Switching towards coal or renewable energy? The effects of financial capital on energy transitions

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Abstract

Does a country's stock of financial capital affect its ability to achieve energy transitions? This paper uses data for up to 137 countries for the period 1998–2013 to investigate the importance of financial capital for changes in the use of each energy type. For high-income countries, I find that financial capital facilitates transitions from fossil fuels to modern renewable energy sources, especially wind. Both private credit from banks and domestic private debt securities support greater wind energy use. For lower-income countries, financial capital supports progression towards fossil fuel energy sources such as coal. Income and natural resource endowments also affect energy transitions.

Keywords: Energy; Transitions; Financial capital (JEL O11, O13, Q42, Q43)

1. Introduction

In this paper I consider the influence of different types of financial capital on consumption of different types of energy. For instance, I focus on wind and coal energy, and seven other energy types. In addition to analysis of national-level data for a world sample, I also present separate assessments for high-income and lower-income countries to reveal differences in energy transitions according to development level. The impacts of financial capital on energy mix have a number of indirect but important implications. These relate to economic growth, environmental outcomes including global climate change, and health outcomes affected by local air pollution.

I investigate whether energy types that are more capital intensive are more reliant on financial capital, using national-level data. Capital intensity as the capital cost per unit of expected energy production (Timmons et al. 2014) is the definition that I use for this paper. Financial capital is the stock of financial assets that can be used to fund future production, and includes institutional assets such as bank deposits, and capital market instruments such as bonds and equity. Two key variables in this paper are bank credit to the private sector and outstanding private debt securities.

Figure 1 shows the different capital intensities for energy types used for electricity generation in the United States. The capital intensity is lowest for the fossil fuel electricity types of natural gas and coal, and increases substantially for renewable energy such as wind and solar. The higher capital intensity for wind and solar partly relates to the lower assumed average capacity factors for these energy types. The capacity factors are the ratio of actual output to potential capacity.

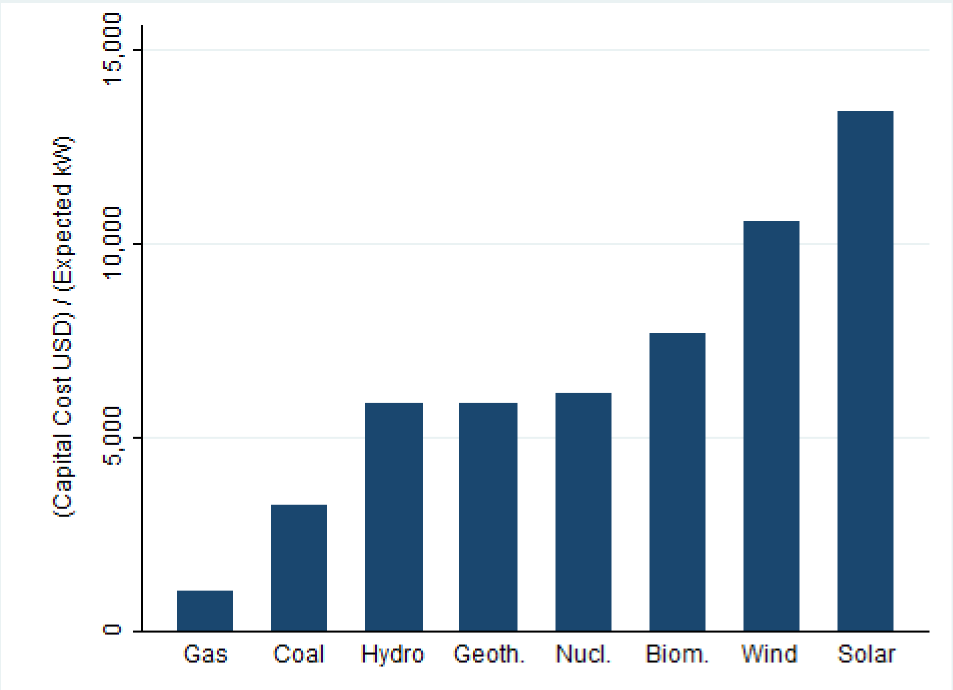

Figure 1. Capital intensity by electricity type (Capital cost divided by expected kilowatts, calculated as capital cost per kilowatt (EIA 2015a) divided by assumed capacity factor (EIA 2015b)). Sources: EIA (2015a; 2015b), Timmons et al. 2014, author calculations

The results of previous studies that have investigated the influence of financial capital on national-level energy use have varied. Brunnschweiler (2010) shows a positive impact of the financial sector on renewable energy production in developing countries. In contrast, Pfeiffer and Mulder (2013) find no evidence of an impact of finance on renewable energy adoption, rather than use, based on one variable to control for the importance of commercial banks relative to central banks in developing countries. For aggregate energy, Sadorsky (2010) finds that stock market development is a contributing factor towards greater energy consumption in emerging economies. The bank sector is an important contributor for energy consumption in a group of Central and Eastern European countries (Sadorsky 2011). I focus on the impacts of financial capital on nine energy types rather than more aggregated energy variables. This highlights the impacts of financial capital on energy mix, and the varying impacts of different energy types on economic and environmental outcomes.

There are a number of other important factors in addition to financial capital in determining energy mix. Larger endowments of energy resources are associated with greater domestic consumption of those energy types and lower use of substitute energy types. Countries have been shown to move up a national-level energy ladder as their gross domestic product per capita increases, progressing to fossil fuels then modern renewables (Burke 2013). Climate conditions could also encourage the use of particular energy types. For instance, hydro energy would be more suitable when there is more water available from greater precipitation, and less evaporation from lower temperatures. Land area is another potentially important control, as more land can provide more domestic energy resources, all else equal.

The differing impacts of financial capital on energy transitions could have a number of economic implications. Energy is a necessary factor of production (Stern 2011), with the type and cost of energy affecting the amount of resources available for other productive uses. Also, reliability of energy supply is an issue, depending on the types and sources of energy. Nations that rely on large amounts of imported fossil fuels have to contend with energy security concerns, while intermittent renewable sources present reliability concerns without cost-effective energy storage.

There are also important environmental implications of the mix of energy types used by national economies. For instance, greater use of fossil fuels contributes to greater risk of adverse climate changes. If financial capital facilitates the transition of lower-income countries towards fossil fuels, financial capital accumulation could contribute to adverse climate change. At a local level, air pollution can be exacerbated by greater use of energy sources such as coal. Transition away from biomass energy could also have favourable impacts on local air pollution, and also have beneficial health impacts in cases where electricity or gas replaces biomass for household cooking.

In section 2 of this paper, I discuss the mechanisms through which financial systems may be important for national-level energy mixes. Section 3 details the method and data. I present the results in Section 4, and conclude in Section 5.

