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Explaining variation in export credit energy lending: implications for planetary health equity

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ABSTRACT

The achievement of planetary health equity is intimately tied to an equitable energy transition away from fossil fuels and towards renewable forms of energy. International finance has a critical role to play in driving this transition. Export credit agencies (ECAs), which are publicly-controlled bilateral financial institutions, are a particularly important subclass of financial institutions given their outsized role in fossil fuel financing. The proliferation of ECA energy lending has not been equally distributed – some countries have heavily involved in ECA financial flows, either are creditor or debtor countries, while others are largely excluded. Despite the importance of ECAs, we know little about the determinants their investment decisions. In this article, we examine the structural determinants of ECA lending decisions for fossil fuel and renewable energy infrastructure using a dynamic longitudinal network-based approach. Our findings suggest that ECA investments are, in part, endogenously driven by path dependence, information asymmetries, economic externalities, and cross-network effects. These findings point to the importance of implementing policies that facilitate information sharing, reduce local content requirements, and ending ECA financing for fossil fuels.

INTRODUCTION

The motivation for this analysis is driven by a much greater need to understand the structural drivers of the intersecting issues of climate change, inequality and human health and wellbeing – collectively referred to as planetary health equity (PHE) (Frank et al., 2023; Friel et al., 2022). We are at a pivotal juncture in recorded human history. Human activity has caused changes in the earth's climate conditions that jeopardize its capacity to sustain life. The attendant disruption is profound, with climate change impacts ravaging global populations through hotter temperatures, wildfires, and more severe and frequent storms, flooding, and landslides (IPCC, 2023). The disruption caused by climate change is affecting everyone, however it is having the greatest – and generally earliest – impact on the poorest and most disadvantaged populations and nations. This will compound existing economic inequalities within and between nation states. And, as epidemiological evidence demonstrates, climate-related events interacting with inequalities will drive further premature death and disease globally (Romanello et al., 2023).

Ensuring PHE demands urgent action on the common systemic drivers of climate change, inequality and poor health. These drivers come in the potent form of the global consumptogenic system (Friel, 2019)– the system of actors, institutions, policies, commercial activities and norms that incentivizes and rewards the excessive extraction, production and consumption of greenhouse gas-intensive goods and services regardless of the environmental, social and health costs.

Fossil-fuel dependant energy systems are central to the maintenance of the consumptogenic system. A rapid transition away from fossil fuels is therefore essential for planetary health equity. Currently, there are massive inequalities between and within countries access to, and use of renewable energy. For example, the World Bank (2024) notes that inequalities in access to renewable energy are increasing between regions with Sub-Saharan Africa being left behind.

Financial capital plays a vital role in the transformation of the consumptogenic and energy systems. Governments and firms require human capital, infrastructure and materials to enable the transition to renewable energy. Significant financial investment is required to provide that support (OECD, 2023b). Energy investment is characterized by high capital requirements, regulatory intensity, long lead times, and exposure to high levels of political risk (Benavides-Franco et al., 2023; Eyraud et al., 2011; Janzwood et al., 2023). Because of these characteristics, public bilateral financial institutions, such as sovereign wealth funds, development banks, and export credit agencies (ECAs), have a unique role to play in supporting energy development.

Export credit agencies (ECAs) are the most consequential state-supported financial institutions involved in the energy sector – ECAs from G20 countries provided over $1 trillion in fossil-fuel financing from 2006-2022 (OCI, 2022). BY comparison, investments from multilateral financial instititons amounted to roughly $151 billion over the same period. ECAs provide direct loans to energy firms and assist them in mitigating against political and commercial risk through insurance products. ECAs are publicly owned or supported financial institutions that provide financial and insurance products to promote national exports. In contrast to multilateral financial institutions (MFIs) – such as World Bank or International Monetary Fund – or actors engaged in capital markets – including investment banks, corporate finance, and private equity – ECAs are controlled by national governments.

With growing demand for energy, whether in the form of fossil fuels or renewables, many countries have used their ECAs to finance energy development. By 2022, 152 countries had engaged in an ECA energy deal either as creditors or debtors. Some countries were only involved in a limited number of transactions. At the other end of the spectrum, major economies, including the United States, China, Japan, Germany, South Korea, and Great Britain concluded 40 or more deals (OCI, 2022).

