates). *Positive shocks* - $\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis. EC \leftarrow\!\shortmid\ Growth - Conservationh\ hypothesis}$ **Unidirectional Granger-causality running from GDP growth rate to growth rate of CC** and from growth rate of Total Electricity End Use (EC) to GDP growth rate. ⇆ ***Feedback Hypothesis*** **Bidirectional Granger-causality** between NG and GDP, PE and GDP and TRE and GDP . *Negative shocks* – growth rates in CC and TRE do **not Granger-cause GDP growth** rate is rejected at 5% level of significance.
Sebri & Ben-Salha (2014)	China, Brazil and India	1971-2010	Renewable energy, approximated by the combustible renewables and waste, is measured in 1000 metric tons of oil equivalent; CO_2 in metric tons while trade openness is defined as the sum of imports and exports divided by the GDP.	WDI	The ARDL bounds testing approach to cointegration and vector error correction model (VECM)	⇆ ***Feedback Hypothesis.*** **Bi-directional Granger causality** exists between economic growth and renewable energy consumption, suggesting the feedback hypothesis, which can explain the role of renewable energy in stimulating economic growth in BRICS countries.
Śmiech & Papiez (2014)	25 EU countries: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Greece, Germany, Ireland, Italy, Latvia, Lithuania, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom	1993–2011	Energy consumption represented by energy use in kg of oil equivalent per capita. Real gross fixed capital formation per capita in constant 2005 U.S. dollars as a proxy of capital and labour force participation rate (% of total population aged 15–64).	WDI, 2013	Bootstrap Granger panel causality approach proposed by Kònya (2006)	⇎ ***Neutrality hypothesis***In the remaining groups the results mostly confirm the **neutrality hypothesis**.

Study	Country or countries	Period	Energy source and measure*	Data source or data sources	Methodology	Main result: Confirmed hypothesis
Ucan et al. (2014)	EU 15	1990-2011	Non-renewable energy consumption constitutes from total petroleum products, natural gas and solid fuels. Renewable energy refers to biomass, hydropower, geothermal energy, wind and solar energy. Both renewable and non-renewable energy consumption are all expressed in 1000 tones of oil equivalent.	EUROSTAT and OECD	Pedroni Panel Cointegration test, the fully modified OLS (FMOLS) technique, panel vector error correction model (Pesaran et al., 1999) and VECM Granger Causality Test.	$\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis. EC \leftrightarrow Growth - Conservationh\ hypothesis}$ Increase in renewable energy consumption leads an increas in real GDP. Non-renewable energy consumption has a negative impact on real GDP, in other words an increase in non-renewable energy consumption decreases real GDP. Uni-directional causality from non-renewable energy consumption to economic growth.
Ozturk & Bilgili (2015)	51 Sub-Sahara African countries	1980–2009	Biomass consumption [used extraction of Biomass in kt].	Penn World Table, version 8.0 and Global Material Flow Database	Autoregressive (AR) and individual AR processes, considers panel common AR and individual AR cointegration analyses and employs panel Dynamic Ordinary Least Squares (DOLS)	$\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis.}$ **Growth hypothesis**: Significant **effect of biomass consumption on GDP** in 51 Africa countries.
Bilgili & Ozturk (2015)	G7 countries: Canada, France, Germany, Italy, Japan, the UK and the USA	1980–2010	(iv) biomass consumption [used extraction of Biomass].	Penn World Table and from Global Material Flow Database	Uçnit root analyses, panel cointegration analyses, conventional OLS and dynamic OLS analyses	$\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis. E}$ The results confirmed the **growth hypothesis** in which biomass energy consumption have positive effects on economic growth of G7 countries.
Bloch et al. (2015)	China	1977 to 2013(supply-side) and 1965 to 2011 (demand-side)	*Supply-side analysis* are output, labor, capital, coal consumption, oil consumption, renewable energy consumption and combined energy consumption. *Demand-side analysis* the variables are income, coal consumption, oil consumption, renewable energy, com- bined energy consumption, coal price, crude oil price, combined coal and oil price index and carbon emissions.	WDI of July 2013, LABORSTA Labor Statistics Database, Labor Organization (ILO) and Statistical Review of World Energy, 2014 published by British Petroleum (BP)	Autoregressive distributed lag (ARDL) and vector error correction modeling (VECM)	$\boldsymbol{EC \leftrightarrow Growth - Conservationh\ hypothesis}$ **Conservation Hypothesis**: Chinese growth is led by all three energy sources. **Economic growth also causes coal, oil and renewables consumption**,

Study	Country or countries	Period	Energy source and measure*	Data source or data sources	Methodology	Main result: Confirmed hypothesis
Omri et al. (2015)	Argentina, Belgium, Brazil, Bulgaria, Canada, Finland, France, Hungary, India, Japan, Netherlands, Pakistan, Spain, Swe- den, Switzerland, the United Kingdom, and the United States.	1990-2011	Nuclear energy consumption (terms of Terawatt-hours), renewable energy consumption (combustible renewables and waste % of total energy defined in thousands of metric tons), gross fixed capital,formation (in billion of constant 2005 US $), total labor force (million), CO2 emissions (million tonnes carbon dioxide), real oil price (the spot price on West Texas Intermediate) crude oil, and oil consumption (in thousand barrels daily).	British Petroleum Statistical Review of World Energy and the WDI	Two- stage least squares (2SLS), three stage least squares (3SLS), and the generalized method of moments (GMM)	$\boldsymbol{\nLeftrightarrow Neutrality\ hypothesis \leftrightarrows Feedback\ Hypothesis. EC \mapsto GDP - Growth\ Hypothesis. EC \hookleftarrow Growth - Conservationh\ hypothesis}$ **Unidirectional causality** running **from nuclear consumption to economic growth** in Belgium and Spain, while a unidirectional causality running from economic growth to nuclear consumption is supported in Bulgaria, Canada, Netherlands, and Sweden. **A bidirectional relationship** appears in Argentina, Brazil, France, Pakistan, and the USA, while no causality exists in Finland, Hungary, India, Japan, Switzerland, and the U.K. Also a **unidirectional causality** running **from renewable consumption to economic growth** in Hungary, India, Japan, Netherlands, and Sweden, while there exist a **unidirectional** running from **economic growth to renewable consumption** in Argentina, Spain, and Switzerland. **A bidirectional relationship** is supported in Belgium, Bulgaria, Canada, France, Pakistan, and the USA, while no causality exists in Brazil, Finland, and Switzerland. Third, we find the existence of a **bidirectional causality between nuclear consumption and economic**; and **a unidirectional causality running from economic growth to renewable energy consumption** for the global panel.
Iyke (2015)	Nigeria	1971–2011	Electricity power consumption per capita (kWh per capita)	WDI, 2014	Phillips–Perron (PP) test, and the Dickey–Fuller generalised least squares (DF-GLS) test KSS test, and the Zivot–Andrews test.	$\boldsymbol{EC \mapsto GDP - Growth\ Hypothesis}$ Distinct causal flow from electricity consumption to economic growth: both in the short run and in the long run. This finding supports the **electricity-led growth hypothesis** that has been conjectured in the literature.

* In all the papers summarized the real GDP is used as the measures of growth. $\nLeftrightarrow Neutrality\ hypothesis \leftrightarrows Feedback\ Hypothesis. EC \mapsto GDP - Growth\ Hypothesis. EC \hookleftarrow Growth - Conservationh\ hypothesis$

4.3. Data and Methodology

4.3.1 Data

In this paper we analyze the nature of the relationship between the GDP and primary energy consumption by source for USA. The data used are quarterly observations from 1973:1 to 2015:2. The primary energy consumption -measured in quadrilium British Thermal Units (BTu)- is disaggregated by source, Total, total fossil fuels, total renewable, Coal, Natural gas, petroleum, nuclear, renewable, hydroelectric, geotermal, and biomass are extracted from the US Energy Infomration Administration (EIA). The GDP data is taken from the US Bureau of Economic Analysis (BEA) an measured in billions of chained 2009 dollars. Before conducting the empirical analysis data were seasonally adjusted and converted to natural logarithms. Time plots of the series are showed in the appendix 1.

4.3.2. Methodology

The aim of our empirical strategy is to determinate the possible existence of Granger causality relationships between GDP and energy consumption, using a set of econometric techniques in order to obtain more robust and comparable results. On the one hand, we analyze the Granger causality tests applying the method proposed by Toda and Yamamoto (1995) and, secondly, the methodolgy proposed by Hatemi-J (2012) as an extenssion of Toda and Yamamoto (1995) which allow to analyse the asymetric causality energy consumption by source and does not require us to test previously the existence of unit root or cointegration, that is, the variables in the system do not need to be stationary and can be used in level form.

4.3.2.1. Granger causality, by energy source: Toda-Yamamoto test.

In energy economics, perhaps the most common techniques of examining the causality effects between variables is using Granger causality method based on the estimation of VAR models and more specifically in energy topics. The methodology proposed by Toda and Yamamoto (1995) tries to measure causality in order to solve the problems stemming from cointegration relationship and non-stationarity of the data series. Furthermore, an asymmetric structure in the study of causality suggested by Granger and Yoon (2002) is considered and extended by Hatemi-J (2012) in order to analyze the effects on causality relationships.

For a wide study about our relationship proposed, we propose the Toda-Yamamoto causality approach as an developed version of the Granger causality test based on augmented-VAR models in levels and extra lags which is a more efficient and robust results than the standard VAR model due to it can lead to biased results, in particular, with finite samples

–see, Johansen and Juselius, (1990); Zapata and Rambaldi (1997), Maddala and Kim (1998); Pesaran et al., (2001) and Clarke and Mirza (2006)–. The main advantage of the Toda-Yamamoto test is that it can be applied irrespective of the order of integration or whether the time series are or not cointegrated (Booth and Ciner, 2005). In our exercise, a bivariate model including the GDP and energy consumption by source variables under analysis, we can describe the benchmark model for this test as follow:

$$\mathrm{GDP_t} = \alpha_1 + \sum_{i=1}^{h+d_{max}} \beta_{1i}\,\mathrm{GDP_{t-i}} + \sum_{j=1}^{l+d_{max}} \gamma_{1j}\,\mathrm{Energy_{t-j}} + \varepsilon_{1t}$$

$$\mathrm{Energy_t} = \alpha_2 + \sum_{i=1}^{h+d_{max}} \beta_{2i}\,\mathrm{Energy_{t-i}} + \sum_{j=1}^{l+d_{max}} \gamma_{2j}\,\mathrm{GDP_{t-j}} + \varepsilon_{2t}$$

Where h and l –in general, p – are the optimal lag structure for the VAR model, according to the Akaike Information Criterion (AIC); k is defined as the sum of $(p + d_{max})$, where d_{max} –extra lagged explanatory variables– is the maximum order of integration for the variables considered in the model; ε_{1t} and ε_{2t}, the residual terms, are Gaussian Distributed and follow white noise processes. Hence, this test estimates a VAR (k) model using a Modified Wald test (MWALD) which statistic is asymptotic distributed as a chi-squared with p degrees of freedom.

For testing the Granger causality between these two variables note, for the first equation, that if $\sum_{j=1}^{l} \gamma_{1j} \neq 0$ implies that Energy_t Granger causes GDP_t. Analagously, the second equation, if $\sum_{j=1}^{l} \gamma_{2j} \neq 0$ represent that GDP Granger causes Energy_t. Consequently, rejecting both hypothesis implies that there exists bi-directional causality in the analysed relationship.

4.3.2.2. Looking for asymmetric causality relationships.

Attending on the empirical works, appear in many cases that causality is rejected because no nonlinear relationships are contemplated. For that, a nonlinear test developed by Hatemi-J (2012) on the initial ideas of Granger and Yoon (2002) is applied in our exercise, allowing us know out whether the cumulative positive and negative shocks can cause different impacts on the causal relationship between GDP and energy consumption by source. Following this strategy, we start specifying our two variables by means of a random walk model:

$$\mathrm{GDP}_t = \mathrm{GDP}_{t-1} + \varepsilon_{1t} = \mathrm{GDP}_0 + \sum_{i=1}^{t} \varepsilon_{1i}$$

and

$$\mathrm{Energy}_t = \mathrm{Energy}_{t-1} + \varepsilon_{2t} = \mathrm{Energy}_0 + \sum_{i=1}^{t} \varepsilon_{2i}$$

where $t = 1, 2, \ldots T$; the constants GDP_0 and Energy_0 are the initial constant values, and the variables ε_{1i} and ε_{2i} are white noise disturbance terms. The shocks –positive and negative- are indified as: $\varepsilon_{1i}^{+} = \max\ (\varepsilon_{1i}, 0)$; $\varepsilon_{2i}^{+} = \max\ (\varepsilon_{2i}, 0)$; $\varepsilon_{1i}^{-} = \min\ (\varepsilon_{1i}, 0)$; $\varepsilon_{2i}^{-} = \min\ (\varepsilon_{2i}, 0)$ respectively. Grouping these terms as follow, $\varepsilon_{1i} = \varepsilon_{1i}^{+} + \varepsilon_{1i}^{-}$ and $\varepsilon_{2i} = \varepsilon_{2i}^{+} + \varepsilon_{2i}^{-}$, we can write out that:

$$\mathrm{GDP}_t = \mathrm{GDP}_{t-1} + \varepsilon_{1t} = \mathrm{GDP}_0 + \sum_{i=1}^{t} \varepsilon_{1i}^{+} + \sum_{i=1}^{t} \varepsilon_{1i}^{-}$$

$$\mathrm{Energy}_t = \mathrm{Energy}_{t-1} + \varepsilon_{2t} = \mathrm{Energy}_0 + \sum_{i=1}^{t} \varepsilon_{2i}^{+} + \sum_{i=1}^{t} \varepsilon_{2i}^{-}$$

Therefore, positive and negative shocks can be wrote as follow:

$\mathrm{GDP}_t^{+} = \sum_{i=1}^{t} \varepsilon_{1i}^{+}$; $\mathrm{GDP}_t^{-} = \sum_{i=1}^{t} \varepsilon_{1i}^{-}$; $\mathrm{Energy}_t^{+} = \sum_{i=1}^{t} \varepsilon_{2i}^{+}$; $\mathrm{Energy}_t^{-} = \sum_{i=1}^{t} \varepsilon_{2i}^{-}$.

Assuming that $y_t^{+} = (GDP_t^{+}, Energy_t^{+})$, $y_t^{-} = (GDP_t^{-}, Energy_t^{-})$, $y_t^{\pm} = (GDP_t^{+}, Energy_{1t}^{-})$, and $y_t^{\mp} = (GDP_t^{-}, Energy_{1t}^{+})$, the causal relationship between the variables can be tested using vector autoregressive model, VAR of order p , for lag order $r = (1, \dots, p)$. To run a Wald test, the VAR (p) model can be written in a compact form (e.g. for the first combination, y_t^{+}),

$Y = DZ + \delta$, where

$Y \coloneqq (y_1^{+}, \dots, y_T^{+})$ (n x T) matrix,

$D \coloneqq \left(\upsilon, A_1 \dots, A_p\right)$ (n x (1 + np)) matrix,

$$Z_t \coloneqq \begin{pmatrix} 1 \\ y_t^{+} \\ y^{+}{}_{t-1} \\ \vdots \\ y_{t-p+1}^{+} \end{pmatrix} \text{ ((1 + np) x 1) matrix, for } t = 1, \dots, T,$$

$Z \coloneqq (Z_0 \dots, Z_{T-1})$ ((1 + np) x T) matrix, and

$\delta \coloneqq (u_1^{+}, \dots, u_T^{+})$ (n x T) matrix

The Wald statistic is $(C\beta)'\left[C((Z'Z)^{-1} \otimes S_U)C'\right]^{-1}(C\beta)$, where $\beta = \mathrm{vec}(D)$, being $\mathrm{vec}(\cdot)$ the column-stacking operator; $\otimes$ is the Kronecker product and C is a p x $n(1 + np)$indicator matrix with elements ones for restricted parameters and zeros for the rest of the parameters; $S_U = \frac{\hat{\delta}'_U \hat{\delta}_U}{T-q}$, where q is the numbers of parameters in each equation of the VAR model. Under the assumption of normality, the Wald statistic follows an asymptotic χ^2 distribution with the same degrees of freedom than the number of restrictions to be tested (in our case, equal to p). The null hypothesis of non-Granger causality, $H_0: C\beta = 0$, is rejected at the α level of significance (1%, 5% or 10%) according to the bootstrap critical values generated by GAUSS software.