2. The relationship between financial systems and energy types

Capital-intensive energy production can be expected to benefit from larger supplies of financial capital at lower cost. When there is a larger supply of aggregate capital available, greater competition between capital providers helps to lower the cost of capital. This lower cost of capital benefits all borrowers in an economy, but the largest benefits accrue to capital-intensive sectors that are more sensitive to cost of capital changes, including energy producers. In another scenario, when there is an excess demand for long-term capital from energy producers, some energy projects will no longer be commercially viable, due to the elevated cost of capital (IEA 2014).

Financial capital constraints can impede industrial expansion (Levine 2005), including in the energy sector. These constraints may relate to factors other than just the cost of capital. For instance, capital quantity can be restricted when bond covenants or loan tenor are not appropriate for energy producers. When financial capital constraints are overcome, aggregate energy capacity and consumption can increase. Energy production is more reliant on external finance than many other industries (Rajan and Zingales 1998).

Access to external finance has been found to be associated with greater innovation (Levine 2005; Ayyagari et al. 2011), and larger financial systems are more likely to be more innovative. Innovation to produce different types of financial fund structures can produce different risk-return profiles related to varying claims on income and capital, including more liquid and divisible investments. For instance, YieldCos are investment fund structures that own infrastructure assets and distribute dividends based on electricity revenue (OECD 2015). As a portfolio of publicly listed energy assets, YieldCos require parent companies to have large amounts of capital, which is more likely in larger financial systems. Larger markets allow greater liquidity and more research analysis, underlying growth of YieldCos and the renewable energy generation that they finance.

Specific constraints on financial capital supply for particular energy types are more likely when aggregate capital supply is lower. Insufficient capital supply for renewable energy in developing countries is an example of constraints for particular energy types, and is evident in the many policy approaches to overcome the supply constraint. International financial institutions and donors have supported numerous financing initiatives for renewable energy in developing countries (Painuly and Wohlgemuth 2006). Energy producers may have greater access to financial capital in developed countries, but this can vary over time. Following the global credit crunch beginning in 2008, there was less capital available for renewable energy, due to capital provider bankruptcies and higher risk aversion (NREL 2011).

Investors in different financial segments have different preferences for the trade-off between risk and return, making some financial segments more appropriate sources of energy capital than others. For instance, pension fund investment primarily has a low risk target, hindering investment in higher-risk energy types. Aversion to higher-risk investments can also be strengthened through regulatory systems or standards. The Basel III capital adequacy standards may increase the cost of long-term energy financing through banks (IEA 2014), while the Solvency II standards discourage insurance company investments in securitized assets (Citi 2015). The banking sector has been the main source of external finance for energy investments in most countries, with capital markets offering another alternative (IEA 2014). Corsatea et al. (2014) note the importance of corporate debt for wind energy development. Larger financial systems are more likely to include investors interested in particular energy types.

Financial capital constraints for energy producers could be overcome through access to either public or private sources of finance. Nuclear energy relies more on public rather than private financial sources (Helm 2012 p. 136). Nuclear presents a different set of risks to other energy types and can dissuade private investment, with political risks related to nuclear waste and the relationship with nuclear weapons, on top of the long-term and capital intensive nature. Nuclear risks are also harder for private capital sources to diversify, as nuclear power plants are larger than other energy sources on average. Geothermal energy development can also be reliant on public finance due to the combination of resource risk, high capital intensity, and long lead times (ESMAP 2012).

Energy producers can potentially benefit from access to capital from both domestic and international sources. Investors have a home bias (Obstfeld and Rogoff 2001), related to many possible reasons such as barriers to international investment, information asymmetries, and behavioural biases (Warren 2010), meaning that domestic capital could be important in supporting domestic energy transitions. In addition, smaller scale energy projects, including some solar photovoltaic projects, may be too small to access international capital sources (Ondraczek et al. 2015). International capital flows might also be important for some energy producers, and access to international markets and international networks for bank syndicate lending can expand available private capital sources. Aid from international development agencies and bilateral government donations has also been a source of energy capital (Tirpak and Adams 2008), but private capital will be increasingly important as financial sectors develop.

3. Data and Method

I estimate Eq. (1):

(1) $$\Delta^{2003-2013}\, T_{j,c} = F_c^{2003}\alpha_j + x_c^{2003}\,\chi_j + \varepsilon_{j,c}$$

where $\Delta^{2003-2013}\, T_{j,c}$ is the change in primary energy supply per capita for energy type j in country c for the ten-year period 2003–2013. F is the financial capital variable, private credit from deposit money banks, and $\boldsymbol{x}$ is a vector of other potential determinants of energy consumption. The error term is $\varepsilon_{j,c}$, with $E(\varepsilon_{j,c}) = 0$.

The regressions for the change in energy consumption for the ten years to 2013 use ordinary least squares estimates with standard errors that are robust to heteroscedasticity. As the same set of independent variables is in each regression for Eq. (1), seemingly unrelated regression estimation is not advantageous compared to ordinary least squares for each equation separately.

I also use the model in Eq. (2) for fixed-effects panel estimation:

$$T_{j,c,t} = F'_{c,t}\alpha_j + x'_{c,t}\chi_j + \varepsilon_{j,c,t} \qquad (2)$$

where T is the primary energy supply per capita for energy type j in country c and year t. In contrast to Eq. (1), the dependent variable in Eq. (2) is the level of energy consumption per capita. $\boldsymbol{F}'$ is a vector of financial capital variables. The fixed-effects panel estimations include additional financial variables compared to Eq. (1). These additional financial variables are excluded from Eq. (1) as the number of countries with available data for each variable is small. $\boldsymbol{x}'$ is a vector including the log of GDP per capita, temperature, and precipitation. Time effects are included in the fixed-effects panel estimation, and the error term is $\varepsilon_{j,c,t}$, with $E(\varepsilon_{j,c,t}) = 0$. The fixed-effects panel estimates are for 1998–2012.

I estimate Eq. (1) and Eq. (2) for total energy consumption per capita and each energy type separately, for nine different energy types that make up 99.9 percent of total primary energy supply in 2013. In addition to analysis of the full sample of up to 137 countries, I also consider two sub-samples for Eq. (1). This is to account for the different dynamics for countries at different stages of development. I use the World Bank (2016) income classifications, combining low-income countries with middle income countries in one group. I refer to these countries as lower-income countries. The other group is high-income countries.

Primary energy consumption data are taken from the International Energy Agency (IEA 2015). For the dependent variables, I divide energy consumption by population data from the World Bank (2016) to produce energy consumption per capita. Energy consumption is for nine different energy types: biofuels and waste, hydro, coal, oil, natural gas, nuclear, wind, solar, and geothermal.[1] Energy consumption per capita for the different energy types is presented in Table 1, showing that high-income countries use larger amounts of energy per capita than lower-income countries for each energy type.