Despite the importance of ECAs in financing the energy transition and ultimately affecting planetary health equity, scholarly attention has been primarily focused on MFIs and capital markets. The role of public bilateral financial institutions, particularly ECAs, have been understudied in International Political Economy (Hughes & Downie, 2023; Peterson & Downie, 2023). To the best of our knowledge, there are no studies of the drivers of ECA energy-related lending decisions. In particular, the structural evolution of the network of ECAs energy finance remains unexplored. We aim to close this gap in the literature by providing a longitudinal network-based framework to explain the structural determinants of ECA energy lending. Our approach provides novel insights into the structural drivers of the evolution of the ECA energy network and contributes to the burgeoning IPE literature on relational and network power and position (Oatley et al., 2013; Pagliari & Young, 2014; Winecoff, 2015).

Countries engage in ECA deals for several reasons. First, we find that the externalities, both informational and economic, generated by ECA energy deals creates incentives for "triadic closure" and the forging of deals between the partners of partners. While this network effect influences both fossil fuel and renewable energy deals, its impact is strongest for renewable energy deals. Second, we find evidence of path dependence in fossil fuel investment – countries that received fossil fuel investment were more likely to attract additional investment relative to other countries. Third, we find evidence of cross-network effects between fossil fuel and renewable energy investments. Debtor countries with existing fossil fuel investments are more likely to attract renewable energy investment while creditor countries are less likely to invest in fossil fuel assets in debtor countries with existing renewable energy investments. Finally, our controls also point to the importance of country level factors, and their interactions, in driving ECA energy lending. Alliances increase the chances of an energy deal occurring between countries. Geographical proximity is linked to renewable energy lending but not fossil fuels. Likewise, democracies, for both debtors and creditors, are more likely to participate in renewable energy deals.

The remainder of the paper is organized as follows. In the next section we provide a brief overview of the literature describing the drivers of ECA energy lending. We then develop our theoretical case for network structural effects and present our hypotheses regarding the incentives for triadic closure, preferential attachment, and cross-network effects. The Modelling ECA energy lending section presents our methodological framework. Results are then discussed, and the final section presents our conclusions, implications for PHE, and avenues for future research.

BACKGROUND ON THE PATTERNS OF ECA ENERGY LENDING

Based on the literature, we begin by outlining the key explanations and examples of ECA investments in energy infrastructure, with a focus on the economic, strategic, and diplomatic interests states face when making ECA decisions.

Economic Interests

Export credit agencies serve to promote exports – a key objective of most governments (Moravcsik, 1989). ECAs' services make them valuable assets for countries and firms seeking to expand exports to new markets, where unclear regulatory environments and unfamiliar political systems can otherwise pose a barrier to market entry. The success of East Asian economies in using export growth to drive economic development highlights the importance of exports to national economies (Johnson, 1982; Wade, 1990). More specifically, export finance can improve the competitiveness of domestic firms by underwriting country risk and reducing the cost of finance as well as the potential costs of debt renegotiation or insolvency (Heiland & Yalcin, 2021).

Firms face currency and political risks when exporting goods and services overseas. Market or foreign monetary policy-driven changes can devalue the currencies foreign buyers use for payment (Gianturco, 2001).Changes in regulation can increase projects costs or stop them altogether. Expropriation, adverse foreign court rulings, or violent conflict can lead to the loss of assets or nonpayment. ECAs cover these risks through insurance products, as well as loans to foreign buyers, effectively assuming all payment risks (Blackmon, 2017). These services are particularly useful for firms in the so-called project finance sector, where deals are characterized by the construction of large-scale infrastructure, long lead times, complex regulatory environments, and sovereign buyers. ECAs are known to provide a "halo effect" for transactions, signalling government financial backing that derisks the project in the eyes of private investors (Morrison, 2016).