4.4. Empirical Results: Granger causality findings

In consequence with the econometric strategy previously described, in this section we present the empirical findings to the Granger causality relationships stablished between the energy consumption by source and growth allowing non-linear behavior between the variables using the methodology suggested by Toda-Yamamoto and Hatemi-J. In the next subsections the results of all these approaches are reported distinguishing by the direction of the causality, that is, depending on the hypotheses to be tested. The estimation results are presented in Tables 2-6, while table 7 show a summary of the main results.

By looking at Table 2 we can see that the GDP does not Granger-cause is rejected at the 1% level of significance for all energy variables -including total primary consumption- considered in the present work except in the case of renewables energies. In this linethe opossite causalite, i.e. from energy consumption by source to GDP, for all cases we find the null hypothesis that energy does not Granger-cause GDP is rejected only in the case of petroleum and nuclear consumption. In consequence, our findings show the evidence of the bidirectional Granger-causal relationship between energy consumption and economic growth also in the petroleum and nuclear energy sources. In adition, to explore the issue in depth we estimated asymmetric Granger-causality test statistics and tested their significance with 5,000 bootstrapped critical values.

The results from asymmetric Granger-causality analysis are showed in Table 3 to table 6 (appendix A2 plots the cumulative shocks-positive and negative- of all variables). In the possitive approach, it is important to distinguish the direction of the causality. Despite the results are similar to the previous findings, we obtain in the case of a positive relationship from energy to GDP that we only reject the null hypothesis clearly in the pretroleum case. For its part, when GDP to energy relationship is observed, our results reveal that the Geothermal energy is Granger caused by positive shock in the economy, while petroleum is non Granger causeed by GDP. Attending on Table 4 that when the Wald test statistic is used for negative shocks the null-hypothesis for non-Granger-causality is rejected at the 10% level of significance only in three cases, total primary energy consumption, total fossil and coal. From GDP to Energy, in the reverse sense, petroleum and nuclear are the cases where we can reject the null hypothesis of causaliity. In other words, when recessions appear the energy the cosumption is reduced.

Table 2. Global effects

Energy sources	$Energy \nRightarrow GDP$				$GDP \nRightarrow Energy$			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Total fossil	3.156	12.378	7.559	6.215	30,666***	11.847	8.203	6.364
Coal	0.619	10.152	6.111	4.512	17,269***	9.929	6.694	5.226
Natural Gas	1.796	11.553	7.826	6.400	10,660**	11.291	7.928	5.990
Petroleum	9,424***	9.240	6.079	4.749	10,220***	9.650	6.197	4.475
Nuclear	11,042**	16.639	10.964	9.029	16,304***	15.024	11.025	9.466
Renewable	0.788	8.503	5.912	4.554	0.071	9.491	5.708	4.272
Hydroelectric	0.857	8.181	5.623	4.398	0.188	9.219	6.113	4.567
Geothermal	0.739	10.290	6.483	4.882	3.447	9.206	6.157	4.138
Biomass	3.110	19.137	14.061	11.276	8.459	19.329	13.475	11.431
Total	4.013	11.472	7.498	6.160	29,980***	11.847	8.058	6.558

Table 3. Positive effects

Energy sources	$Energy^{+} \nRightarrow GDP^{+}$				$GDP^{+} \nRightarrow Energy^{+}$			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Total fossil	1.391	9.382	6.197	4.621	9,055*	9.648	6.530	4.612
Coal	1.758	9.305	5.895	4.709	12,335***	9.391	6.102	4.631
Natural Gas	1.290	10.206	6.309	4.734	7,501**	9.835	6.167	4.717
Petroleum	29,552***	23.172	17.258	13.826	13.010	21.262	16.171	13.416
Nuclear	10.864	18.513	13.337	10.975	22,789***	18.284	13.515	11.473
Renewable	0.268	8.928	6.231	4.687	0.000	9.787	5.931	4.853
Hydroelectric	2.307	8.887	6.065	4.604	0.198	9.681	6.179	4.873
Geothermal	2.473	10.781	6.487	4.488	14,724***	10.383	6.544	4.975
Biomass	4.438	11.581	6.132	4.824	1.270	11.065	6.275	4.821
Total	2.010	9.977	6.036	4.707	11,218***	9.927	6.444	4.521

Table 4. Negative effects

Energy sources	$Energy^{-} \nRightarrow GDP^{-}$				$GDP^{-} \nRightarrow Energy^{-}$			
	Test statistic	Bootstrap critical values			Test statistic	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Total fossil	1.523	9.653	6.308	4.799	15,806***	11.434	6.263	4.760
Coal	0.325	12.451	7.013	4.981	8,173**	11.759	6.351	4.759
Natural Gas	4.645	12.189	8.217	6.397	5.686	12.897	7.913	6.008
Petroleum	41,086***	16.614	10.190	8.060	1.227	14.414	10.289	8.389
Nuclear	27,243**	34.072	18.488	12.049	2.753	23.209	13.992	10.222
Renewable	1.576	13.077	6.514	4.599	2.130	11.992	6.771	4.777
Hydroelectric	3.882	13.356	6.643	4.787	0.007	10.862	6.220	4.786
Geothermal	1.585	14.033	6.999	4.805	1.901	14.263	7.814	4.681
Biomass	1.647	13.663	7.306	4.529	0.319	15.466	7.306	4.434
Total	1.717	10.075	6.196	4.480	11,528**	12.232	6.299	4.799

Finally, asymmetries have also been studied from the mixed causalities, that is, taking into account negative to positive effects and vice versa. In this set of results shown in Tables 5 and 6 we find that the negative shocks in oil consumption have positive shocks in the GDP, while in the opposite direction, we can highlight the positive shocks of GDP cause decreases in consumption Total fossil, coal, coal and biomass. Looking at Table 6 shows the results recognized as positive shocks in renewable energies in general and hydropower in particular cause negative shocks in the GDP. In the opposite direction, the results allow to verify that the negative shocks in GDP generated only positive shock of energy consumption in the total consumption and fossil overall.

Table 5. Mixed effects (I)

	$Energy^{-} \nRightarrow GDP^{+}$				$GDP^{+} \nRightarrow Energy^{-}$			
	Test	Bootstrap critical values			Test	Bootstrap critical values		
Energy sources	statistic	1%	5%	10%	statistic	1%	5%	10%
Total fossil	2.297	10.793	6.080	4.654	10,116**	12.684	8.138	6.248
Coal	4.115	9.870	6.372	4.793	7,748*	11.783	8.328	6.485
Natural Gas	0.744	13.595	8.386	6.299	2.154	11.672	7.970	6.314
Petroleum	8,113**	9.412	6.392	4.582	3.925	9.190	5.739	4.627
Nuclear	4.632	15.644	11.226	9.143	0.285	9.461	5.953	4.518
Renewable	0.203	10.300	6.219	4.538	0.125	8.722	5.810	4.528
Hydroelectric	0.632	10.241	6.822	5.029	1.826	8.662	5.750	4.627
Geothermal	4.244	10.952	6.459	4.794	5.942	14.722	9.797	8.366
Biomass	1.448	11.089	7.088	5.132	8,240*	14.204	9.767	7.823
Total	2.171	10.629	6.126	4.648	8,953**	12.909	7.669	6.131

Table 6. Mixed effects (II)

Energy Sources	$Energy^{+} \nRightarrow GDP^{-}$				$GDP^{-} \nRightarrow Energy^{+}$			
	Test	Bootstrap critical values			Test	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Total fossil	0.663	10.838	5.948	4.485	5,729*	11.089	6.102	4.626
Coal	0.275	11.103	6.534	4.563	5.115	15.649	8.357	6.316
Natural Gas	1.308	10.133	5.815	4.338	3.057	10.671	6.531	4.651
Petroleum	1.379	11.708	6.012	4.567	3.647	11.960	6.512	4.623
Nuclear	1.598	10.239	6.259	4.748	0.426	11.868	6.507	4.503
Renewable	5,132*	9.066	5.784	4.312	0.070	9.806	6.014	4.652
Hydroelectric	4,549*	10.060	5.886	4.505	0.717	10.624	6.158	4.652
Geothermal	1.816	12.539	6.939	4.502	0.314	11.156	6.736	4.705
Biomass	3.347	13.365	7.825	5.055	1.020	11.515	7.028	5.061
Total	0.804	10.230	5.696	4.570	7,362**	11.164	6.128	4.631

Finally, in order to better meet the set of found results, we have constructed the Table 7 where they are synthesized. Among the most relevant findings, we can note that in the case of oil do not get any asymmetric effect even though there seems to be a priori the feedback hypothesis (total score), when the asymmetries are observed the confirmed hypothesis is the growth hypothesis. Moreover, it seems clear that the conservation hypothesis is very clear to all, overall fossil and coal. The relationship established by the feedback hypothesis is not supported by our empirical findings and the neutrallity hypothesis is confirmed for renewables. In sum, recessions stop using coal, while in expansions the most demanding energy are natural gas, nuclear and geothermal.

Table 7. Summary of Results

Hypothesis	H_0: Energy $\nRightarrow$ GDP Growth	H_0: GDP $\nRightarrow$ Energy Conservation	Bidirectionality Feedback	No causality Neutrality
Toda-Yamamoto test		Total Fossil, coal, Natural gas and Total	Petroleum and Nuclear	Renewable- Hydroelectric, geotermal and biomass
Asymmetric test *1) Positive effects*	Petroleum	Total fossil, coal, natural gas, nuclear and geotermal- Total		Petroleum; Renewable, Hydroelectric and Biomass
2) Negative effects	Petroleum and Nuclear	Total fossil, coal- Total		Natural gas, petroleum, nuclear, renewable, hydroelectric, geotermal and biomass
3) Mixed effects I	Petroleum	Total fosil, coal, biomass- Total		Coal, Natural gas, petroleum, nuclear, renewable, hydroelectric and geotermal
3) Mixed effects II	Renewable and Hydroelectric	Total fossil- Total		Coal, natural gas, petroleum, nuclear, renewable, hydroelectric, geotermal and biomass

4.5. Conclusions

The interest in knowing the causal link between growth and energy consumption has focused the interest of researchers, academics and politicians because of its implications on economic development and on the environment the appropriate use of energy resources. Unfortunately, although a large number of articles have been devoted to trying to explain this relationship, most surprising is the lack of consensus in the literature on the directions of causality. This work have analyzed the reaction of income shocks in USA on primary energy consumption and the reverse impact, distinguishing by total fossil -coal, natural gas and petroleum- nuclear, and renewable –Hydroelectric, geotermal and biomass for the period 1973:1 to 2015:2. To this end, we applied the nature of Granger causality trough the Toda and Yamamoto (1995) and Hatemi-J. (2012) approaches for a Granger causality analysis from a time series perspective in order to evaluate the existence of assymetries on this bidirectional relationaship. Our empirical results suggest that the impact of GDP on primary energy consumption is heterogeneous and energy source-specific and an asymetric behaviour appear among cycles. Moreover, it seems clear that the conservation hypothesis is very clear to all, overall fossil and coal. The relationship established by the feedback hypothesis is not supported by our empirical findings and the neutrallity hypothesis is confirmed for renewables. On the other hand, a mixed behaviour is founded in the case of fossil. Moreover, it seems clear that petroleum is causing the GDP but is not sensitive to the economic cycle, that is, the accumulated GDP shocks cause no disruption in petroleum consumption. In other words, we could confirm that the US economy is still highly dependent on this energy source. In this sense coal consumption it is very sensitive to cycles and when the economic cycle is expansive-cumulative shocks- positives seems to be a positive boost to geothermal and biomass energy to negative. In sum, recessions stop using coal, while in expansions the most demanding energy are natural gas, nuclear and geothermal. However, due the existence of a diferent pattern observed by primary energy source and, even most importnatly, the effect economic cycle on the type of energy consumption in its economy. It would be advisable for policy makers to have this on their agenda not only the high dependence for growth in oil consumption, but also the time when policy measures are taken to establish a suitable framework for a balance between energy sources renewable and nonrenewable.