Table 1. Primary energy supply per capita by income grouping, 2013.

Tonnes of oil equivalent per capita from energy type:	Biofuels and waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Lower-income	0.18	0.03	0.51	0.29	0.17	0.01	0.00	0.00	0.01	1.21
High-income	0.22	0.10	0.81	1.60	1.45	0.41	0.03	0.01	0.02	4.66
World	0.19	0.05	0.57	0.55	0.42	0.09	0.01	0.01	0.01	1.90

Note: These statistics cover 137 countries. Source: IEA (2015).

For the financial variables in the model, the data are from the Global Financial Development Database (GFDD 2015) with key variables being bank credit to the private sector and outstanding private debt securities. The variable for private sector credit from deposit money banks, divided by GDP, has been a key focus of the empirical literature on the role of private financial institutions in economic outcomes (Čihák et al. 2012). This variable indicates banking sector depth, representing private rather the public sources of capital, and is available for a broad group of countries. In addition to financial institutions, financial markets are also important sources of finance. For the panel regression, I use financial market variables for outstanding debt securities and stock market capitalization to represent financial market depth. To assess the impact of aggregate private credit and debt, I combine three variables to form a composite private debt and credit variable; the three variables are private sector credit from deposit money banks, outstanding domestic private debt securities, and outstanding international private debt securities. Also, I use an aggregate public debt variable, made up of outstanding domestic public debt securities and outstanding international public debt securities. Each financial component variable is divided by GDP. Table 2 shows that there is substantial variation in financial variables between different countries, with the standard deviation for each variable of a similar magnitude to the mean.

[1] Using IEA categories, the coal variable in this paper includes coal, peat, and oilshale. Oil includes crude, natural gas liquids and feedstocks, and oil products.

Table 2. Financial variable descriptive statistics, 1998-2012.

Variable	Minimum	Mean	Maximum	Standard Deviation
Private credit	0.13	0.87	2.73	0.50
Domestic private debt	0.00	0.30	1.63	0.30
International priv. debt	0.00	0.28	3.64	0.45
Private debt and credit	0.15	1.44	6.85	1.03
Public debt	0.03	0.41	1.89	0.27
Equity	0.05	0.76	5.70	0.67

Note: Each variable is divided by GDP. Source: GFDD (2015). There are 551 observations

I show some examples of positive relationships between financial capital and energy types in Figure 2 and Figure 3. Figure 2 shows a positive relationship between domestic private debt and wind energy consumption for the group of high-income countries. For lower-income countries a positive relationship between private credit and coal energy consumption is evident in Figure 3. These scatter plots give an indication of the relationship between financial capital and energy types without controlling for other variables.

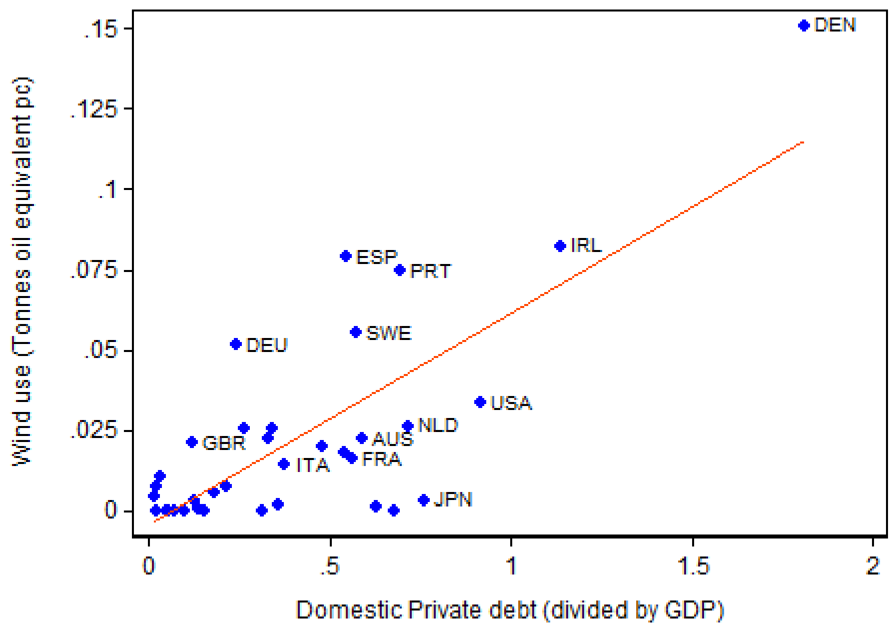

Figure 2. Outstanding domestic private debt securities divided by GDP and wind consumption per capita in tonnes of oil equivalent. 36 countries are included, based on data availability of high-income countries. Sources: IEA, GFDD, WDI

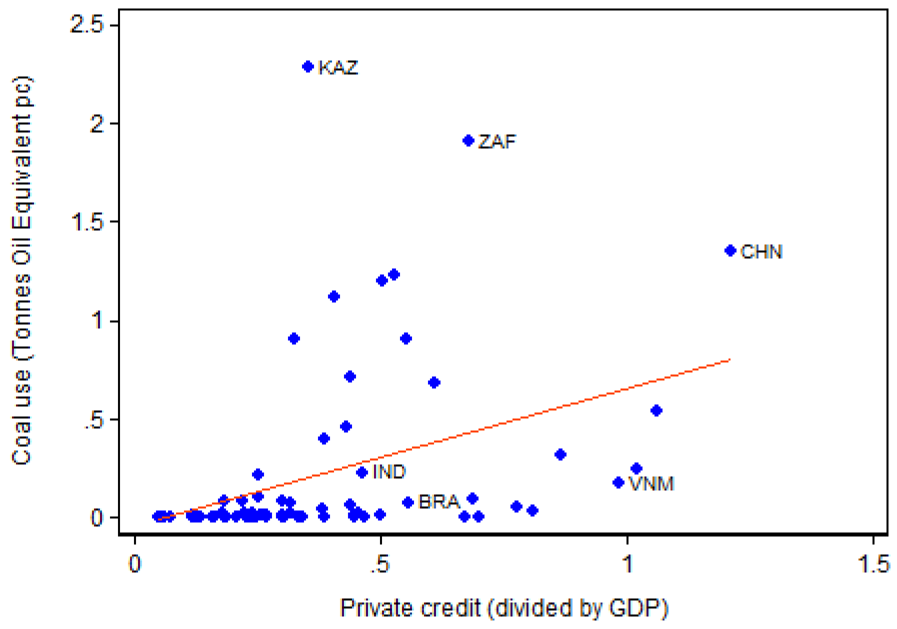

Figure 3. Bank credit to the private sector divided by GDP and coal consumption per capita in tonnes of oil equivalent. 74 lower-income countries are included, based on data availability. Sources: IEA, GFDD, WDI