Strategic Interests

Export credit agencies are employed to serve strategic objectives that advance states' national security positions. Historically, ECAs have played a key role in states' energy security strategies; American and European ECAs underwrote oil and gas infrastructure in Russia and Eastern Europe in the wake of the September 11 attacks to support energy source diversification. Following the United States' invasion of Iraq, the U.S. Export-Import Bank (ExIm) underwrote the risks for hydrocarbon firms' operations in the country, increasing the U.S. footprint in Middle Eastern oil production (Becker & McClenahan, 2003). China has deployed its ECAs to support the construction of the China-Pakistan Economic Corridor, which allows the PRC's oil imports to avoid passing through the Strait of Malacca, where the U.S. Navy maintains a strong presence (Akram & Fareed, 2019; Ji, 2007). In response to the Russian invasion of Ukraine, the U.S. ExIm was enlisted to support the provision of natural gas supplies to Ukraine and Western European allies (Cahill & Palti-Guzman, 2023). ECAs have long been central actors in the minerals sector, which has taken on an intensely strategic dimension as states' compete for access to lithium, cobalt, nickel, and other minerals deemed critical to the energy transition and computing power. The PRC uses its ECAs to develop critical minerals production throughout Africa (Bräutigam, 2010). The U.S. and Australian ECAs have engaged in cooperative actions to increase the supply of critical minerals to allied states (*US, Australia Consider Ex-Im Bank, Public Finance for Critical Mineral Projects - Bloomberg*, n.d.).

Diplomatic Interests

Just as ECAs play a role in states' strategic efforts to enhance their own security position, they may be used to support foreign governments' policy goals to foster diplomatic relationships. The U.S. ExIm was created, in part, to support the development of relations with the then newly-created Soviet Republic by establishing trade with major American manufacturers. Then, in the years following the close of World War II, ExIm played a central role in the postwar reconstruction of Western Europe, helping cement alliances against the Communist Bloc. Throughout the Cold War, U.S. and European ECAs facilitated infrastructure investment in South America and Sub-Saharan Africa, advancing the diplomatic goals of the containment doctrine (Becker & McClenahan, 2003).

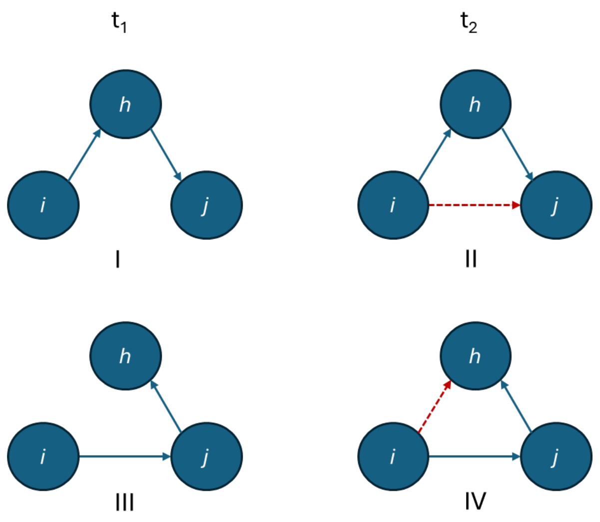
More recently, ECAs have been enlisted to support "energy diplomacy," by underwriting projects that support states' energy security or progress towards national climate goals. Japan's ECAs have been central to its commercial diplomacy in the Pacific, which seeks to build regional relationships through the construction of infrastructure that increases consumptive capacity for the nation's LNG surplus (IEEFA, 2023). Similarly, the United States has supported LNG import and electricity generation infrastructure throughout Latin America and Sub-Saharan Africa, building international relationships and markets for its natural gas exports. The U.S. ExIm financed a large solar generation project in Mozambique (EXIM, 2019) and Export Finance Australia recently concluded a deal to finance offshore wind facilities in Taiwan (EFA, 2023).

Explaining ECA Energy Lending

The structure of the ECA energy network is unlikely to be purely the result of standard domestic or international political economy factors. More specifically, it is implausible that a series of independent dyadic interactions generated the structure of the network. For example, to assume that the decision by Australia to invest in the extraction and transportation of natural gas in Papua New Guinea does not have an impact on Chinese or Japanese investment decisions in the same country appears to be unrealistic. Instead, and following from the nascent but growing network literature in IR and IPE, we advance two theoretical arguments.

First, and following from the literature on international cooperation (Hollway & Koskinen, 2016; Kim & Manger, 2017; Kinne, 2013; Manger et al., 2012) we argue that states have a series of incentives to achieve triadic closure in their lending decisions - one of the most common network effects in real world networks (Granovetter, 1973; Newman et al., 2006). In the ECA context, if countries *i* and *h* are linked by an energy deal and countries *h* and *j* are similarly linked (Panel I in Figure 1), there shoulder a tendency for countries *i* and *j* to close the triangle and form an agreement (Panel II). Similarly, if country *i* invests in country *j* and country *j* invests in country *h* (Panel III), then there should be a tendency for country *i* to invest in country *h* (Panel IV).