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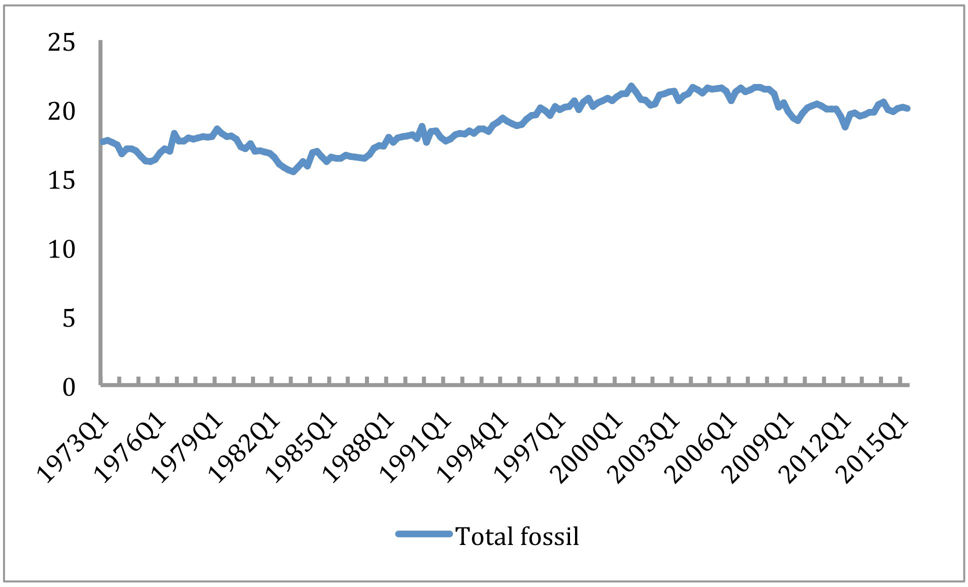
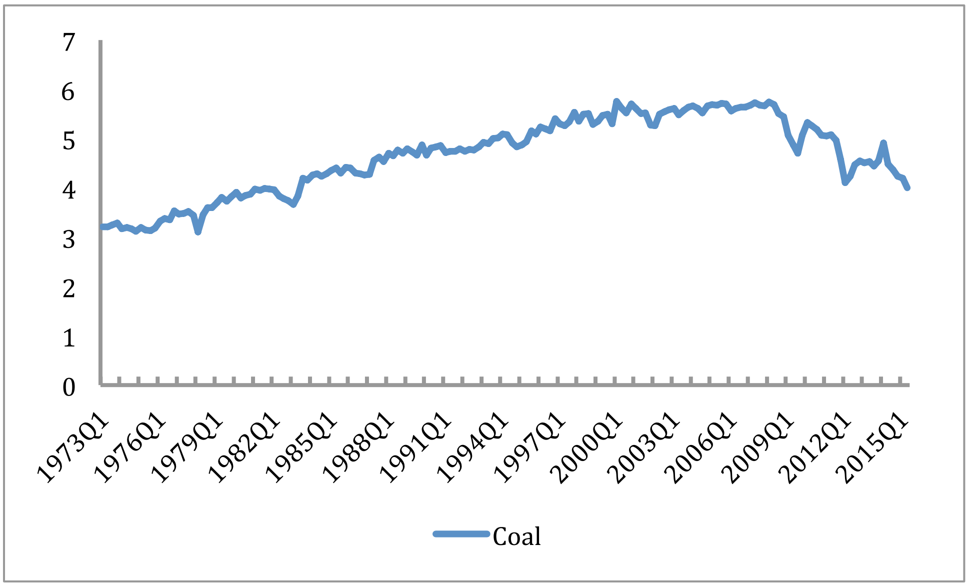
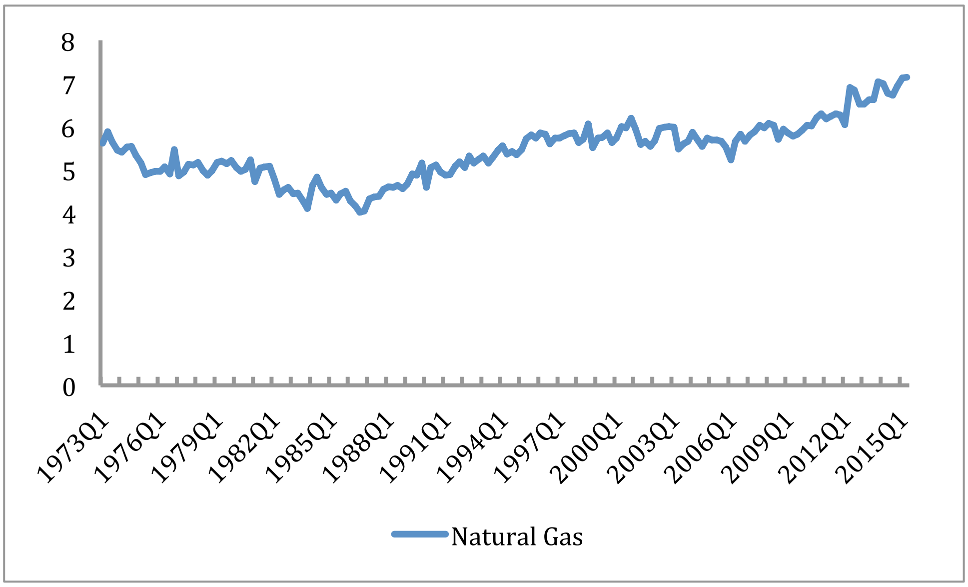
APPENDIX

A1. Time plots of the variables



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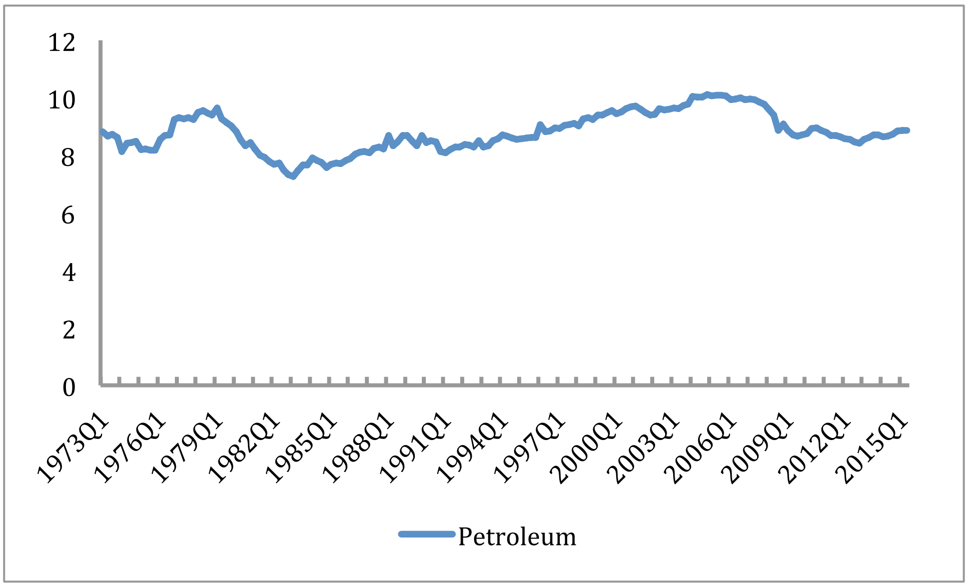
2015Q1
Natural Gas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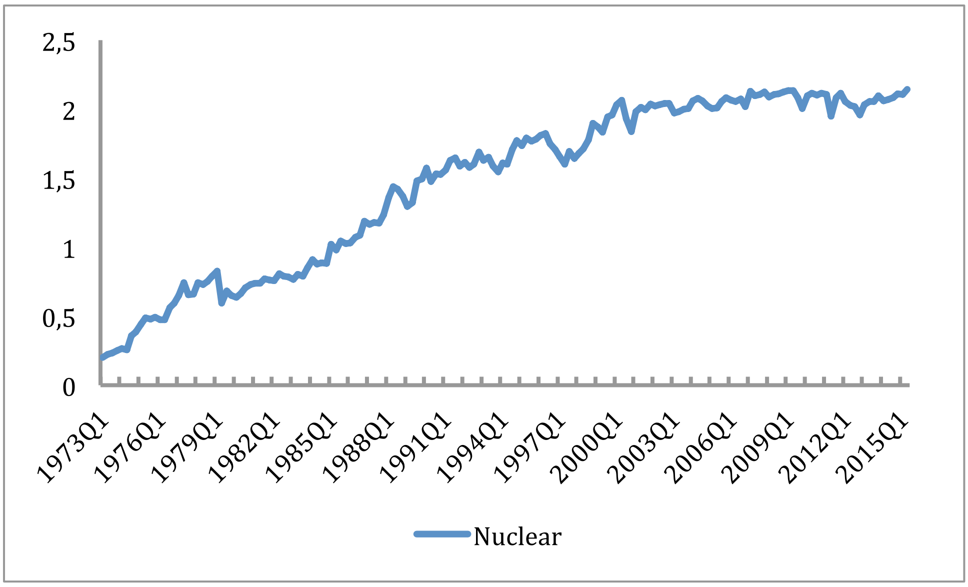
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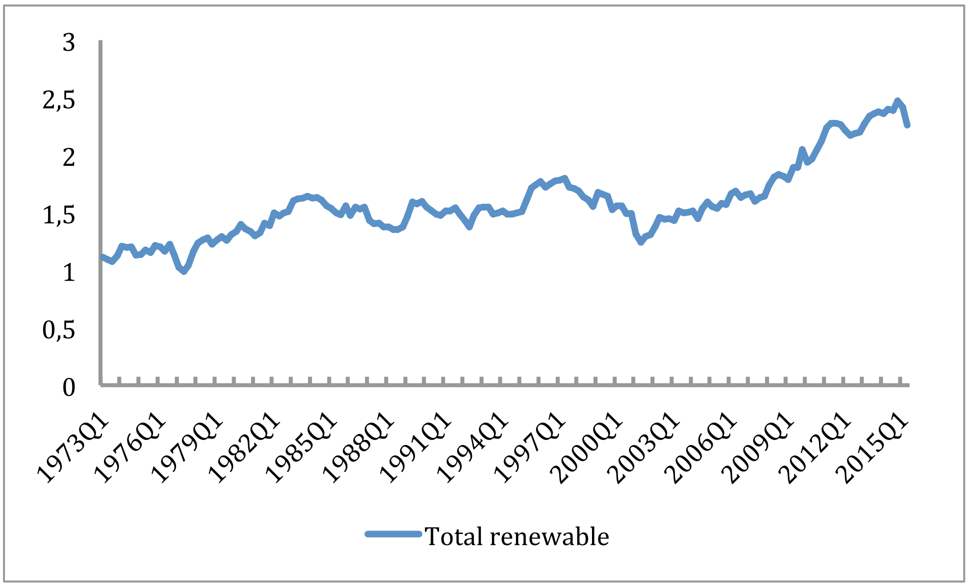
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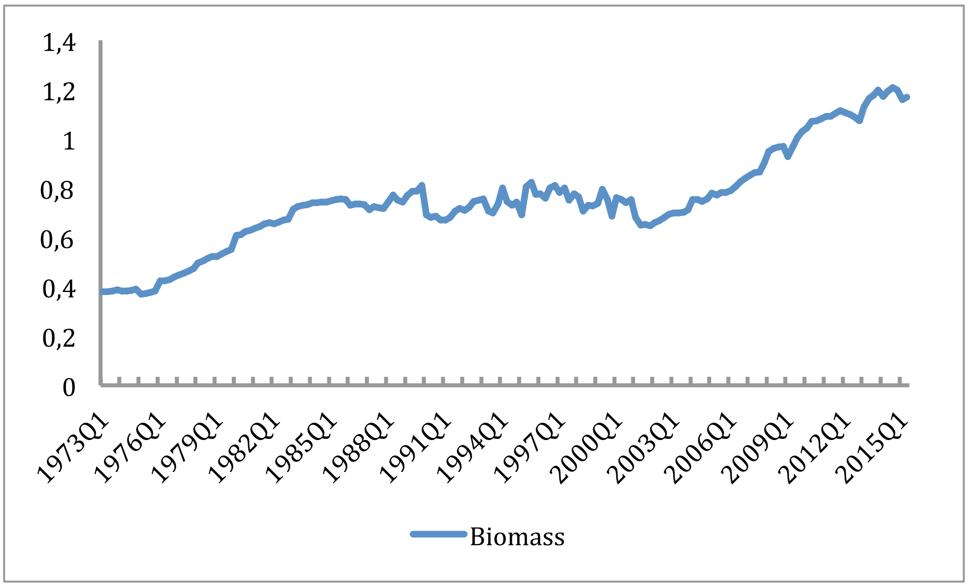
2015Q1
Total renewable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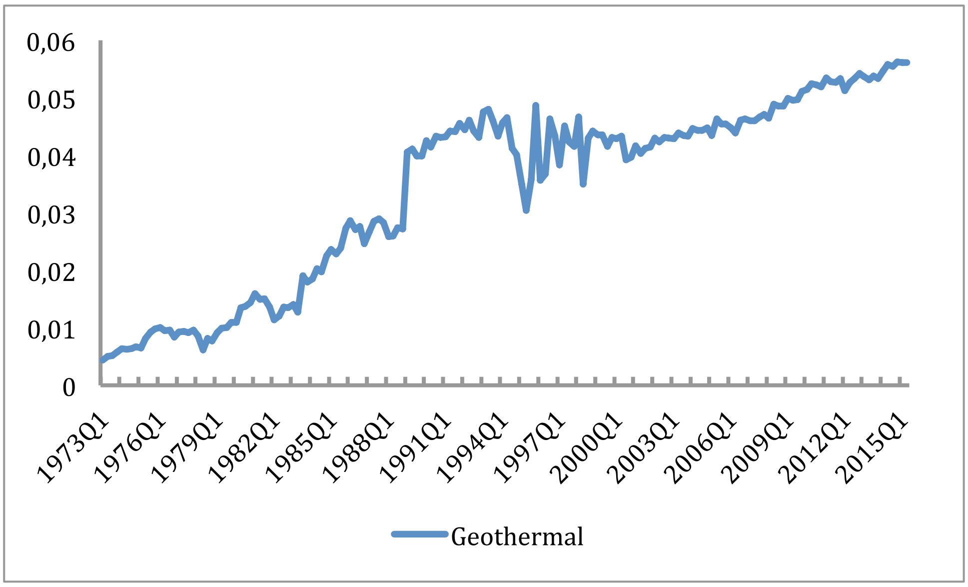
Biomass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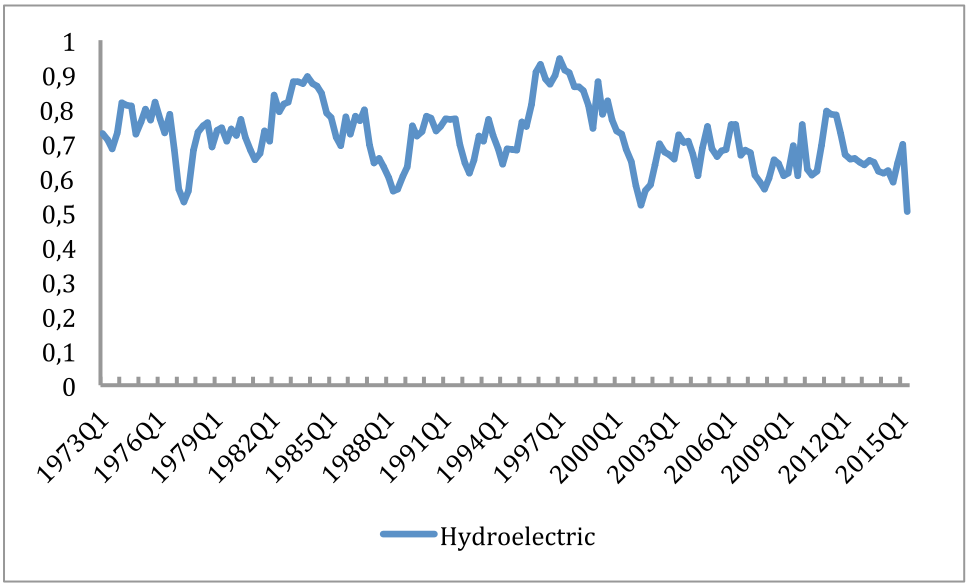
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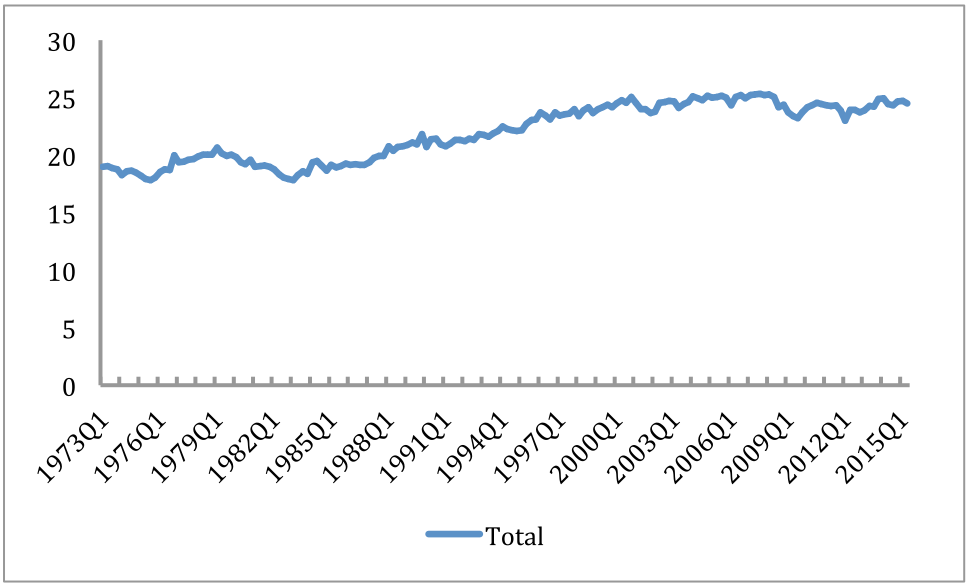
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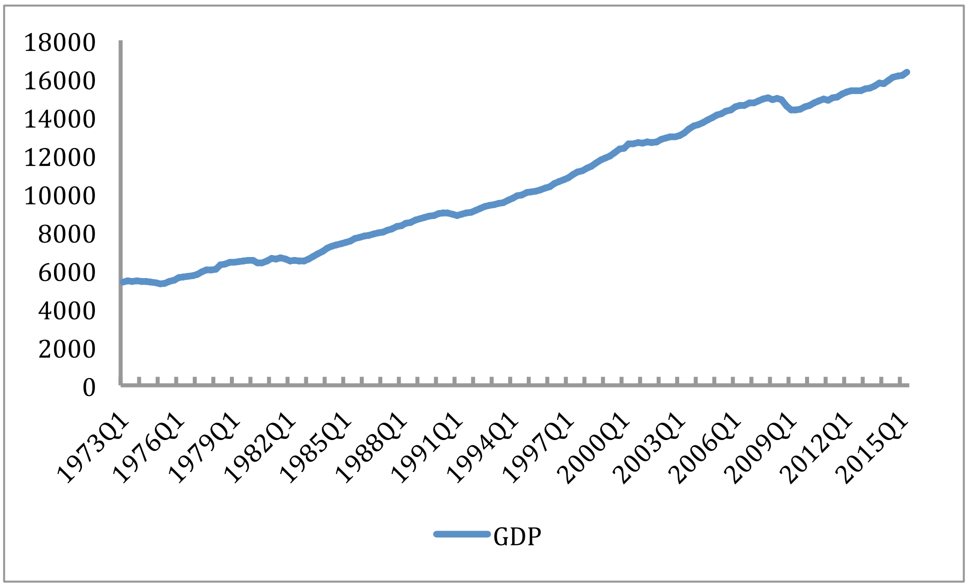
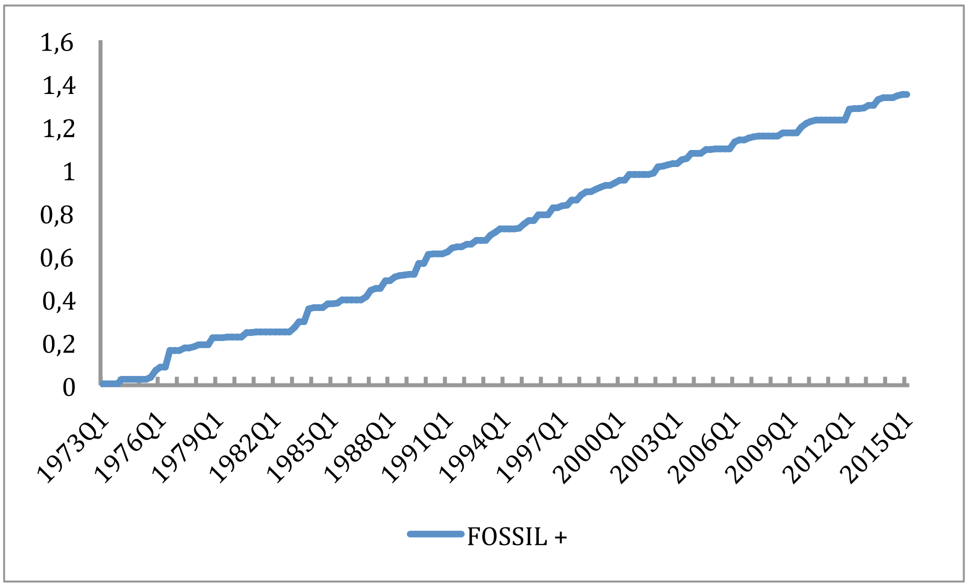
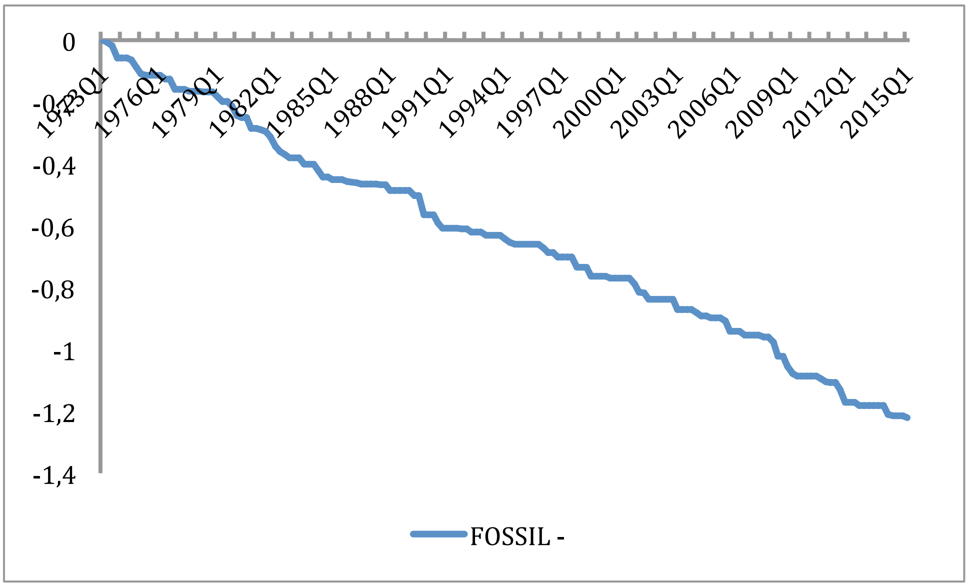
2012Q1
2015Q1
Total