Other potential determinants that can influence energy type use include the log of GDP per capita, fossil fuel reserves per capita, forest area per capita, land area per capita, average precipitation and temperature, initial total energy consumption per capita, and the percentage change in total energy consumption per capita over the previous five years. I include these controls because GDP and natural resource endowments are important for energy mix (Burke 2010; Burke 2013), and to control for initial energy use. Initial energy use will impact on future energy use because energy production depends on long-lived infrastructure. The growth rate of previous energy use can also impact on future energy use through the impact on predicted energy demand (Popp et al. 2011) and energy investment decisions, and has been found to impact on energy types such as hydro (Pfeiffer and Mulder 2013). Countries with higher growth rates in energy use may pursue energy types which can be more quickly installed and which are cheaper with proven technology at the time of investment. The independent variables are initial values from the start of the ten-year period, with some exceptions; precipitation and temperature are ten-year averages up to 2013, coal reserves are only available for 2011, and the five-year percentage change in energy consumption is for the five years to 2003.

In addition to the key data sources for energy (IEA 2015) and finance (GFDD 2015), I also use some further sources. Fossil fuel reserves are from the United States Energy Information

Administration (EIA 2015c). Fossil fuel reserves are for coal, oil, and natural gas.[2] I use GDP per capita,[3] total population,[4] land area, and forest area data from the World Development Indicators (World Bank 2016). Precipitation and temperature data are from the climate dataset CRU CY v.3.22 from the Climate Research Unit (Harris et al. 2014).

I address the potential for endogeneity in a number of ways. I use a model specification with changes in the dependent variable to reduce the likelihood of reverse causation. When investigating the changes in the energy variables over the ten-year period to 2013, the independent variables are initial values to assess the impact of the historical level effects from the start of the ten-year period. This is especially suitable for financial capital, which may take time to impact on energy production and consumption, due to long lead times in energy investment. Reverse causation from energy types to financial segments is unlikely for modern energy types, such as wind and solar, which are small components of national energy mixes (as shown in Table 1). In contrast, financial sectors are large and mature on average, with the large size in relation to GDP evident in Table 2. The impact of other energy types on financial development would also generally be outweighed by other non-energy sectors, because the finance sector is used by all sectors of the economy and not just the energy sector or just one specific energy type.

A potential source of endogeneity from omitted variable bias could arise from the absence of a policy variable, but this should not be an issue for the key financial variables. While policy variables are important for renewable energy (Zhao et al. 2013), policy support and financial sector size are unlikely to be highly correlated. This relates to financial sectors servicing entire economies rather than just the energy sector, or just single energy types. The implication is that the omission of a policy variable in this paper would not be a major source of bias for the coefficient for the financial sector variables.

To further address potential endogeneity, Eq. (2) uses panel data for the dependent variable in levels. Inclusion of time dummies helps to account for globally-common omitted variables, such as changes over time in global energy prices or technology. Advances in technology have been found to have a small effect in raising investment in some renewable energy types

[2] I use BP (2015) conversion factors to convert oil and gas into thousand tonnes of oil equivalent, and an EIA (2015c) conversion factor to convert coal into thousand tonnes of oil equivalent
[3] Purchasing Power Parity (constant 2011 international dollars)
[4] I use population data from WDI to convert variables into per capita values

in OECD countries (Popp et al. 2011). Country-specific factors, such as time-invariant aspects of institutions or policies, are also accounted for in the fixed-effects model.

Reverse causation for the panel estimation from Eq. (2) could arise in a few special cases, when an energy type has a causal impact on a particular financial market segment. For example, development of geothermal or hydro energy could lead to larger international private debt borrowing, as the combination of high capital intensity, long time horizons, and geological risk factors discourages capital providers in some countries. In response to this possible endogeneity, I use a composite financial variable for debt and credit that includes domestic and international market debt, in addition to domestic bank credit to the private sector. Reverse causation is less likely for an aggregated variable that includes both bank credit and market debt.

4. Results

Table 3 shows results for Eq. (1) for each of the nine energy types and total energy consumption per capita for the full sample of countries.[5] The financial variable, bank credit to the private sector divided by GDP, has positive and statistically significant impacts on two of the nine energy types. Wind and solar energy both have positive coefficients that are statistically significant at the one percent level, indicating that these capital-intensive energy types benefit from greater supplies of financial capital.[6] Other capital-intensive energy types, such as nuclear, do not have significant coefficients for the financial capital variable. Nuclear energy is more reliant on public funding and is not in the same type of rapid growth phase that wind and solar energy are experiencing.

The coefficient for private credit is negative and statistically significant for oil and natural gas. In the natural gas regression, the coefficient for private credit is negative and significant at the five percent level. This suggests that greater supplies of financial capital encourages lower use of energy types with lower capital intensity, such as natural gas energy, and more use of capital-intensive energy types. There is also a negative coefficient for oil energy,

[5] The coefficients for each energy type, and a coefficient for other energy types not included, sum to give the coefficient in the final column labelled total. Other energy types not included make up approximately 0.1 percent of total energy use.

[6] I find similar coefficients for the private credit variable using dependent variables that are the change in per capita energy production, and the level of primary energy supply per capita rather than changes. There is also a positive and significant coefficient for private credit using electricity output from wind. Other robustness tests also produce similar results for the wind regression, including dependent variables for the ten-year period to 2012 instead of 2013, the five-year period to 2013 instead of the ten-year period to 2013, and non-linear estimators including fractional logit and Poisson models.

significant at the one percent level, with more efficient use of oil through technology innovation being a possible explanation. For instance, greater access to finance can support improvements in fuel economy through innovative automobile design. Improvements in fuel economy for average new passenger light-duty vehicles (IEA 2012) are an example of efficiency improvements that allow oil consumption per capita to fall in some countries. Road transport energy use is a large and growing component of final oil consumption (Gao et al. 2015), and is likely a factor in explaining the negative coefficient.

Table 3 also suggests that trends in energy consumption can extend for considerable lengths of time. There is a positive and highly significant coefficient for the percentage change in total primary energy supply for the five years before 2003, in explaining the dependent variable of the ten-year change in total primary energy supply after 2003. Increasing total energy use before 2003 is also associated with greater coal use after 2003. In addition, the coefficient for the level of initial energy use in 2003 is negative for the coal regression and significant at the one percent level. Taken together, the last two points suggest that countries with lower initial levels of energy use, but higher growth rates of energy use, have continued to increase their use of coal.