Figure 1: Triadic incentives: information and economic externalities



Closure may result from a number of different processes within a network (Juozaitienė & Wit, 2024; Robins et al., 2009). What might drive closure in the ECA context? First, indirect ties serve as a source of information on the risk of investment for ECAs. Investment in energy infrastructure is often in the billions of dollars and may generate considerable risk for ECAs. However, the successful completion of a deal conveys information to third countries about the trustworthiness and reliability of the recipient country. Furthermore, completion of a deal may reveal something about the preferences of either sender or recipient countries regarding the structure and terms of the deal. This dynamic is strengthened by institutional factors most notably the OECD Arrangement on Officially Supported Export Credits which facilitates information sharing between OECD ECAs as well as non-members. The OECD Arrangement explicitly states:

a) The Participants undertake to share information with non-Participants on notifications related to official support.
b) A Participant shall, on the basis of reciprocity, reply to a request from a non-Participant in a competitive situation on the financial terms and conditions offered for its official support, as it would reply to a request from a Participant.

The incentives for triadic closure likely vary according to energy type given the different risk profiles of fossil fuels versus renewables. Several factors make fossil fuel investment seemingly less risky and, as a result, reduce the informational incentives for triadic closure. Fossil fuel technology is more established than renewable energy technology while the rate of innovation in renewable energy technology is higher. Additionally, renewable energy investments are recent relative to the long track record of fossil fuels – countries have lots of experience with fossil fuel energy deals (i.e. they know what can go wrong, how to manage risk, and how to structure deals). Renewable energy investments may entail more risk for investors as the returns are less clear and the output cannot be traded easily on global markets easily (i.e. it is far harder export the energy from a wind farm than to export barrels of oil or liquified natural gas)

Second, dyadic ties can also generate negative externalities for third countries. Investments in energy infrastructure may increase access to energy for creditor countries at the expense of third countries. For example, much of Japanese and Korean investment in Australian natural gas infrastructure is designed to promote gas exports to their home economies. Perhaps more importantly, energy investments may also promote the exports of creditor countries – one of the express purposes of ECAs - at the expense of third countries. For example, even if US exporters have a comparative advantage in certain aspects of renewable energy technology, it is likely that Chinese exporters will reap the lion's share of economic rewards from a Chinese-financed investment. This is especially likely given the presence of local content provisions in ECA energy deals. Taken together, these two mechanisms create an incentive for states to 'close the loop' and engage in triadic closure to mitigate the impact of economic externalities.

The informational and externality mechanisms are not mutually exclusive and may serve as complements rather than substitutes. States may be more likely to engage in ECA deals with those to whom they are indirectly tied because they wish to avoid trade diversion or and have access to privileged information about the trustworthiness and preferences of the "friends of their friends". The point remains that the tendency towards closure may be one of the relational mechanisms that has driven the current topology of the ECA energy landscape.

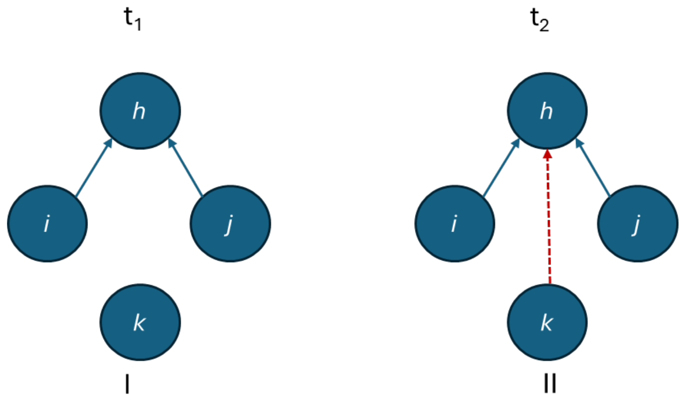
This leads to our first two hypotheses:

Hypothesis 1a: Countries will be more likely engage in ECA deals with the partners of their existing ECA partners.

Hypothesis 1b: This effect should be stronger for renewable energy lending arrangements relative to fossil fuels.