A2. Time plots of cumulative shocks (positive and negative)

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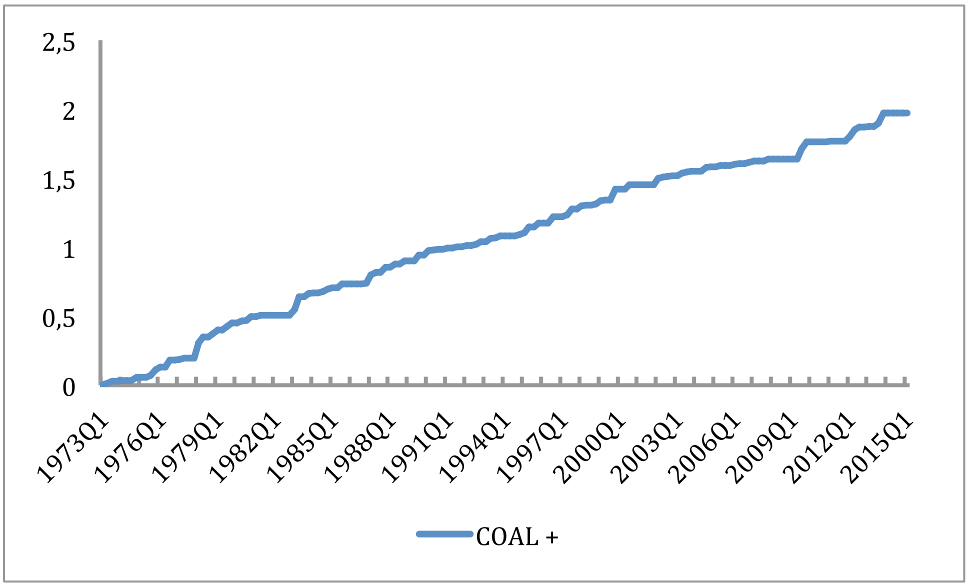
FOSSIL -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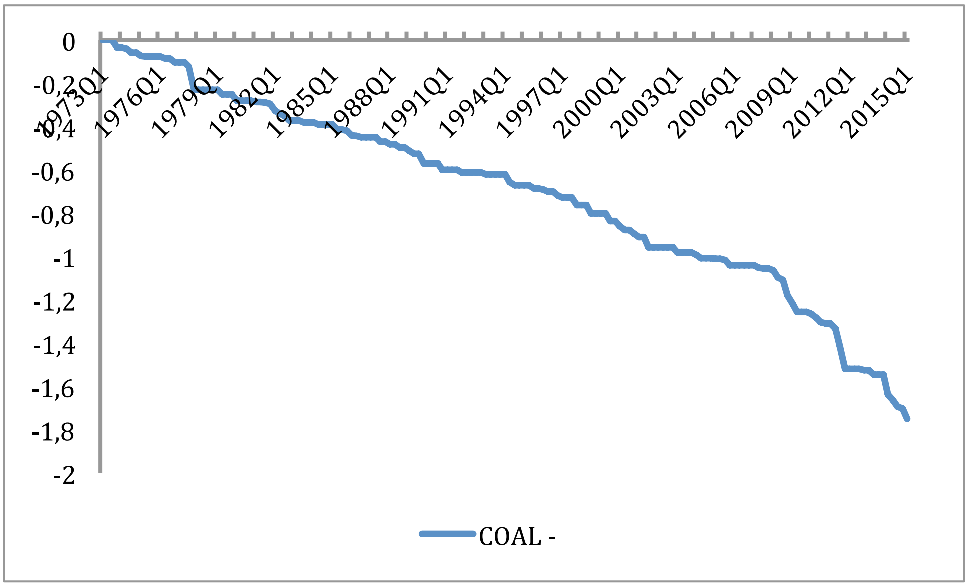
2015Q1
COAL +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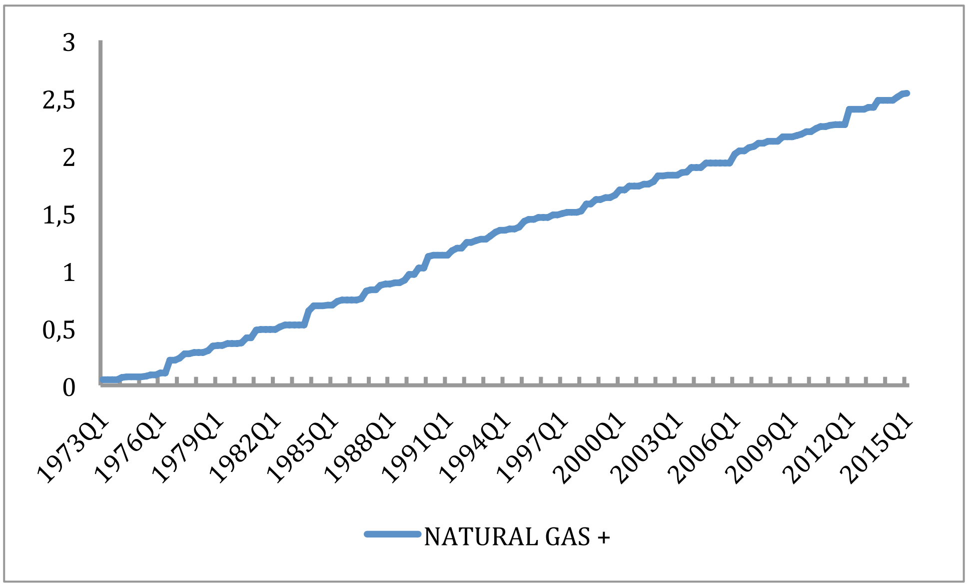
COAL -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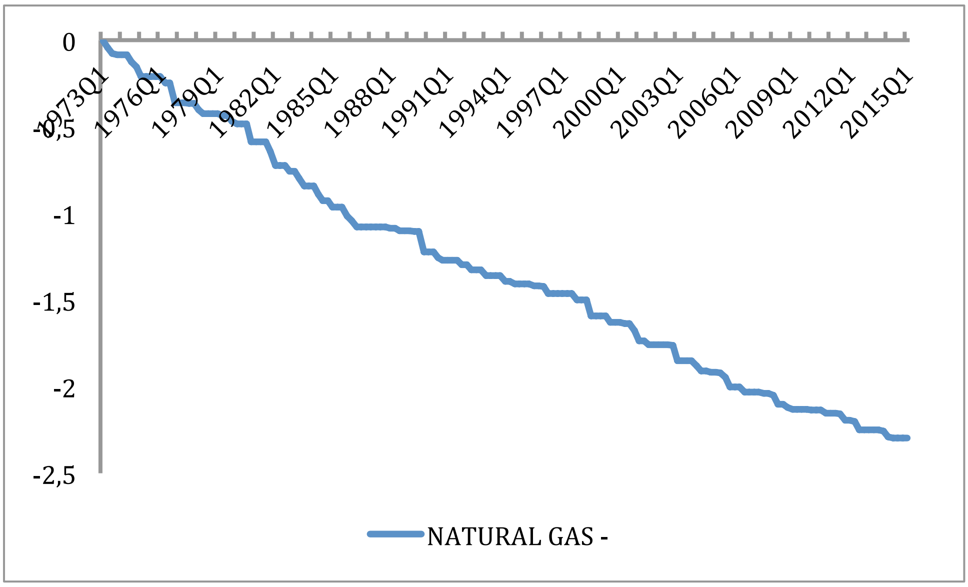
2012Q1
2015Q1
NATURAL GAS +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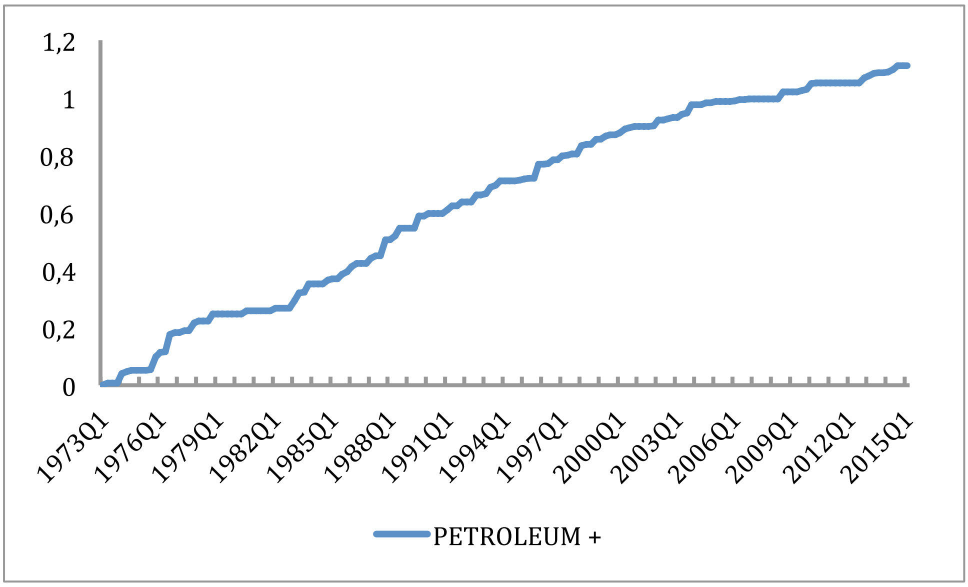
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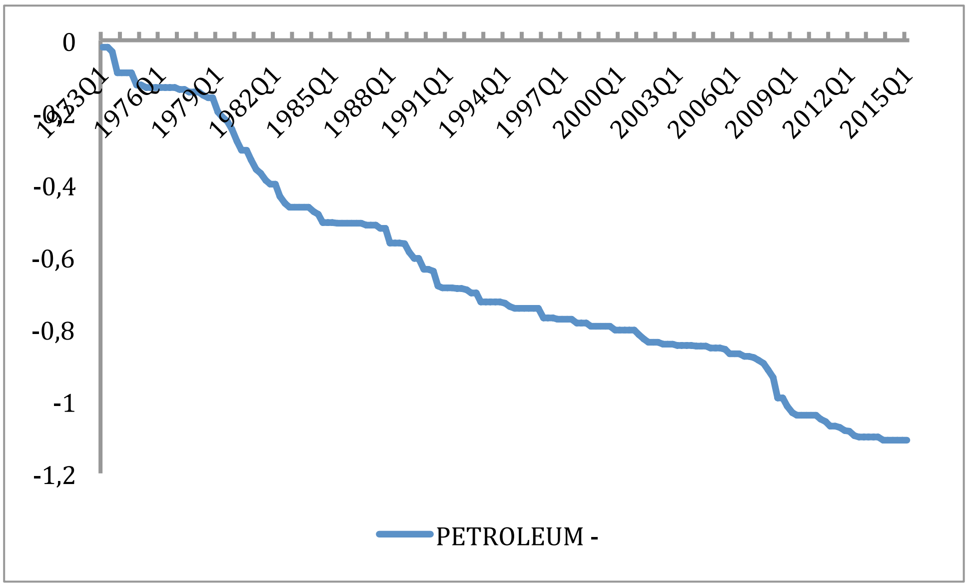
2015Q1
PETROLEUM +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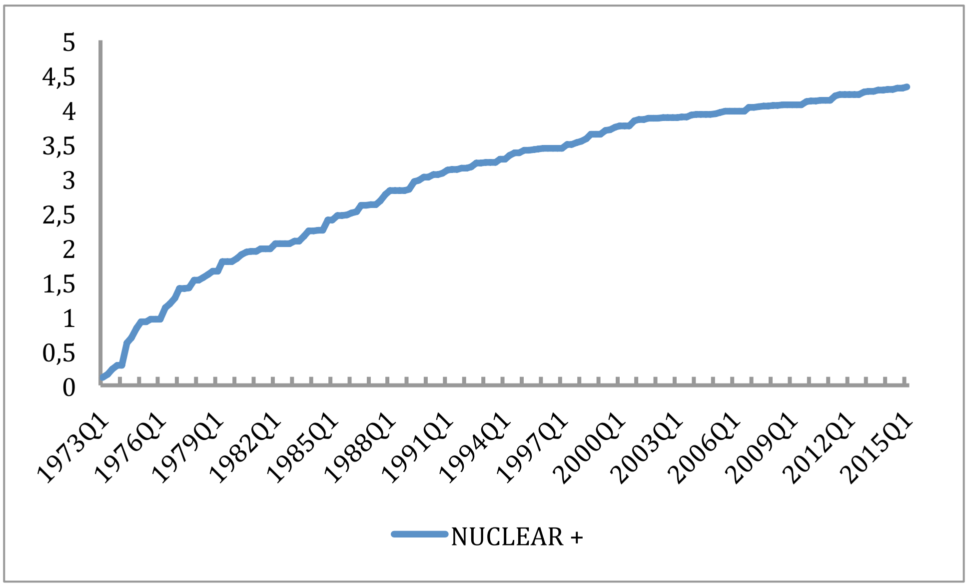
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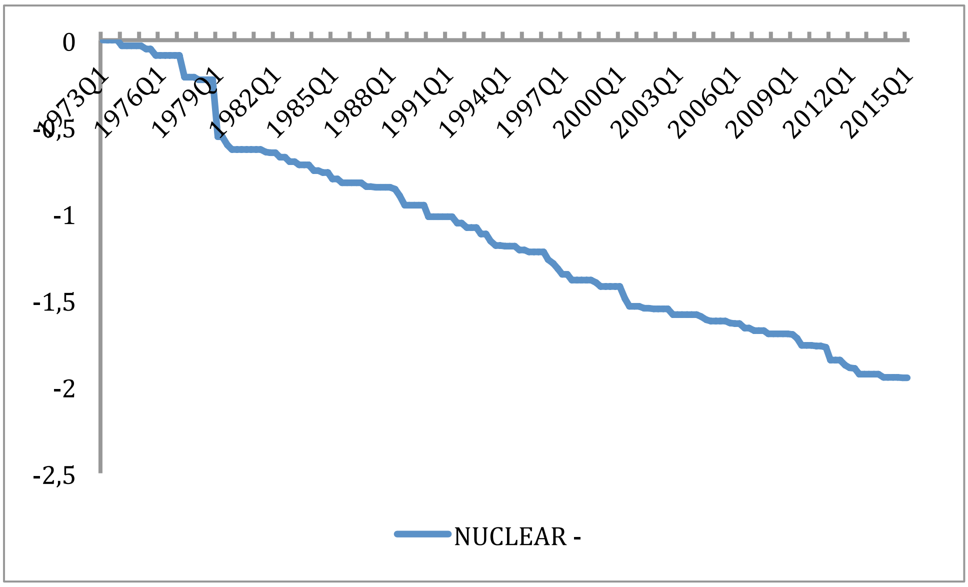
2012Q1
2015Q1
NUCLEAR +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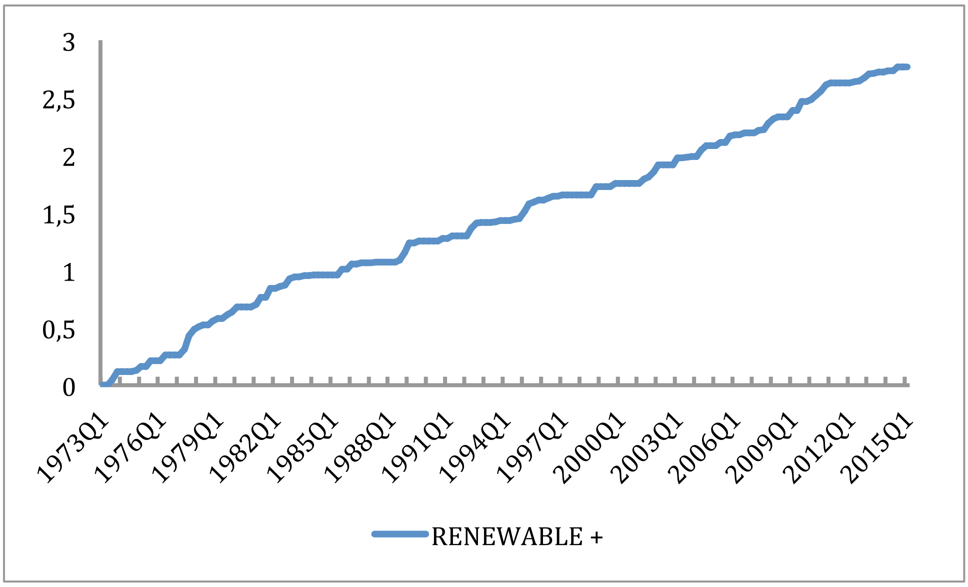
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2012Q1
2015Q1
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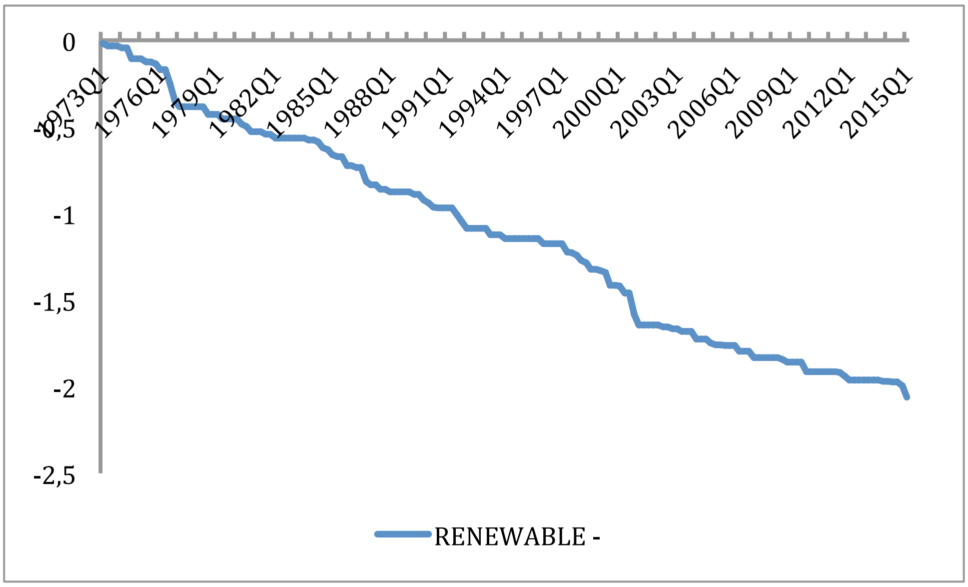