The variables in the model explain 45 per cent of the cross-country variation in the change of per capita wind energy use.[7] The coefficients of determination for other energy types are also quite high in Table 3. An exception is nuclear energy, with only six per cent of variation explained by the financial and other variables in the model. This is expected given that private financial capital is less suited to funding the diverse risks for nuclear energy. Most nuclear capacity was also added prior to the ten-year period to 2013.

The economic significance of financial capital for wind energy consumption is considerable. For example, a one standard deviation increase in private credit by deposit money banks leads to an increase of 0.5 of one standard deviation for the change in wind energy consumption per capita, all else equal. Also, a 1 percent change in the average value of the private credit variable would lead to a change of 1.1 percent in the dependent variable. Private credit is the only variable in Table 3 that is significant at the one percent level for the wind regression, indicating the importance of financial capital for wind energy growth.

[7] Other variables that could impact energy supply include foreign direct investment and gross capital formation. These variables are not statistically significant when used to replace the financial capital variable.

Table 4 repeats the results for the ten-year changes in energy consumption, but only for high-income countries. The coefficient values for wind and solar energy are very similar between Table 3 and Table 4. The coefficient for private credit is significant at the five percent level for high-income countries in Table 4 for the wind regression, but is no longer significant for the solar regression due to the higher standard error for the smaller sample. Private credit still has a negative relationship with oil energy for high-income countries, with significance at the five percent level.

Other explanatory variables in Table 4 also match expectation. The final column of Table 4 shows a negative coefficient for the log of GDP per capita in explaining the change in total energy use per capita. This suggests that higher income is associated with lower energy use growth. There is a positive coefficient for precipitation in causing hydro increases and a negative coefficient for temperature, highlighting that hydro is more suitable with more available water and lower evaporation. Land area has positive coefficients for hydro and geothermal energy, significant at the one percent level, as more land provides more space for domestic resources. There are less cross-border flows of these energy types compared to fossil fuels which are more readily imported. Reserves of one energy type can substitute for other energy types. For example, countries with larger gas reserves experienced reductions in the amount of oil energy consumed in Table 4, all else equal. Higher reserves of an energy type could also encourage higher use of another energy type. For instance, larger coal reserves are associated with greater solar use in Table 3 and 4, possibly due to concerns over future carbon emissions. Renewable and non-renewable energy are substitutes in some industries but complements in others (Kumar et al. 2015).

The impact of financial capital on energy mix will depend on the current position of countries on the energy ladder (Burke 2013), which is largely determined by income and resources. A key difference in financial capital impact for lower-income countries is evident in Table 5, where there are positive coefficients for the coal and oil regressions, significant at the one percent level. This confirms that financial capital supports transition to the next rung on the energy ladder, which is coal and oil for lower-income countries. The economic significance of the impact of private credit on coal for lower-income countries is considerable. A one standard deviation increase in the private credit variable leads to an increase of 0.7 of one standard deviation in the change in coal use per capita for the lower-income group, all else equal.

Greater supplies of financial capital are also positively associated with higher total energy consumption per capita for the lower-income countries, significant at the one percent level. This is in contrast to the negative but non-significant relationship for high-income countries. For lower-income countries, larger supplies of financial capital have the potential to lessen constraints during periods of energy consumption growth. For high-income countries, the negative impact of financial capital on total primary energy use suggests a potential efficiency effect. Financial capital could be important in the development of more energy-efficient investment and consumption goods.

Larger natural endowments of energy resources lead to greater use of that energy type in lower-income countries, as countries with larger reserves of fossil fuels use greater amounts of their domestic resources. This is similar to the finding of Burke (2010) for the electricity sector. An exception in this paper is for oil, where there is a negative coefficient for the oil reserves variable. This is driven by an outlier, as the negative coefficient disappears when Libya is excluded from the analysis. Libya had a decrease in oil consumption per capita despite large oil reserves, in the context of Libya's ongoing conflict since 2011. Larger amounts of natural resources also lead to positive changes in total primary energy use in lower-income countries on average. As shown in Table 5, this applies for coal reserves, gas reserves, and forest resources, but not oil reserves. The relationship of increasing use of energy types for countries with larger reserves of that energy type does not appear in Table 3 or Table 4. This is because mature energy systems that also have large fossil fuel reserves would have greater use of fossil fuels in both components of the dependent variable (the dependent variable is 2013 energy use per capita less 2003 energy use per capita). There is a positive and significant relationship between fossil fuel reserves and use of that energy type when the dependent variable is in levels.

Table 3. Results, change in primary energy supply per capita for the ten years to 2013

	Dependent variable: Ten-year change in primary energy supply (tonnes oil equivalent per capita)									
	Biofuels and waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Private credit,	0.004	0.025	0.054	-0.294***	-0.340**	0.021	0.022***	0.009***	0.182	-0.337
divided by GDP	(0.023)	(0.031)	(0.084)	(0.101)	(0.150)	(0.055)	(0.007)	(0.003)	(0.155)	(0.268)
Log GDP per capita	0.017**	-0.043	-0.012	0.028	0.009	-0.018	0.002*	0.002***	-0.242	-0.251
	(0.009)	(0.029)	(0.022)	(0.036)	(0.064)	(0.015)	(0.001)	(0.001)	(0.151)	(0.185)
Coal reserves,	-0.037*	-0.123*	-0.005	0.162***	0.107	0.017	0.002	0.007***	-0.596	-0.466
KTOE per capita	(0.019)	(0.074)	(0.123)	(0.058)	(0.164)	(0.027)	(0.003)	(0.002)	(0.377)	(0.514)
Oil reserves,	-0.019**	-0.020	0.075***	-0.013	-0.139	0.015*	-0.003	-0.003***	-0.118	-0.229
KTOE per capita	(0.008)	(0.019)	(0.027)	(0.072)	(0.111)	(0.008)	(0.002)	(0.001)	(0.100)	(0.152)
Gas reserves,	-0.004	-0.017	0.039***	-0.097***	-0.039	0.003	-0.000	-0.000	-0.090	-0.204**
KTOE per capita	(0.004)	(0.012)	(0.013)	(0.030)	(0.061)	(0.003)	(0.001)	(0.000)	(0.062)	(0.090)
Forest area, sq. km,	0.265	-1.995	-1.693	-0.402	0.611	0.410	0.081	0.016	-10.822	-13.806
per capita	(0.363)	(1.464)	(1.090)	(0.948)	(1.715)	(0.337)	(0.054)	(0.018)	(7.787)	(9.871)
Land area sq. km,	-0.273***	1.022	0.413**	0.647*	-0.423	0.115*	-0.043**	-0.033***	5.333	6.795*
per capita	(0.088)	(0.676)	(0.206)	(0.374)	(0.785)	(0.068)	(0.020)	(0.009)	(3.453)	(4.083)
Temperature,	-0.003**	-0.003*	-0.005*	-0.003	0.022**	0.001	-0.000*	0.000**	-0.011	-0.003
ten-year average	(0.001)	(0.002)	(0.003)	(0.006)	(0.009)	(0.002)	(0.000)	(0.000)	(0.008)	(0.014)
Precipitation, meters	-0.003	0.037**	0.059***	-0.006	-0.076	-0.002	-0.002	-0.004***	0.167*	0.169
ten-year average	(0.009)	(0.019)	(0.019)	(0.048)	(0.053)	(0.007)	(0.002)	(0.001)	(0.094)	(0.127)
Initial energy use	0.004	0.028	-0.044***	-0.064**	0.100	-0.002	0.000	-0.000	0.152	0.172
per capita	(0.005)	(0.019)	(0.015)	(0.032)	(0.077)	(0.004)	(0.001)	(0.000)	(0.097)	(0.128)
Change in total	-0.072	0.017	0.427**	0.171	1.388**	0.110***	-0.022**	-0.003	-0.091	1.943***
energy use pc	(0.059)	(0.069)	(0.190)	(0.243)	(0.616)	(0.042)	(0.009)	(0.004)	(0.298)	(0.664)
R^2	0.265	0.448	0.205	0.627	0.438	0.055	0.445	0.379	0.459	0.408