Closure is not the only relational mechanism that impacts the decisions of states. Other network effects – specifically preferential attachment – may influence ECA lending decisions. Preferential attachment, or the tendency of actors to form ties with popular actors or events (as measured by the number of their connections), is another common network property (Newman et al., 2006; Wasserman & Faust, 1994). Many real-world networks, both social and biological, with complex topology, are characterised by a tendency for ties to accumulate on nodes that already occupy central positions - rich nodes get richer (Barabási & Albert, 1999). If countries *i* and *j* both invest in *h* (Panel 1 in Figure 2), there shoulder a tendency for country *k* to also invest in *h* (Panel II).

Figure 2: Path dependence and the rich getting richer



While preferential attachment is a fascinating property, what is of even more interest are the potential mechanisms that drive preferential attachment. Kinne (2013) argues that two causal mechanisms, the conveyance of information about trustworthiness and preferences, underpin preferential attachment in the context of bilateral agreements more generally. Possessing a large number of connections may indicate that a state is more trustworthy while more information about preferences are revealed by each subsequent ECA deal that a state engages in. Building from Kinne and echoing Kim & Manger (2017), we propose that a path dependence mechanism may explain preferential attachment in the context of ECA energy finance.

So how does path dependence relate to preferential attachment between or among states or institutions in the context of ECA energy finance? States that receive a particular form of energy finance are more likely to stick to that path because of the cost associated with deviation. Deviation imposes an informational cost as once a country has negotiated an ECA deal, information about its preferences is revealed. Reputational costs may also count, as countries that deviate are perceived as less trustworthy by potential partners. Having revealed its preferences and conveyed information about its degree of trustworthiness should make a country more attractive to potential partners and more likely to receive investment overtures. At the domestic level, energy investments may create domestic political economy interests centred on maintaining a carbon or renewable energy-based economy. In turn, these interests can be expected to block measures – such as reneging on an energy deal – that could jeopardize future investment. These factors combined should set a country on an energy investment path from which deviation is difficult.

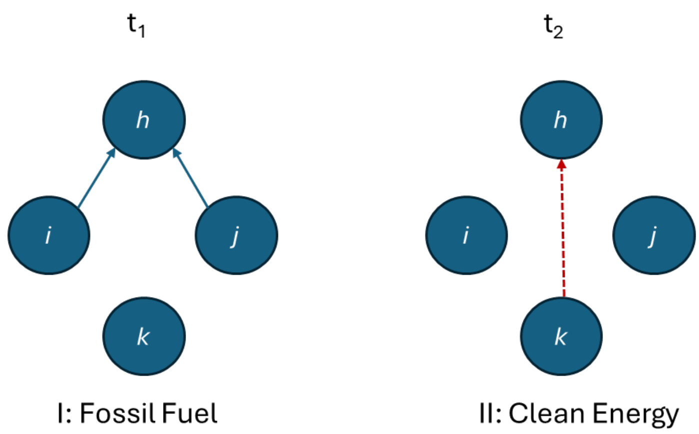
As in the case of triadic closure, it is likely that the strength of the preferential attachment effect varies based on the type of energy investment. Despite the potential importance of informational costs, reputational costs, and the development of domestic political economy interests we must contend with the fact that fossil fuel resources are not homogenously distributed. Given this, it is likely that the preferential attachment effect should be stronger for fossil fuel investments relative to renewable energy investment as those countries that possess fossil fuel resources are likely to attract additional investment by virtue of the fact that they possess fossil fuel assets.

Taken together, this leads to our next two hypothesis:
Hypothesis 2a: The more ECA finance (fossil fuel or renewable) a country engages in, the more likely that it will negotiate further arrangements.

Hypothesis 2b: This path dependence/preferential attachment effect should be stronger for fossil fuels relative to renewable energy.

In addition to within-network interdependencies, i.e. closure and preferential attachment, cross-network interdependence may also influence the decisions of states (Hollway & Koskinen, 2016; Htwe et al., 2020; Milewicz et al., 2018). For example, if a country participates in a fossil fuel deal, this could influence its decision to engage in a renewable energy deal and *vice versa*. More specifically, we are interested in whether investment in one network has an impact on investment decisions in the other network. If country *h* receives ties from *i* and *j* in the fossil fuel network (Panel 1 in Figure 3), this could increase or decrease the chances of *h* receiving a tie from *k* in the renewable energy network (Panel 2).