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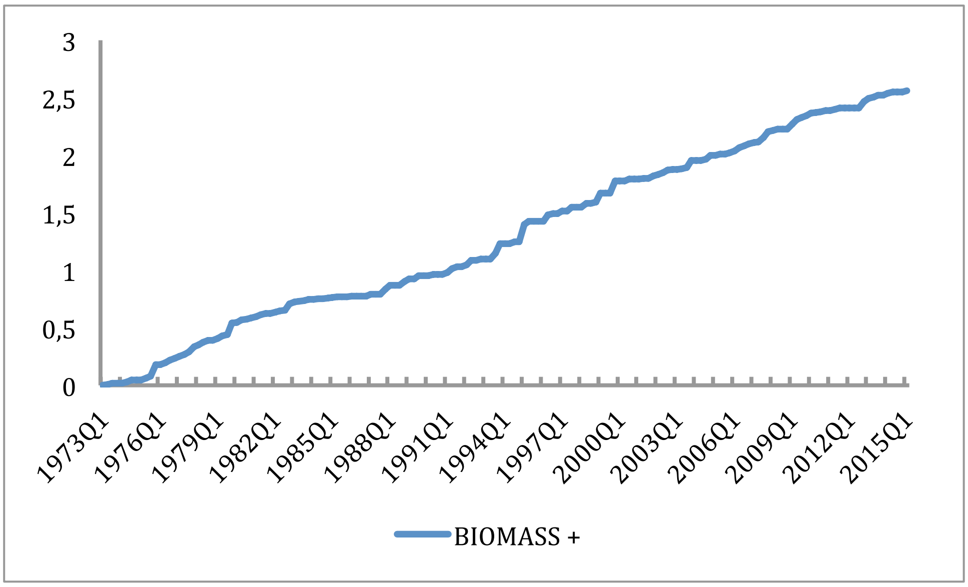
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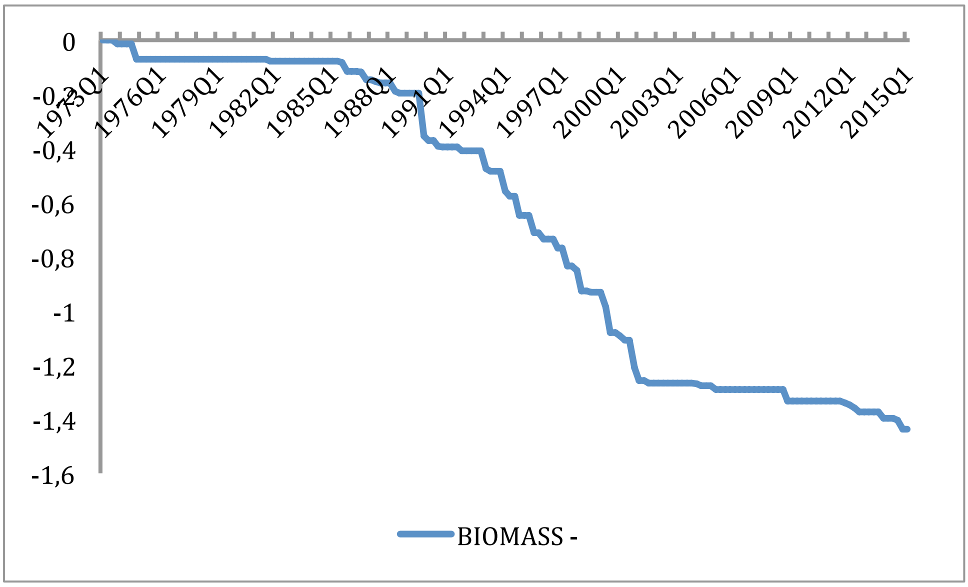
BIOMASS +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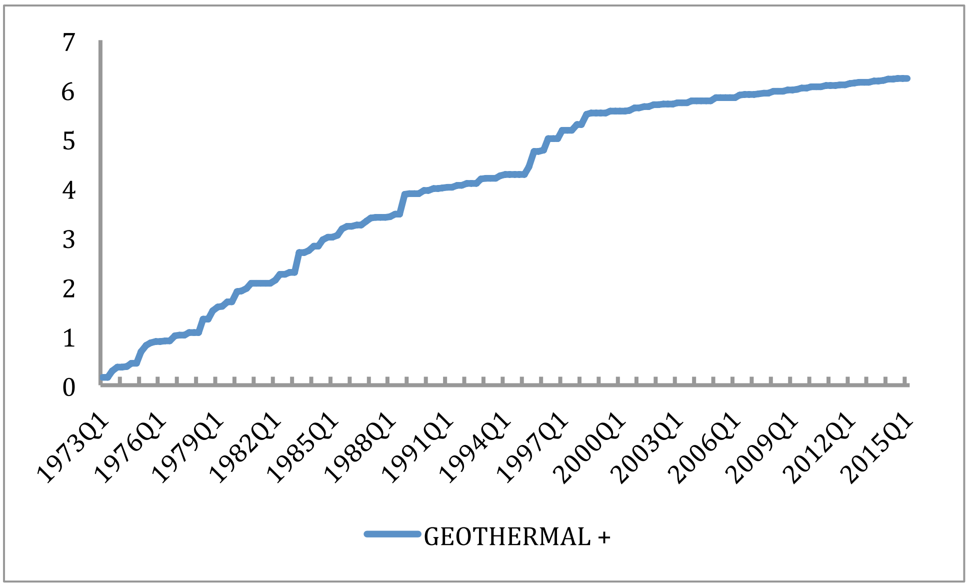
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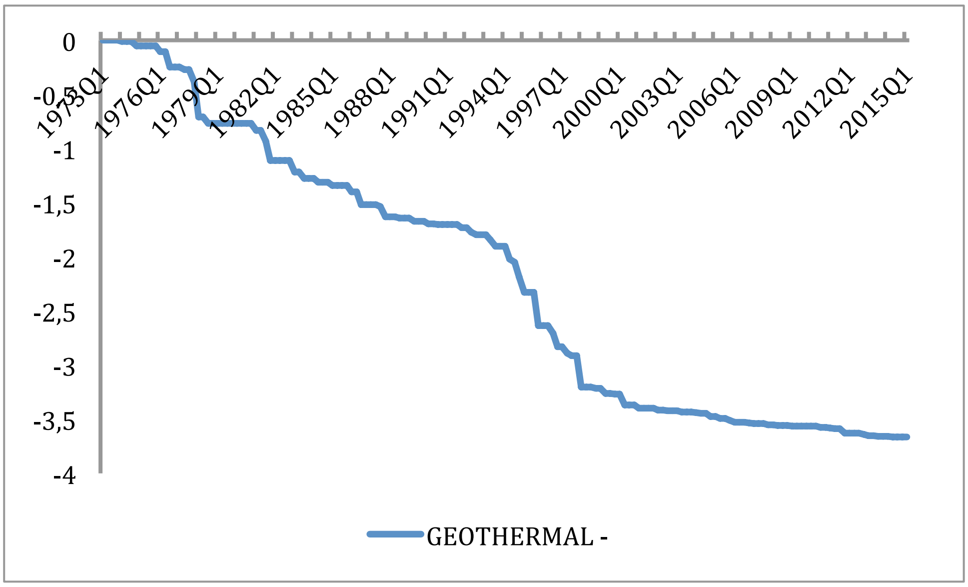
2015Q1
GEOTHERMAL +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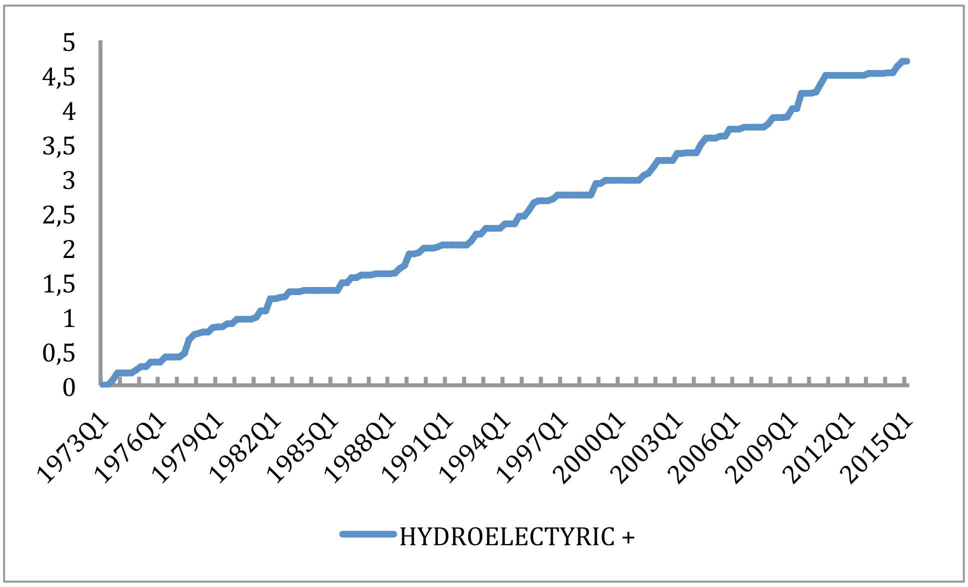
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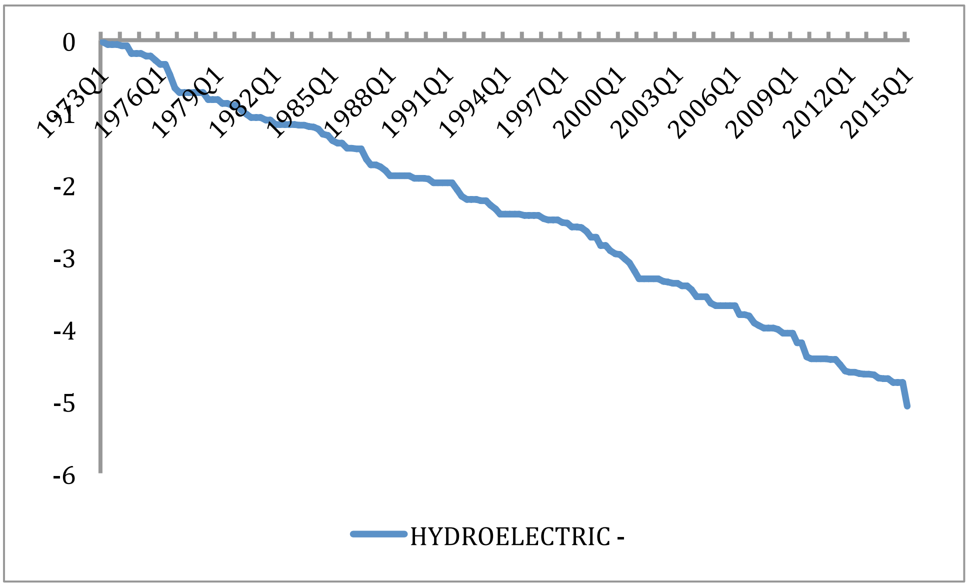
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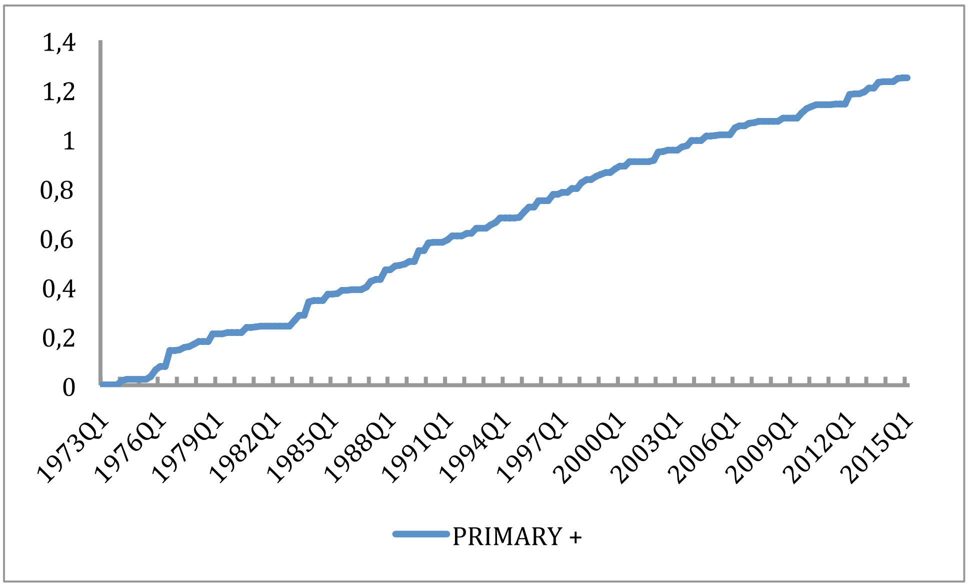
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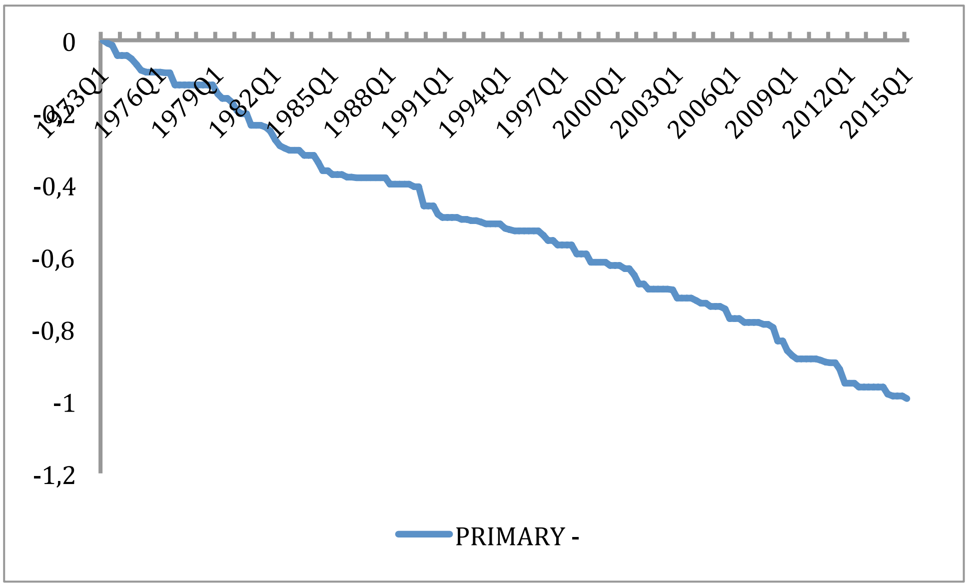
2015Q1
PRIMARY +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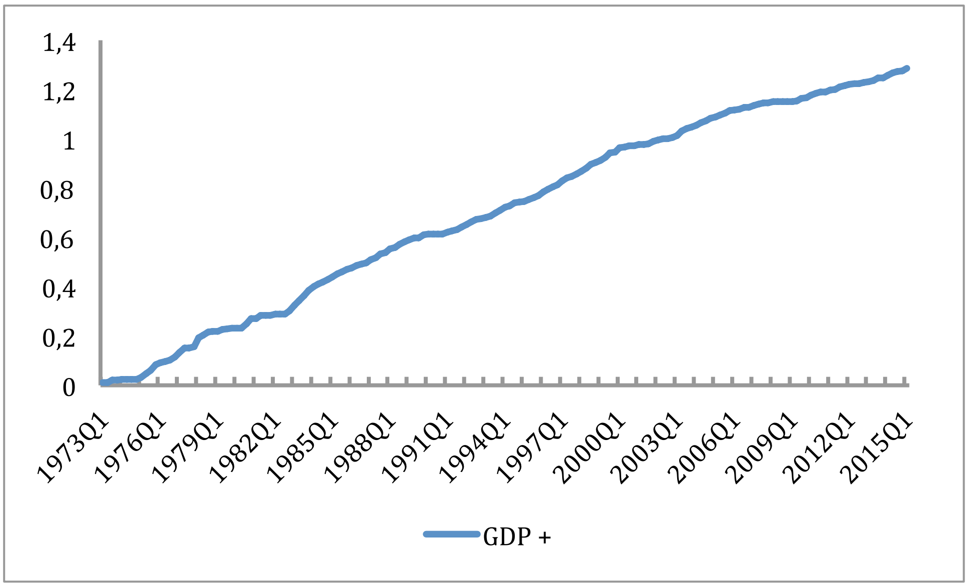
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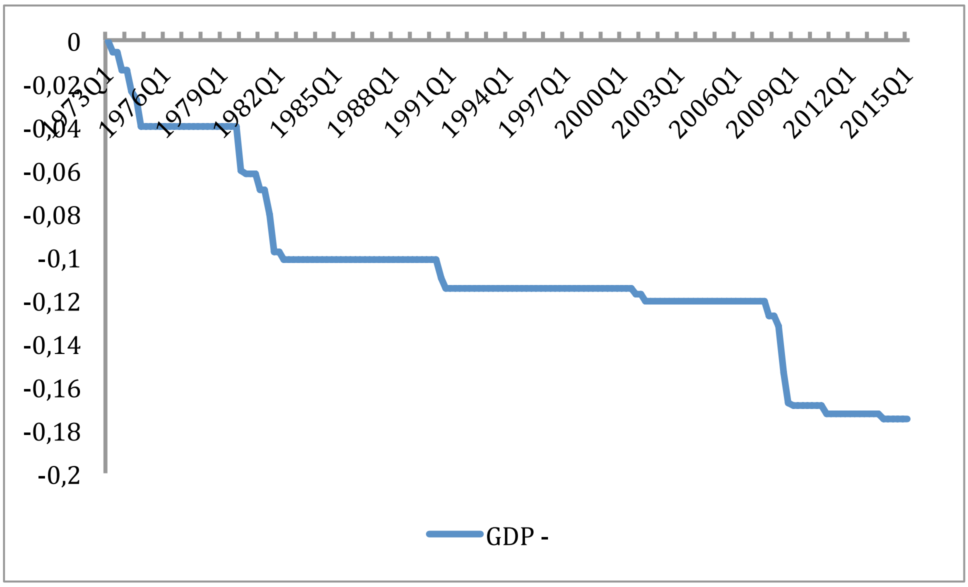
2012Q1
2015Q1
GDP +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1991Q1
1994Q1
1997Q1
2000Q1
2003Q1
2006Q1
2009Q1
2012Q1
2015Q1
GDP -