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below the coefficients. All countries are included if data are available. The sample covers 114 countries for coal and solar regressions and 115 for other types. The independent variables are initial values; they are for the year 2003 unless otherwise noted. Coal reserves are for 2011. Temperature and precipitation are 10 year averages to 2013 to measure climate rather than weather. Initial energy use is total primary energy supply per capita. Change in total energy use per capita is a percentage change for the five years to 2003.

Table 4. Results, change in primary energy supply for the ten years to 2013, high-income countries

	Dependent variable: Ten-year change in primary energy supply (tonnes oil equivalent per capita)									
	Biofuels and waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Private credit,	-0.018	0.031	0.019	-0.588**	-0.151	0.044	0.028**	0.009	0.402**	-0.235
divided by GDP	(0.036)	(0.045)	(0.087)	(0.241)	(0.209)	(0.105)	(0.014)	(0.006)	(0.192)	(0.342)
Log GDP per capita	-0.018	-0.089	-0.090	-0.026	-0.347	0.043	0.008	0.004	-0.725***	-1.276***
	(0.053)	(0.057)	(0.092)	(0.321)	(0.353)	(0.051)	(0.011)	(0.007)	(0.246)	(0.451)
Coal reserves,	-0.017	-0.168***	-0.069	-0.004	-0.030	-0.047	0.008	0.010**	-0.784***	-1.056***
KTOE per capita	(0.049)	(0.049)	(0.072)	(0.186)	(0.192)	(0.049)	(0.007)	(0.005)	(0.253)	(0.385)
Oil reserves,	-0.023	0.010	0.112**	-0.047	-0.101	0.006	-0.003	-0.004**	0.032	-0.018
KTOE per capita	(0.021)	(0.015)	(0.044)	(0.081)	(0.095)	(0.018)	(0.004)	(0.002)	(0.069)	(0.123)
Gas reserves,	-0.008	-0.010	0.049**	-0.110**	-0.012	0.007	-0.000	-0.001	-0.077**	-0.164**
KTOE per capita	(0.011)	(0.008)	(0.022)	(0.048)	(0.052)	(0.010)	(0.002)	(0.001)	(0.035)	(0.067)
Forest area, sq. km,	-0.612	-7.872***	-3.899**	-2.667	6.119	2.516*	0.143	-0.010	-41.173***	-48.798***
per capita	(0.885)	(1.327)	(1.866)	(3.548)	(3.803)	(1.384)	(0.177)	(0.103)	(6.360)	(7.736)
Land area, sq. km,	-0.396*	2.607***	0.755*	1.870	-0.579	0.206	-0.087*	-0.052	12.895***	17.110***
per capita	(0.231)	(0.371)	(0.427)	(1.366)	(1.532)	(0.262)	(0.047)	(0.036)	(1.723)	(1.631)
Temperature,	-0.004	-0.010***	-0.008*	-0.001	0.042***	0.004	-0.000	0.000	-0.037***	-0.014
ten-year average	(0.003)	(0.003)	(0.005)	(0.015)	(0.014)	(0.004)	(0.001)	(0.000)	(0.014)	(0.022)
Precipitation, meters	-0.032	0.060**	0.163**	-0.078	-0.056	-0.009	-0.006	-0.009**	0.275**	0.306
ten-year average	(0.031)	(0.028)	(0.069)	(0.214)	(0.147)	(0.034)	(0.007)	(0.004)	(0.120)	(0.301)
Initial energy use	0.010	0.026**	-0.050*	-0.054	0.075	-0.011	-0.000	-0.000	0.182***	0.183**
per capita	(0.015)	(0.012)	(0.027)	(0.071)	(0.078)	(0.013)	(0.003)	(0.002)	(0.053)	(0.093)
Change in total	-0.259	-0.087	0.664*	-0.178	3.293***	0.274	-0.026	-0.001	-0.835	2.850**
energy use pc	(0.191)	(0.157)	(0.356)	(0.775)	(0.854)	(0.168)	(0.033)	(0.021)	(0.736)	(1.172)
R^2	0.391	0.869	0.286	0.668	0.747	0.100	0.401	0.388	0.895	0.845

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below the coefficients. High-income countries are included if data is available. The sample covers 46 countries, but 45 for solar and coal regressions. The independent variables are initial values; they are for the year 2003, but coal reserves are for 2011, as coal reserves are not available in 2003. Temperature and precipitation are 10 year averages to 2013 to measure climate rather than weather. Initial energy use is total primary energy supply per capita in 2003. Change in total energy use per capita is the five-year percentage change to 2003.