Figure 3: The codetermination of fossil fuel and renewable energy investment



Investments in the fossil fuel infrastructure of a country may reveal information about its trustworthiness and reliability and, as a result, may make renewable energy investments more likely. Furthermore, countries with existing fossil fuel infrastructure are taking steps to reduce their emissions through green industrial policy and carbon pricing policies (Meckling et al., 2017) while new international norms around emissions are emerging (Green, 2018) which may encourage renewable energy investment on the part of both debtor and creditor countries alike. Renewable energy investment may also help to offset the emissions generated by fossil fuel assets – an attractive proposition for carbon-intensive economies. In addition, renewable energy investments directly support domestic energy demand while fossil fuel investments are often geared towards meeting international demand. In the case of fossil fuel exporters, the emergence of a domestic renewable energy sector does not pose an existential threat to their interests. Taken together, these factors may positively influence the decision of creditors to invest in renewable energy infrastructure in countries with existing fossil fuel infrastructure. This leads to the following hypothesis:

Hypothesis 3a: The more fossil fuel investment a country has received, the more attractive it becomes for renewable energy investment.

A similar informational effect may hold for investments in renewable energy that precede fossil fuel investment. However, we suspect that the non-informational dynamics outlined above will outweigh the informational effect in this case. Put another way, countries that have received significant renewable energy investment will not be amenable to new fossil fuel investment due to the influence of environmental norms and domestic political economy interests generated by green industrial policies. This leads to the following hypothesis:

Hypothesis 3b: The more renewable energy investment a country receives, the less attractive it becomes for fossil fuel investment.

MODELLING ECA ENERGY LENDING

Data for the ECA energy networks was drawn from the Public Finance for Energy Database (OCI, 2022) – to our knowledge the most comprehensive collection of ECA financial data. This dataset cover fossil fuel and renewable energy transactions from 2006-2022 and includes direct funding of domestic and international firms. As we are interested in the drivers of ECA overseas energy investment, we excluded domestic investment from our analysis. Based on the OECD Arrangement on Officially Supported Export Credits (OECD, 2023a), we assume that that funding agreements have an average lifespan of 6 years.

We highlight the evolution of ECA energy lending by examining the renewable energy 'ego networks' of two of the most important creditors – China and the United States. Both country's ECAs have been major funders of renewable energy projects globally.