PART IV: CO_2 emissions in USA

Chapter 5: The Environmental Kuznets Curve and CO2 emissions in the United States. Is time varying the relationship between GDP and CO2 emissions?

In the present paper, we analyze the existence of the Environmental Kuznets Curve (Kuznets, 1955) using the methodology proposed by Kejriwal-Perron (2010) and applying Jaunky´s (2011) specification using quarterly data from 1973:1 to 2015:2. Our results show the existence of the Environmental Kuznets Curve (EKC) in United States.

5.1 Introduction

As in most developed countries, in U.S., there has been a growing concern since the early 90's about the establishment of a production system with energy-efficient technologies and good practices to preserve the environment. While globally, following the publication of the report known as The Limits to Growth (1972) and the Brundtland report in 1987 of the World Commission of Environment and Development, there has been growing environmental awareness that has created a commitment by industrialized countries to adjust the emission of polluting gases. Dinda and Coondoo (2006) argue that developed economies have to forgo income growth and developing countries have to restrain their growth ambitions to reduce carbon emissions. In this context, United States appear on the heart of the environment debate, creating legal reforms on August 3, 2015, President Obama and Enviromental Protection Agency announced the Clean Power Plan – a historic and important step in reducing carbon pollution from power plants that takes real action on climate change.[1]

[1] In this action, the Environmental Protection Agency (EPA) is establishing final emission guidelines for states to follow in developing plans to reduce greenhouse gas (GHG) emissions from existing fossil fuel-fired electric generating units (EGUs). Specifically, the EPA is establishing: subcategories of existing fossil fuel- fired EGUs—fossil fuel-fired electric utility steam generating units and stationary combustion turbines; state-implementation of state plans that establish emission standards emission performance rates, which may be accomplished by meeting the state goals.

Environmental economics literature has not ignored this issue, as illustrated by Grossman and Krueger (1991), who suggested that the relationship between economic development and environmental quality has the form of an inverted U-shape that is explained by the idea that economies experience environmental degradation in their infancies with low per capita income levels. Once a determinate level of per capita income is reached, economies are able to establish less polluting industries, as is proposed by the Environmental Kuznets Curve (EKC hereafter). In other words, the EKC hypothesis sostaine the idea that pollution transitions from being a normal good to being an inferior good as income increases.

A large number of papers have been produced that attempt to explain the relationship between economic growth and pollution (Grossman, 1995; Martinez-Allier, 1995, Arrow et al., 1995 Carson and Maccubin, 1997; Suri and Chapman, 1998; Torras and Boyce, 1998 and Stern, 2004 or He and Richard, 2010 among others). Unfortunately, the validity of this theory has not yet been established (see among others Stern, 2004, Aslanidis, 2009, Payne, 2010, He and Richard, 2010 or Jordan, 2010). This ambiguity is due, among other reasons, to the lack of robustness of the different studies due to the results being highly sensitive to the econometric estimation technique used (Stern, 2004).

It is notable that even though a number of studies have addressed this relationship, they have not considered the analysis of the cointegration relationship between economic growth and CO_2 emissions. Wagner (2008) noted that per capita gross domestic product (GDP) and CO_2 emissions data series are often non-stationary, and this difficulty has not been adequately addressed in the EKC literature. The existence of unit roots in both variables makes it mandatory to test for the possible existence of cointegration relationships between them (regardless of the econometric specification). Furthermore, the amplitude of the temporal series indicates the potential existence of structural changes; therefore, results obtained by cointegration would show only a linear relationship over the entire period, obscuring the possibility that the relation was different over time.

The main contribution of this paper addresses this issue. Following the specification proposed by Jaunky (2011), we present a novel methodology to verify the EKC hypothesis in United Stes, trough testing the possible existence of cointegration relationships between CO_2 emissions and economic growth. After confirming the existence of and obtaining the elasticity between the two variables, we study the possibility of structural breaks in the relationship using the methodology proposed by Kejriwal-Perron (2010). Finally, we analyze the different elasticities obtained for each period to test for the existence of the EKC in United States. The proposed results indicate that the United States economy, in recent years it has begun to fulfill the Environmental Kuznets Curve.

The structure of the paper is as follows: In the second section we review the questions that the literature suggests regarding EKC analysis, the evidence for the United States case and the theoretical framework. Subsequently, the data and methodology used appear in the third section. The fourth section presents the results that will ultimately inform the main conclusions.