Table 5. Results, change in primary energy supply for the ten years to 2013, lower-income countries

	Dependent variable: Ten-year change in primary energy supply (tonnes oil equivalent per capita)									
	Biofuels and waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Private credit,	-0.026	0.007	0.353***	0.181***	0.089	-0.005	-0.001	0.004	-0.008	0.590***
divided by GDP	(0.026)	(0.013)	(0.136)	(0.045)	(0.077)	(0.010)	(0.003)	(0.003)	(0.009)	(0.172)
Log GDP per capita	-0.010	0.004	-0.026	0.016	0.059*	0.001	0.001	0.000	0.003	0.051
	(0.008)	(0.002)	(0.020)	(0.013)	(0.035)	(0.003)	(0.001)	(0.000)	(0.003)	(0.049)
Coal reserves,	-0.022	-0.001	0.392***	0.313***	0.464**	-0.011	-0.004	-0.001	-0.002	1.126***
KTOE per capita	(0.019)	(0.008)	(0.096)	(0.044)	(0.215)	(0.015)	(0.003)	(0.002)	(0.005)	(0.312)
Oil reserves,	-0.006	0.017	0.287	-0.218**	-0.585**	-0.015	-0.004	0.002	-0.002	-0.582
KTOE per capita	(0.049)	(0.022)	(0.184)	(0.111)	(0.255)	(0.024)	(0.005)	(0.005)	(0.010)	(0.383)
Gas reserves,	-0.057	-0.049	0.283	1.069***	2.501***	0.040	-0.018**	-0.019**	-0.024	3.668***
KTOE per capita	(0.079)	(0.034)	(0.293)	(0.190)	(0.459)	(0.041)	(0.008)	(0.009)	(0.029)	(0.632)
Forest area, sq. km,	0.226	0.011	0.250	1.212***	1.298**	0.007	-0.007	0.008	-0.095	2.817***
per capita	(0.296)	(0.097)	(0.398)	(0.314)	(0.569)	(0.030)	(0.008)	(0.006)	(0.065)	(0.919)
Land area, sq. km,	-0.098	-0.034*	0.040	-0.020	-0.416***	-0.010	-0.004	-0.006*	0.023	-0.378
per capita	(0.081)	(0.021)	(0.181)	(0.090)	(0.129)	(0.008)	(0.003)	(0.003)	(0.019)	(0.259)
Temperature	0.001	-0.000	-0.005*	-0.002	-0.001	-0.000	-0.000	-0.000	-0.000	-0.009*
ten-year average	(0.001)	(0.000)	(0.003)	(0.002)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)
Precipitation, meters	0.008	0.003	0.027*	-0.011	-0.008	0.000	-0.000	-0.001**	0.006	0.024
ten-year average	(0.008)	(0.003)	(0.016)	(0.014)	(0.013)	(0.001)	(0.000)	(0.000)	(0.005)	(0.024)
Initial energy use	0.024**	-0.003	-0.057	-0.107***	-0.104	0.001	0.002	0.001	-0.002	-0.244*
per capita	(0.010)	(0.004)	(0.035)	(0.028)	(0.095)	(0.009)	(0.002)	(0.002)	(0.002)	(0.129)
Change in total	0.065	0.032	0.143	-0.081	-0.029	0.006	0.000	0.002	0.029	0.185
energy use pc	(0.048)	(0.033)	(0.115)	(0.054)	(0.112)	(0.007)	(0.002)	(0.002)	(0.025)	(0.210)
R^2	0.093	0.231	0.604	0.564	0.533	0.064	0.239	0.328	0.139	0.679

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors are in brackets below the coefficients. Low-income and middle-income countries, referred to as lower-income countries, are included if data is available. The sample covers 69 countries. The independent variables are initial values; they are for the year 2003, but coal reserves are for 2011, as coal reserves are not available in 2003. Temperature and precipitation are 10 year averages to 2013. Initial energy use is total primary supply per capita in 2003. Change in total energy use per capita is the five-year percentage change to 2003.

Fixed-effects panel estimates in Table 6 confirm the result that financial capital has been important for the transition to wind energy. Using a panel of country data for 1998–2012, I find that bank credit to the private sector has a positive impact on wind energy, significant at the one percent level. This finding of financial capital supporting wind energy use is similar to Brunnschweiler (2010) who finds a positive impact of private credit on renewable energy use for non-OECD countries for the period 1980–2006. Outstanding domestic private debt securities divided by GDP also has a positive association with wind energy consumption in this paper, again significant at the one percent level.[8] Public debt and stock market capitalization are not associated with greater wind energy use and the positive association with the private debt variable is for domestic rather than international securities.

By including additional financial variables in Table 6, compared to the results in Tables 3–5, it is evident that the amount of outstanding international private debt securities is strongly correlated with greater hydro and geothermal energy use. Endogeneity is a potential concern in this instance, as the use of large amounts of hydro or geothermal energy may cause countries to increase their off-shore borrowing from specialist debt suppliers. Specialist finance providers for energy types such as geothermal energy (NREL 2011) deal with the specific combination of risk factors including geological risks. To account for the reverse causation potential, I aggregate private credit and debt variables, with this composite variable labelled as Private credit and debt in Table 7.

The positive relationship of greater private credit and debt causing greater wind energy consumption on average is confirmed in Table 7, with significance at the five percent level. The variables in the model explain 53 percent of the variation for wind energy consumption. In addition to finance favouring wind energy, there is also evidence of finance contributing to the transition away from coal energy in Table 7. This transition away from coal relates to high-income countries as the panel data is comprised primarily of high-income countries, due to greater availability of financial system data for high-income countries. In contrast to the importance of financial capital for wind energy use, other factors such as GDP per capita are more important for some of the fossil fuel energy types. There are positive and significant coefficients for the log of GDP per capita in explaining coal and oil use in Table 6 and Table 7.

[8] The coefficients and the R-squared are similar for the wind regression when using one-year lags, controlling for carbon dioxide emissions, and controlling for the oil price instead of the time dummies.

Table 6. Results, fixed-effects panel estimates, 1998–2012

	Dependent variable: Primary energy supply (tonnes oil equivalent per capita)									
	Biofuels and waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Private credit	0.015	-0.228**	-0.065	0.026	-0.040	-0.007	0.016***	0.003	-0.703**	-0.979**
	(0.021)	(0.110)	(0.041)	(0.051)	(0.043)	(0.021)	(0.005)	(0.002)	(0.295)	(0.416)
Domestic private	0.000	-0.109	-0.017	0.027	0.140*	0.018	0.024***	0.003	-0.695	-0.632
debt securities	(0.046)	(0.105)	(0.080)	(0.097)	(0.080)	(0.033)	(0.009)	(0.005)	(0.464)	(0.689)
International private	-0.014	0.416***	-0.003	-0.119***	-0.049*	-0.007	-0.004	-0.003	1.795***	2.015***
debt securities	(0.015)	(0.137)	(0.022)	(0.031)	(0.029)	(0.015)	(0.005)	(0.002)	(0.556)	(0.716)
Public debt	-0.095**	0.004	0.076	-0.306***	-0.016	-0.119	0.013	0.001	0.195	-0.261
Securities	(0.048)	(0.066)	(0.109)	(0.082)	(0.074)	(0.098)	(0.009)	(0.003)	(0.407)	(0.496)
Stock market	-0.027**	-0.034	0.018	0.102	0.067**	0.011	-0.004	0.001	-0.052	0.077
capitalization	(0.014)	(0.043)	(0.037)	(0.072)	(0.028)	(0.013)	(0.004)	(0.001)	(0.135)	(0.209)
Log GDP	-0.090**	0.166***	0.768***	0.396**	-0.033	0.124	-0.025**	-0.006	0.618**	1.917***
per capita	(0.044)	(0.060)	(0.147)	(0.163)	(0.122)	(0.083)	(0.011)	(0.006)	(0.256)	(0.448)
Temperature	0.006*	0.024**	-0.009	-0.010	-0.045***	-0.006	0.000	0.000	0.072**	0.035
	(0.004)	(0.011)	(0.012)	(0.010)	(0.011)	(0.008)	(0.001)	(0.000)	(0.034)	(0.046)
Precipitation,	-0.009	0.028*	-0.002	-0.041	0.005	-0.013	0.002	-0.001	0.055	0.011
meters	(0.006)	(0.017)	(0.022)	(0.032)	(0.022)	(0.011)	(0.002)	(0.001)	(0.042)	(0.081)
R^2 (within)	0.355	0.516	0.398	0.280	0.346	0.125	0.600	0.249	0.508	0.451