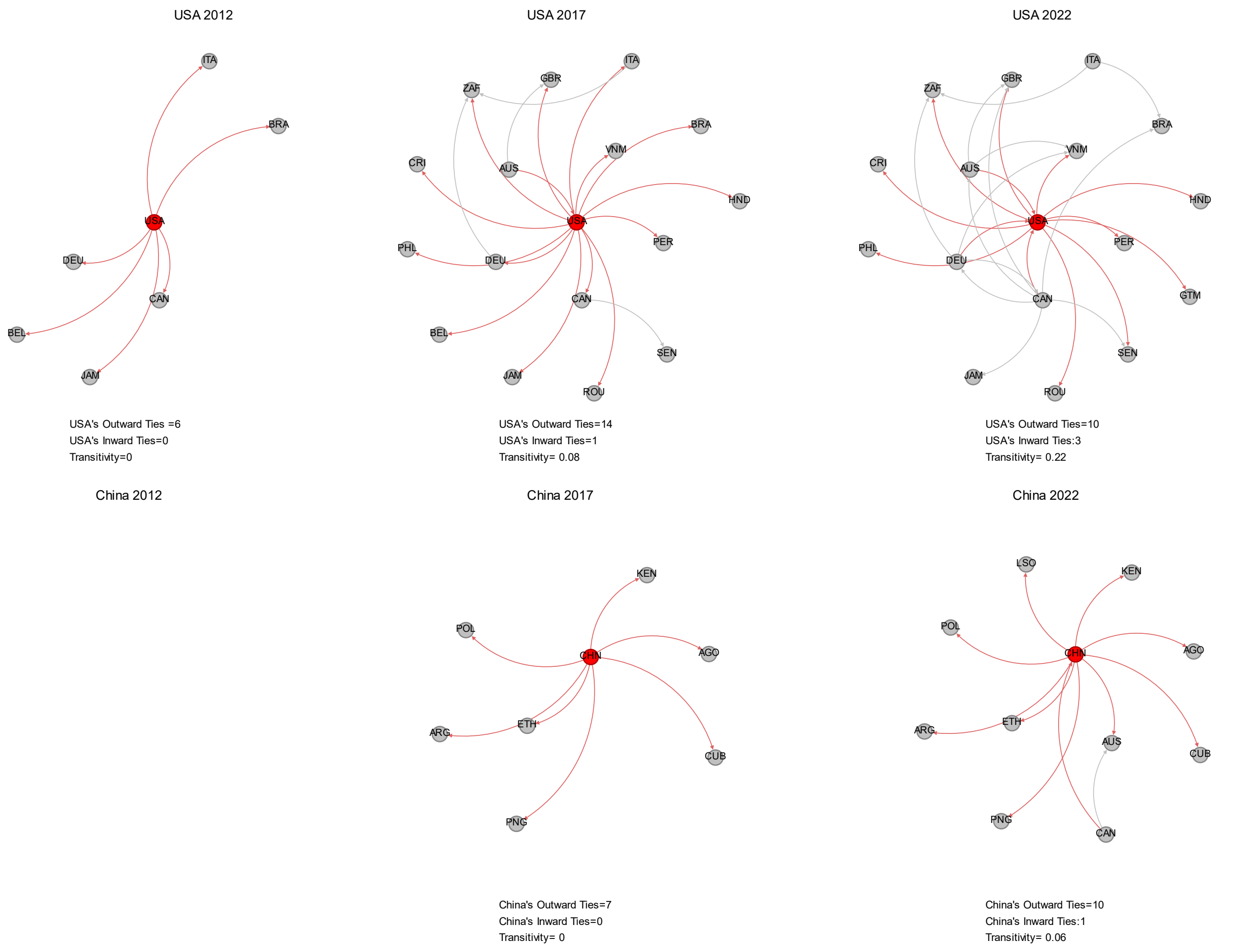
Figure 4 (on the following page) shows the variation in the development of the US' and China's ego networks for renewable energy at 5-year intervals. Relative to China, the US has been more involved in renewable energy deals for the last decade. In 2012, the US had already developed a network of ECA deals with six partners – by contrast, China had yet to sign a single renewable energy deal. Over the next half decade, the US engaged in eight outward investment deal with new partners and participated in an inward deal with Australia. Over this same period, China signed seven outward deals. By 2022, the US's ego network had evolved into an extensive network and increasingly integrated network of inward and outward deals with key economic and strategic partners. China's network during the same period was characterized by a more hierarchical structure with less integration between China's partners.

In IR and IPE, the dominant quantitative approach to modelling the relationships between countries involves the use of dyadic cross-sectional time-series models. Only recently have inferential network methods been turned to longitudinal data. Inferential network methods offer several advantages over traditional dyadic analyses. Typically, dyadic models assume that the ties between variables (ECA energy deals in this case) exist independently of one another once time and dyadic and monadic variables have been controlled for. In the case of ECA lending, this assumption of independence is particularly problematic given that there are very good reasons to assume that the probability of tie formation depends, at least partially, on other ties being formed in the network. For example, it is unrealistic to assume that Chinese energy investment does not take into US or Japanese investment (or *vice versa*). Ignoring dependence in a network is likely to result in specification errors.

Traditional dyadic analysis is also not well-suited to estimating unobserved or higher-order network dependence, such as the tendency towards triadic closure, between actors. Stochastic actor-orientated models (SAOM) provide a way of overcoming the thorny issues associated with interdependence (Snijders, 2001). The basic idea underpinning SAOMs is that actors gauge their position in a network and attempt to maximise their utility by changing ties/relationships with other actors. SAOMs allow one to measure the endogenous effects of network structure (such as closure), individual actor level variables (monadic covariates such as GDP), and dyadic covariates (such as the difference between GDP of two states) simultaneously on network and actor behavioural change. Like other statistical models, SAOMs rely on several simplifying assumptions.

Figure 4: US' and China's ego networks.

Red lines represent ECA deals between the ego and its partners. Grey lines represent deals between the partners of the ego. Transitivity (sometimes referred to as the clustering coefficient) is the overall probability that adjacent nodes are connected – it is calculated by dividing the number of observed closed triangles by the maximum possible number of triangles.



First, the network follows a continuous-time Markov process. The first observation of network ties conditions the model – this observation is not modelled but is used to provide the starting point for the model. This allows SAOMs to do away with the stationary assumption common to time series analysis. Network evolution is assumed to follow a Markov process whereby each change is contingent on the current state of the network $X(t)$ and not past states (Steglich et al., 2010). While observations occur in discrete time, i.e. between t_1,t_2,t_3 etc, the underling process of network change, which is unobserved, is assumed to be continuous.