5.2. A brief review of the EKC

The hypothesis proposed by the EKC is that CO_2 emissions and GDP per capita have a relationship with an inverted U-shape. An economy in its initial stage generates high pollution levels, and as it develops, it is capable of reducing pollution levels (some surveys of the EKC are Stern, 2004, Dinda, 2004, or more recently Pasten and Figueroa 2012). The empirical work of Grossman and Krueger (1991) was designed to measure the influence of free trade agreements in North America on the environment. As their most important conclusion, they argued that the increase in international trade and therefore economic growth also led to less pollution.[2]

[2]The work of Beckerman (1992) and Panayotou (1993) are the first to use the term EKC as an extension of the relationship between the level of inequality and income per capita than proposed Kuznets (1955).

From a theoretical point of view, the direct relationship between growth and CO_2 emissions set out in the EKC hypothesis has resulted in an extensive field of research in environmental economics (Grossman and Krueger, 1995, Cole et al. 1997; List and Gallet 1999; Lopez and Mitra, 2000; Hettige, 2000; Andreoni and Levinson, 2001; Harbaugh et al. 2002; Pfaff et al. 2004, or for a survey Borgeshi 1999; Dinda, 2004 or recently Kijima et al. 2010, Bo, 2010, Esteve and Tamarit, 2012, Kaika and Zervas, 2013, Iglesias et al. 2013 or Niu and Li 2014 among others).

However, a debate over the acceptance of the EKC hypothesis was raised by the work of Ekins, (1997) and de Bruyn and Heintz (1999) because they did not find evidence for this hypothesis for several pollutants analyzed. Later, Dinda (2004) analyzed the curve interpretation and deviations from the methodology and techniques employed. Following an extensive literature review, we conclude there is no unanimity on the existence of the EKC because studies differ not only in the econometric strategy but also in the way they measure CO_2, the geographical area, missing factors that would determine the environmental progress (see He and Richard, 2010), public policies, transparency and participation (Carpentier, 2006), problems caused on global terms, such as longevity in the atmosphere (Niu and Li, 2014), or how to establish the turning point of the relationship between income and pollution (Selden and Song, 1994 and

List and Gallet, 1999). In this regard, several studies have noted the influence of the energy crises as a breakdown in the relationship proposed in the EKC, reinforcing the importance of studying the relationship over time rather than relying on a static analysis (see Moomaw and Unruh, 1997 or Payne, 2010). Jalil and Mahmud (2010) and Soytas et al. (2007) discussed the advantages of using time series data to test the proposed relationship of the EKC hypothesis.

Summarizing the deviations in the interpretation of the EKC, the work of Zhao et al. (2013) observes that the country degree of development featured differing EKC patterns with a very rapid increase in CO_2 emissions, concluding that although the overall development of a country or region might not follow an EKC pattern, the EKC hypothesis might still be justified during different periods of economic growth. A more complete explanation is provided by Roca and Padilla (2003) who describe different arguments presented in the literature to explain the functional form of an inverted-U relationship between CO_2 and growth. This is caused by technological advances that allow for reductions in CO_2 emissions caused by the substitution of the industrial sector by the service sector. The service sector is more productive, and it causes reductions in environmental pressures per unit of income. Alternatively, this change could occur because the income increase leads towards the consumption of goods with high environmental quality (McConnell, 1997, Selden and Song, 1994, Lopez, 1994 and Roca, 2003).[3] This controversy raises three alternative forms that the relationship between growth and CO_2 emissions could take: (i) monotonically increasing, (ii) an inverted U-shaped or (iii) an N-shape, which implies that the decrease of pollution is a temporary occurrence (Galeotti et al., 2006 or Kaika and Zervas, 2013). To resolve the question regarding the interpretation of the EKC, in this paper, following the Jaunky (2011) approach, we check the relationship proposed by EKC theory following the interpretation of the income elasticity of CO_2 emissions.

5.2.1 CO_2 emissions in the United States and EKC

The role of the US economy in the total world energy consumption and production is vital. According to the EPA, Carbon dioxide (CO2) emissions in the United States increased by about 7% between 1990 and 2013. Since the combustion of fossil fuel is the largest source of greenhouse gas emissions in the United States, changes in emissions from fossil fuel combustion have historically been the dominant factor affecting total U.S. emission trends. Changes in CO_2 emissions from fossil fuel combus-

[3] The argument over technological change, as detailed in the work of Roca and Padilla (2003), is ruled by the so-called "rebound effect", by which the increase in environmental efficiency derived from technology leads to greater technological demands that nullify this effect. Also, it would be unconvincing if environmental improvement resulted from the replacement of the service sector by industry, if we suppose that the environmentally most problematic sectors are producing inferior goods, which is not likely (Torras and Boyce, 1998).

tion are influenced by many long-term and short-term factors, including population growth, economic growth, changing energy prices, new technologies, changing behavior, and seasonal temperatures. Between 1990 and 2013, the increase in CO_2 emissions corresponded with increased energy use by an expanding economy and population, and an overall growth in emissions from electricity generation. Transportation emissions also contributed to the 7% increase, largely due to an increase in miles traveled by motor vehicles.

Although there is an extense literature on CO2 emissions from an international perspective, very few authors have considered CO2 emissions at US a sub-national level for the United States. Soytas et al. (2007) study long-run causality between carbon emissions, energy use and income in the US. They find no evidence of causality between either income and carbon emissions or income and energy use. Empirical evidence on the case of the United States has focused on the study at sub-national, where the empirical evidence suggest that the estimated pollution-income relationships vary across states, lending support to our premise that differences in consumer preferences matter in empirical analyses of the EKC so that highly aggregated data are inappropriate for estimating such relationships (Plassmann & Khala, 2006). For its part, Burnett et al. (2013) suggest that estimation results and rigorous diagnostic analysis for the U.S. case that economic distance plays a role in intra- and inter-state CO_2 emissions and there are statistically significant, positive economic spillovers and negative price spillovers to state-level emissions. Baek and Gweisah (2013) found that, in both the short- and long-run, economic growth has a beneficial effect on environmental quality, whereas energy consumption has a detrimental effect on the environment in the U.S. In this sub-national approach, Aldy (2005) reveal mixed evidence for the environmental Kuznets curve hypothesis with CO2 emissions at the state-level in the contiguous U.S. and Carson (2010) points out that this distinction is important because it helps control for net electricity importing states that consume energy without experiencing externalities associated with their production. At this stage, recently Apergis et al. (2014) points that it is important to discuss the existing literature on the EKC conducted at regional-level for the US economy, due the mixed evidence founded in this country depending on the of state- level point-source emissions for air toxics, different statistical techniques and functional form and provided some support for the EKC hypothesis, variables that proxy for collective action, the states, econometric approach or data structure, since in the presence of cross-sectional dependence, time-series evidence, is also likely to be biased.

5.2.2 EKC and the CO_2-GDP elasticity

A particular analysis to test the EKC hypothesis consists of estimating the CO_2-GDP elasticity. This paper follows the specification proposed by Jaunky (2011) for testing the EKC hypothesis in United States. We propose the equation to determine the relationship between CO_2 emissions and per capita emissions:

$$\mathrm{L\,CO_2}_{\mathrm{t}} = \mu_0 + \mu_1 \mathrm{LGDP_t} + \varepsilon_t \tag{1}$$

where LCO_2 is the natural logarithm of the per capita CO_2 emissions, while LGDP is the natural logarithm of the per capita GDP[4], ε_t is the error term, μ_0 is the constant term, and μ_1 estimates the CO_2-GDP elasticity.

An elasticity of μ_1>1 (stage 1, environmental degradation) changes in per capita GDP generates a more proportional increase in CO_2 emission, i.e., the country is in an early stage of environmental sustainability characterized by little environmental responsibility. If 0< μ_1<1, the economy is stage 2 (environmental stabilization), where a GDP increase leads to a less-proportional increase in CO_2 emissions. Finally, for μ_1<0, GDP and CO_2 have a negative relationship. This is the last stage of the EKC, where

[4]The exercise was also conducted opting for the use of variables in per capita terms. The results are very similar to those presented in this work and are available to the reader upon request.

the economy is in a phase of environmental optimization. Only when the economy is in Stage 3 is the EKC is confirmed. Figure 1 describes these three stages proposed by Jaunky (2011) with their respective elasticities.

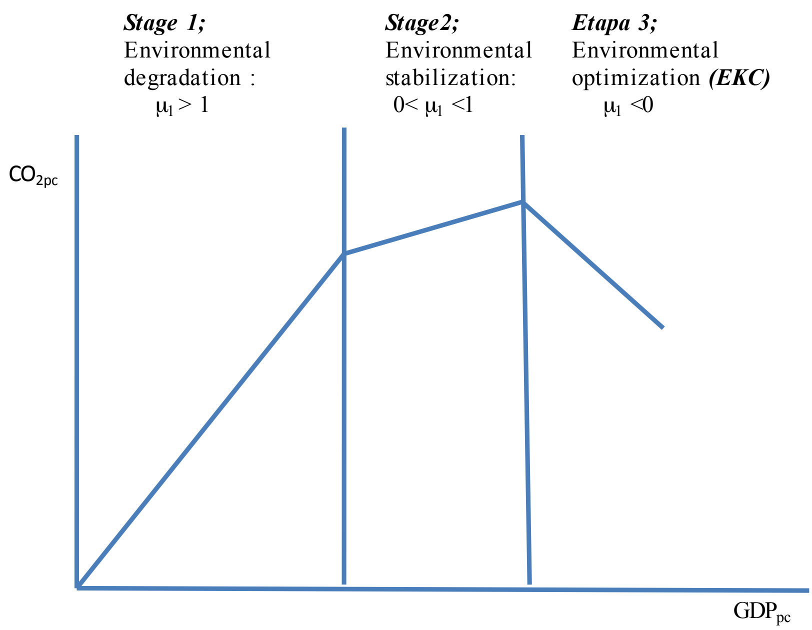

Figure 1. Environmental Kuznets Curve, elasticities across stages
Source: Compiled from the elasticities assumption proposed by Jaunky (2011)

As we can see in the figure above, the GDP and CO_2 relationship is time varying, confirming the existence of structural breaks and different phases in the relationship. Accordingly, when an economy reaches a higher degree of development, the relationship between economic growth and emissions of CO_2 change. As a result, it would cast doubt on the existence of the curve if the elasticity obtained for each period had a similar pattern to that described in the figure 1.

5.3. Data and methodology

In our empirical analysis, we use quarterly data from United States for the period 1973:1-2015:2. The variable definitions and the main sources are described as follows. GDP is defined as real gross domestic product (measured in billions of chained 2009 US $), data taken from U.S Bureau of Economic Analysis (BEA). Total CO_2 emission is expressed in million metric tons of carbon dioxide, available in US Energy Information Administration (EIA). Time series are seasonally adjusted by X12 ARIMA. Figure 1 and 2 in the appendix plots the time series.

To complete our analysis, the methodology used follows three steps. First, we propose a test for unit roots. Second, we look for structural breaks to confirm or reject the stability of the long-term relationship between GDP per-capita and CO_2 emissions. Third, to complete the analysis, we measure the elasticity estimations of both variables to show what type of relationship is present in each possible regime.

5.3.1 Testing for unit roots

Because the estimation of a linear cointegration model requires the series to be non-stationary, we start by testing for a unit root in the GDP per-capita and CO_2 emissions. We apply the class of unit root tests developed by Ng and Perron (2001), which solve several statistical problems associated with more 'conventional' unit root tests.[5] All test statistics formally examine the unit root null hypothesis against the stationary alternative.

Table 1 reports the results. As shown, the existence of two unit roots is clearly rejected at the usual significance levels for all variables, and the null hypothesis of non-stationarity in levels is clearly rejected at the usual significance levels for both variables. Thus, according to the results of these tests, these two series would be I(1).

[5] In general, the majority of conventional unit root tests, such as the Dickey-Fuller tests and the Phillips-Perron tests, suffer from three problems. First, many tests have low power when the root of the autoregressive polynomial is close to but less than one (de Jong et al., 1992). Second, most tests suffer from severe size distortions when the moving-average polynomial of the first-differenced series has a large negative autoregressive root (Schwert, 1989; Perron and Ng, 1996). Third, the implementation of unit root tests often requires the selection of an autoregressive truncation lag *k*; however, as discussed in Ng and Perron (1995), there is a strong association between *k* and the severity of size distortions and/or the extent of power loss. Ng and Perron (2001) solved these problems, and we refer to their article for further details.

Table 1. Ng and Perron[a,b] tests for a unit root

I(2) vs. I(1)	Case: p = 0, $\bar{c}$= □ 7.0			
Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{t}^{GLS}$	$\bar{M}SB_{\alpha}^{GLS}$	$\bar{M}P_{T}^{GLS}$
y_t	-7.901*	-1.987*	0.252*	3.102**
$co2_t$	-56.037***	-5.282***	0.094***	0.466***
I(1) vs. I(0)	Case: p = 1, $\bar{c}$= □ 13.5			
y_t	-4.734	-1.377	0.291	18.290
$co2_t$	-7.962	-1.912	0.240	11.688

Notes: [a]*, ** and *** denote significance at the 10%, 5% and 1% levels, respectively;
[b]The *MAIC* information criteria are used to select the autoregressive truncation lag, *k*, as proposed in Perron and Ng (1996). The critical values are taken from Ng and Perron (2001), table 1.

Critical values:	Case: p = 0, $\bar{c}$= □ 7.0			Case: p = 1, $\bar{c}$= □ 13.5		
Variable	10%	5%	1%	10%	5%	1%
$\bar{M}Z_{\alpha}^{GLS}$	-5.7	-8.1	-13.8	-14.2	-17.3	-23.8
$\bar{M}SB_{\alpha}^{GLS}$	0.275	0.233	0.174	0.185	0.168	0.143
$\bar{M}Z_{t}^{GLS}$	-1.62	-1.98	-2.58	-2.62	-2.91	-3.42
$\bar{M}P_{T}^{GLS}$	4.45	3.17	1.78	6.67	5.48	4.03

5.3.2. Looking for structural breaks

Having confirmed the non-stationarity of both variables, we now apply the tests for structural change that have been proposed Kejriwal and Perron (2008, 2010). We use a 15% trimming, which limits the maximum number of breaks allowed under the alternative hypothesis to 2. Both the intercept and the slope are allowed to change.

Table 2. Kerjiwal-Perron tests for testing multiple structural breaks

				Number of breaks selected		
supF_T(1)	*sup*F_T(2)	*sup*F_T(3)	*UD*$_{max}$	*Sequential*	*BIC*	*LWZ*
				0	*3*	*3*
				T_b	T_b	T_b
4.572	8.247	7.458	8.247		*1980:1*	*1980:1*
					1986:2	*1986:2*
					2007:4	*2007:4*

Notes:
*,**, and *** denote significance at the 10%, 5% and 1% levels, respectively.
The critical values are taken from Kejriwal and Perron (2010).

Table 2 shows the results of the stability tests and the number of breaks selected by the sequential procedure proposed by Bai and Perron (2003) as well as the Bayesian and the modified Schwarz information criteria (BIC and LWZ, respectively). The $supF_T(1)$ and $supF_T(2)$ and $supF_T(3)$ test is not significant, suggesting that the data do not support a three-break model, although the BIC and LWZ select three breaks and provide evidence against the stability of the long-term relationship. Overall, the results of the Kejriwal-Perron tests suggest a model with three breaks, estimated at 1980:1, 1986:2 and 2007:4, and four regimes: 1973:1-1980:1, 1980:2-1986:2, 1987:3-2007:4 and 2008:1-2015:2.