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors clustered by country are in brackets below the coefficients. Coefficients for dummy variables for each year, and coefficients for constant terms, are not shown. All countries are included if data is available. There are 546 observations for solar and 551 observations for the other energy types. This includes 47 countries. All financial variables are divided by GDP.

Table 7. Results, fixed-effects panel estimates, combined private credit and debt variable, 1998–2012

	Dependent variable: Primary energy supply (tonnes oil equivalent per capita)									
	Biofuels, waste	Hydro	Coal	Oil	Natural Gas	Nuclear	Wind	Solar	Geo-thermal	Total
Private credit and debt, divided by GDP	-0.000	0.072	-0.030*	-0.037	-0.013	-0.002	0.009**	0.000	0.382	0.379
	(0.007)	(0.057)	(0.017)	(0.024)	(0.017)	(0.006)	(0.004)	(0.001)	(0.295)	(0.345)
Public debt, divided by GDP	-0.110**	0.288	0.109	-0.366***	0.011	-0.115	0.006	-0.001	1.223	1.028
	(0.045)	(0.243)	(0.093)	(0.083)	(0.067)	(0.093)	(0.009)	(0.003)	(1.103)	(1.296)
Stock market capitalization, divided by GDP	-0.025*	-0.087	0.014	0.115	0.075**	0.012	-0.002	0.001	-0.274	-0.174
	(0.014)	(0.093)	(0.035)	(0.075)	(0.030)	(0.015)	(0.003)	(0.001)	(0.324)	(0.425)
Log GDP per capita	-0.091**	0.166	0.774***	0.401***	-0.003	0.128	-0.023*	-0.006	0.542	1.883**
	(0.044)	(0.133)	(0.142)	(0.155)	(0.118)	(0.081)	(0.013)	(0.006)	(0.561)	(0.755)
Temperature	0.006*	0.025	-0.009	-0.010	-0.046***	-0.007	0.000	0.000	0.079	0.043
	(0.004)	(0.019)	(0.012)	(0.011)	(0.011)	(0.008)	(0.001)	(0.000)	(0.064)	(0.080)
Precipitation, meters	-0.009*	0.024**	-0.001	-0.039	0.011	-0.013	0.002	-0.001	0.024	-0.014
	(0.006)	(0.010)	(0.022)	(0.032)	(0.023)	(0.011)	(0.002)	(0.001)	(0.046)	(0.065)
R^2 (within)	0.351	0.156	0.394	0.271	0.324	0.124	0.525	0.228	0.179	0.159

Notes: ***, **, * show statistical significance at 1, 5 and 10 per cent level respectively. Robust standard errors clustered by country are in brackets below the coefficients. Coefficients for dummy variables for each year, and coefficients for constant terms, are not shown. All countries are included if data is available. There are 546 observations for solar and 551 observations for the other energy types. This includes 47 countries.

5. Conclusion

In this paper I find that financial capital has different impacts for different energy types depending on country development level, using data from 1998–2013 for up to 137 countries. For lower-income countries, the transition is towards fossil fuels such as coal energy. For high-income countries, financial capital supports transitions away from fossil fuels and towards more capital-intensive wind energy. In both cases, financial capital appears to support transition to the next energy type on the energy ladder. Financial capital impacts on energy transitions have economic implications for energy supply and security, and environmental implications for global climate change and local pollution levels.

For high-income countries, financial capital is particularly important for capital-intensive energy types such as wind, and to a lesser degree solar. The structure of financial systems is also important for energy use, as countries with larger pools of domestic credit and debt use more wind energy, all else equal. Other types of financial capital, such as public debt and equity, have not been strongly associated with wind energy expansion.

This paper shows the importance of domestic private capital for energy transitions, but other forms of capital could also play an important role. Greater use of international private capital could be supported by policy to reduce barriers to international finance. In addition, public capital also has a role in supporting new technologies that are perceived by private financial capital providers as too risky, before a track record of returns is established. Public capital is also of greater importance in countries where state owned enterprises have a greater role in the energy sector.

For lower-income countries, the impact of financial capital in contributing to the transition towards fossil fuels such as coal will have a number of implications. Local air quality may deteriorate, with increased pollution from coal energy production, although pressure on deforestation to support biomass energy may reduce. At the global level, financial capital contribution to greater coal use in lower-income countries may exacerbate potential climate change risks.

The results in this paper suggest that countries that have larger financial sectors are more likely to increase their use of more capital-intensive energy types. An implication is that countries that experience growth in their financial sectors could also experience growth in energy types that are more capital-intensive than incumbent energy types. For example, Vietnam could experience growth in coal energy and reduction in biomass share, given that private credit from banks more than doubled in the decade to 2013. For the Netherlands, wind energy could grow considerably, given that private credit from banks increased by over 30 percent in the decade to 2013. Comparison of India and China is also relevant; increasing coal use could be more likely in India than in China given that private credit has increased by more than 60 percent in India in the decade to 2013, but by less than 10 percent in China. Variation in financial sector size and growth could lead to different energy mix paths for countries, but financial capital is only one of the relevant variables.

While financial capital is important for energy transitions, other variables such as income and natural endowments are important for energy types that are established in particular markets. In contrast to renewable energy reliance on financial capital, fossil fuel use is more closely related to income and fossil fuel reserves. Hydro energy depends on availability of water resources.

The importance of financial capital for the composition of energy mixes has implications for government policy. In addition to policy designed to have direct impacts on energy production, such as carbon pricing and feed-in-tariffs, there is also potential for financial policy to have an indirect impact on consumption of different energy types. Financial institutions and policies that influence the size and structure of financial systems have potential to indirectly increase the use of energy types that are more capital intensive than incumbent energy types.

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