Table 3. Arai-Kurozumi-Kejriwal cointegration tests with two structural breaks

Test $\widehat{V_3}(\hat{\lambda})$	$\hat{\lambda}_1$	$\hat{T}_1$	$\hat{\lambda}_2$	$\hat{T}_2$	$\hat{\lambda}_3$	$\hat{T}_3$
0.088	0.17	1980:1	0.32	1986:2	0.82	2007:4
Critical values	10%	5%	1%			
$\widehat{V_k}(\hat{\lambda})$	0.070	0.093	0.155			

Notes:
a *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
b Critical values are obtained by simulation using 500 steps and 2000 replications.
The Wiener processes are approximated by partial sums of i.i.d. N(0, 1) random variables.

Because the above stability tests reject the null coefficient stability when the regression is spurious, we need to confirm the presence of cointegration among the variables. We use the residual-based test of the null of cointegration against the alternative of cointegration with unknown multiple breaks proposed in Kejriwal (2008), $\widehat{V_k}(\hat{\lambda})$. Arai and Kurozumi (2007) show that the limit distribution of the test statistic, $\widehat{V_k}(\hat{\lambda})$, depends only on the timing of the estimated break fraction $\hat{\lambda}$ and the number of I(1) regressors m. In our case (three-break model), critical values are obtained for $\hat{\lambda}_1$=0.17, $\hat{\lambda}_2$=0.32, and $\hat{\lambda}_3$=0.32 by simulation using 500 steps and 2000 replications. The Wiener processes are approximated by partial sums of i.i.d. N(0,1) random variables. Table 3 shows the results of the Arai-Kurozumi test, allowing thre breaks. Again, the level of trimming used is 15%. The results show that the test $\widehat{V_1}(\hat{\lambda})$ cannot reject the null of with three structural breaks at at 1980:1, 1986:2 and 2007:4.

Once the presence of structural breaks has been confirmed and to compare the coefficients obtained from a three-break model with those reported from a model without any structural break, we proceed with a comparison of the estimates of the elasticity CO_2-GDP obtained from a three-break model with those obtained from the full sample.

5.3.3 Elasticity estimates

For the full sample, we estimate the long-term regression model using the Dynamic Ordinary Least Squares (DOLS)[6] estimation method of Stock and Watson (1993) and extended by Shin (1994).[7] The Shin (1994)

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[6] LS estimation of the equation might suffer from two problems: nuisance parameter dependences due to serial correlation in the residuals and the possible presence of endogeneity in the explanatory variable.

[7] In order to overcome the problem of the low power of classical tests for under the presence of persistent roots in the residuals of the regression, Shin(1994) suggested a new test where the null hypothesis is .

approach is similar to the KPSS tests, which, in the case of, is implemented in two stages. [8,]

Therefore, the first step in our estimation strategy consists of the estimation of a long-term dynamic equation including leads and lags of the explanatory variables in the long-term regression model, i.e., the so-called DOLS regression:

$$\ln(CO2t) = \mu_0 + \mu_1 ln(GDPt) + \sum_{j=-q}^{q} \varphi_j \, \Delta lnGDPt + \varepsilon_j \qquad (5)$$

In the second step, we use the statistic Cμ, a LM-type test designed by Shin (1994), to test the null of cointegration against the alternative of no cointegration in DOLS regression.[9] In Table 4, we report the estimates from the DOLS regression and the results from Shin's test. The results show that the null of deterministic cointegration is not rejected at the 1% significance level.

[8] These tests are called the Kwiatkowski et al. (1992) tests and assume the null hypothesis of stationarity.

[9] C□ is the test statistic for deterministic cointegration, i.e., when no trend is present in the regression.

Table 4. Stock –Watson-Shin's DOLS [a,b,c,d] estimation of linear cointegration

Parameter Estimates	Full sample 1973:1-2015:2	First regime 1973:1-1980:1	Second regime 1980:2-1986:2	Third regime 1986:3-2007:4	Four regime 2008:1-2015:2
μ_0	4.900*** (0.106)	3.279*** (0.613)	6.700*** (0.063)	3.382*** (0.097)	10.987*** (1.823)
μ_1	0.246*** (0.012)	0.437*** (0.071)	0.040 (0.086)	0.411*** (0.010)	-0.391** (0.190)
R^2	0.785	0.842	0.486	0.958	0.565
Test: C_μ^c	0.135	0.079	0.174	0.197	0.111
$\hat{\sigma}^2$	0.047	0.021	0.027	0.021	0.029

Notes: [a]Standard Errors (in brackets) are adjusted for long-run variance. The long-run variance of the cointegrating regression residual is estimated using the Barlett window, which is approximately equal to $INT(T^{1/2})$as proposed in Newey and West (1987).

[b]We choose $q = INT(T^{1/3})$as proposed Stock and Watson (1993).

[c]C_μ is an LM statistic for cointegration using the DOLS residuals from deterministic cointegration, as proposed Shin (1994). A *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

[d]The critical values are taken from Shin (1994), table 1, from m=1:

Critical values:

	10%	5%	1%
C_μ	0.231	0.314	0.533

Because there is evidence of the presence of structural breaks in 1980:1, 1986:2 and 2007:4 for the cointegration relationship, we divide our sample into four subsamples (periods) to analyze whether the CO_2-GDP elasticity changes across the periods. We estimate equation (5) for the three subsamples. The estimates for the subsamples are reported in the last four columns of Table 4. In the three periods, we cannot reject the null of deterministic cointegration at the 1% level of significance. We obtain significant estimates of μ_1, i.e., the estimated values for $\widehat{\mu_1}$= 0.437, 0.411

and -0.391, these parameter estimates are the values of the CO_2-GDP elasticity for the first, third and fourth subsamples, respectively. Thus, ignoring shifts creates an erroneous finding when testing the existence of the EKC.

In summary, our results report an elasticity consistent with stage 2 (environmental stabilization) for the first (before the first break), second and third sub-periods (before the three break) estimated, i.e., for 1973:1-1980:1, 1980:2-1986:2 and from 1986:3 to 2007:4. During these periods, United States was in the second stage of the EKC characterized by environmental stabilization; a possible explanation for the first break is the second oil crisis occurred at the end of the year 1979. The second break could correspond with the crisis derived of the OPEC Oil price collapse. The last break clearly corresponds with the beginning of the last economic crisis. Focusing in the results of the last regime, two conclusions emerge clearly. First, comparing the coefficient in the full sample with the last regime, the latter is are not only much smaller than the full sample value but also the sign switch from positive to negative. Second, the negative sign implies that from the beginning of the economic crisis, United States has crossed the border from the *"Environmental stabilization"* to *"Environmental optimization"*. Consequently, ignoring structural changes can lead to misleading conclusions.

5.4. Conclusions

This paper has analyzed the relationship between income and CO_2 emissions in United States using quarterly time series data from 1973:1-2015:2. The method offered by Jaunky (2011) has been applied to test the existence of the EKC hypothesis. Although the literature is inconclusive due to deviations of the strict principles of Kuznets, our analysis uses a broad time period and techniques that measure the cointegration of the variables and the study of the breaks. As a result, this study sheds some light on the available empirical evidence for United States.

The result shows that this relationship is not stable over time, finding three breaks, and therefore four periods during which this ratio has varied. In the three first period, United States has been in the environmental stabilization stage, and since the last quarter of 2007, the elasticity CO2-GDP turn negative, i.e, United States have achieved the Environmental Stabilization stage, then, the EKC hypothesis is confirmed.

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APPENDIX

Figure 1. GDP (in logs)

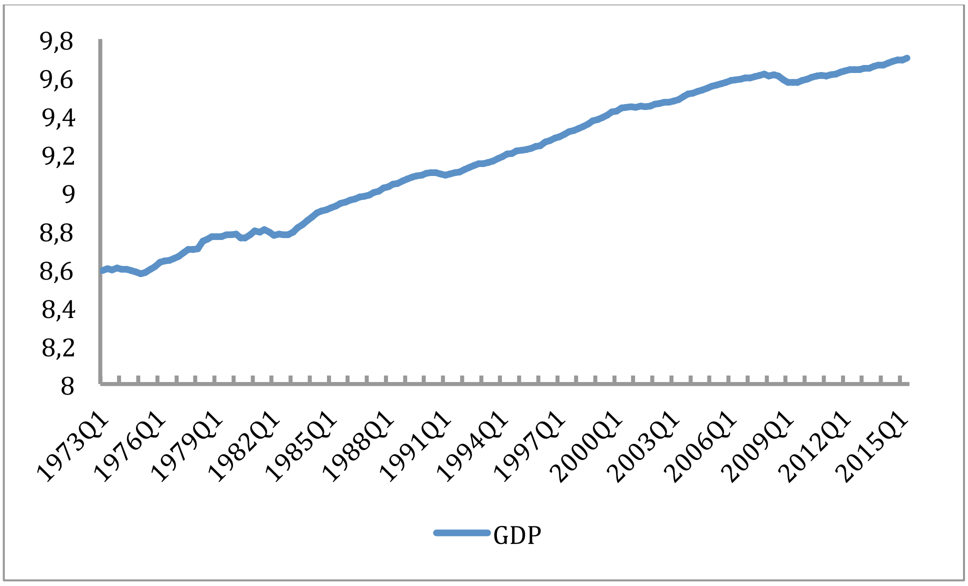
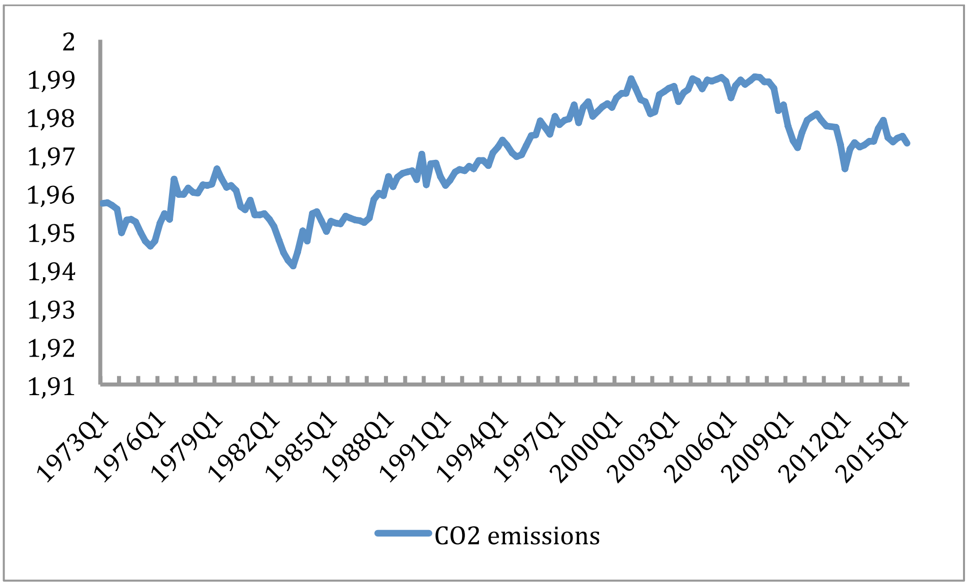


Figure 2. CO2 emissions (in logs)



Resumen en castellano

La presente tesis versa sobre la relación existente entre el crecimiento económico y distintas variables energéticas como el consumo de energía o las emisiones de CO2. Esta relación ha sido ampliamente estudiada en la literatura empírica de la economía de la energía.

Los artículos realizados tratan de buscar nueva evidencia sobre dicha relación. Así, en el primer capítulo, se trata de dar respuesta a la relación entre el consumo de energía y el PIB, haciendo uso de datos trimestrales españoles, desde 1980 hasta 2010.

Los resultados muestran como la elasticidad del consumo de energía sobre la renta es positiva. Una vez determinada dicha relación, se ha contrastado si es estable a lo largo del tiempo, permitiendo la existencia de quiebres estructurales siguiendo la metodología propuesta por Gregory and Hansen (1996) y Hatemi-J (2008). Las estimaciones muestran como dicha relación es variante en el tiempo. Finalmente, se contrasta las relaciones de causalidad en sentido de Granger, encontrándose evidencias mixtas.

En el segundo capitulo se realiza un análisis para el contraste de la relación de causalidad anteriormente descrita, pero contrastando a la vez, si dicho consumo de energía es persistente, es decir, si los cambios transitorios en dicho consumo se convierten en permanentes1. La metodología utilizada es la propuesta por Sinclair (2010) utilizando métodos de componentes no observables. Los resultados avalan la existencia de persistencia (histéresis) en el consumo de energía. La metodología permite estimar el componente cíclico de ambas variables, pudiendo realizar un contraste de causalidad en sentido de Granger. Los resultados muestran causalidad bidireccional. Finalmente, la posible existencia de quiebres estructurales, es contrastada mediante la técnica de Bai-Perron2 (1998,2003). Esta, indica la existencia de un quiebre estructural a principios del año 2009 (al comienzo de la reciente crisis económica), y, donde se confirma la existencia de dicha relación bidireccional pero solo para el último periodo, es decir, solo a partir de la crisis económica actual, manteniéndose durante todo el periodo la causalidad desde el ciclo económico al consumo de energía.

El tercer trabajo, versa sobre las relaciones de causalidad del PIB con el consumo de energía, desagregando esta última por su origen (fósil,

[1] El concepto de persistencia en economía se asemeja al de histéresis utilizado principalmente en la rama de física.

[2] Al contrario que en la metodología de Kerjiwal-Perron, es necesario que las series sean estacionarias, condicionante que se cumple en los componentes cíclicos y que es confirmado mediante un contraste de raíces unitarias.

carbón, petróleo, gas natural, nuclear, renovable, biomasa y geotermal). Para dicho estudio, se hace uso de la metodología de Toda-Yamamoto (1996) y su ampliación propuesta por Hatemi-J (2012) para el caso de asimetrías. Básicamente, los resultados muestran la existencia de “neutral hypothesis” para el caso de las energías renovables y de “conservation hypothesis” para el caso de las energías fósiles. Sin embargo, cuando se permite asimetría, se observa como emerge la “growth hypothesis” para el caso del petróleo, resultado este importante, dada la importancia relativa del petróleo sobre el total del consumo energético.

Finalmente, el último capítulo de la presente tesis, amplia el campo de estudio, interesándose por la relación existente entre el PIB y las emisiones de CO2. Para ello se contrasta la existencia de la “Curva medioambietal de Kuznets” (EKC).

Los resultados iniciales no muestran que dicha curva se cumpla, siendo la elasticidad positiva, y, por tanto, poniendo de manifiesto que a mayor crecimiento económico mayor será las emisiones de CO2. Sin embargo, teniendo en cuenta la existencia de quiebres estructurales, usando para ello la metodología de Kerjiwal-Perron (2008, 2010) para la detención de dichos quiebres y las técnicas de cointegración de Arai-Kurozumi (2009) que permiten quiebres en la relaciones de cointegración. Tres son los quiebres encontrados. Al reestimar la elasticidad, se observa que la relación es dependiente en el tiempo, y, lo que es más importante, como teniendo en cuenta la existencia de dichos quiebres, si se cumple la hipótesis de la EKC para el caso de Estados Unidos.

Con la presente tesis hemos intentado dar nuevas evidencias de las relaciones entre el consumo energético, las emisiones de CO2 y el PIB. Se observa como dichas relaciones son diferentes en los distintos periodos de tiempo, según el origen de la fuente de energía y según las fases de expansión y recesión. Finalmente, se confirma la existencia de la EKC en Estados Unidos, pero señalando la necesidad de tener en cuenta que las relaciones a largo plazo entre las variables son cambiantes con el tiempo.