Second, only one actor may change a single tie, "ministeps" in SAOM language, at each step of the simulation. When applied to ECAs, this would assume that a country can only create or terminate a single tie at each ministep. In turn, the ministeps create the context within which actors make decisions – an endogenous process. We assume that when Canadian firms extend export credit to US companies, this changes the investment climate for both countries as well as for all other countries in the system. Put another way, each ministep has an impact on the probabilities of tie formation for all actors. Actors – countries for the purposes of this paper – decide to terminate or create a tie based on maximizing their respective objective functions.

ECA deals are modelled as a directed network as we have information on the recipients and senders of investment. Unlike in the case of non-directed networks (such as trade agreements), there is no assumption that actors coordinate changes in their ties – i.e. Canada could terminate its support for fossil fuel firms in the US without the consent of those firms. Put another way, a change in ties in the network is contingent on the actions of a single actor rather than a dyad. The initiating country (*i*) has three choices: create a new tie with country *j*, maintain the status quo with *j*, or terminate a tie with *j* (Table 1).

Table 1: Directed Tie Formation

Time 1	Time 2	
i j	$i \rightarrow j$	*Creation of ECA agreement*
i j	*i j*	*Maintenance of ECA agreement*
$i \rightarrow j$	$i \rightarrow j$	*Maintenance of ECA agreement*
$i \rightarrow j$	*i j*	*Termination of ECA agreement*

Longitudinal Network Data

As we assume that different factors drive investment decisions for fossil fuels and renewable energy and that the renewable energy and fossil fuel investment co-evolve with one another, we created two separate networks – a renewable energy network and a fossil fuel network. We broke each network into three waves: 2006-2012, 2013-2017, and 2018-2022. These waves coincide with end of the Global Financial Crisis, the start of China's Belt and Road Initiative, and the start of overt US-China geoeconomic competition. The starting wave period is longer due to the sparsity of renewable energy deals in the early years of network which posed a problem for convergence.

Our network dependent variables are $N{*}M{*}T$ arrays where the presence of a tie is binary - 1 for a ECA energy deal and 0 for its absence. N corresponds to the number of countries engaged in some form of ECA deal (152), M to the number of possible tie partners (152), and T to the number of observations points or waves (3).

Our model includes several control variables, proximity and political risk, which are commonly featured in studies on the determinants of investment. Distance data was sourced from the *GeoDist Database on Bilateral Geographical Information* (Mayer & Zignago, 2011) and political risk was drawn from *World Governance Indicators* (Kaufmann & Kraay, 2023).

There is a debate in the investment literature as to the role of regime type in promoting economic growth and, consequently, the investment decisions of foreign investors (Biswas, 2002). We include regime type, based on data from *Varieties of Democracy* project (Coppedge et al., 2022), to control for a similar dynamic with respect to ECA lending decisions. More specifically, we control for the democracy level of creditor countries as well as the similarity in regime type between debtors and creditors. This specification allows us to pick on homophilic tendencies of debtors and creditors based on regime affinity. We also control for the potential geopolitical drivers of ECA investment by including an alliance variable, sourced from the *Alliance Treaty Obligations and Provisions Project* (Leeds et al., 2002).

We also include several variables to control for the potential trade creation effects of ECA lending for creditor countries as these may influence ECA lending decisions. The more a creditor country relies on trade to drive economic growth, the more beneficial ECA activity should be to it. We therefore include a variable (trade share of GDP) sourced from the *World Bank Development Indicators* (World Bank, 2022). Similarly, we include the log transformed gross domestic product (GDP), sourced from the *World Bank Development Indicators*, for recipient countries. The intuition being that larger (debtor) markets are more attractive to ECAs as these market are likely to generate greater demand for exports from creditor countries.

In addition to these controls, we include several structural variables that capture closure, preferential attachment, and cross-network effects. These are expanded on in the next section.

Estimation

In order to analyse the evolution of the two networks, we utilize the Simulation Investigation for Empirical Network Analysis package for R (RSIENA) (Ripley et al., 2020; Snijders & Pickup, 2016). Due, in part, to its novelty, RSIENA is not extensively employed in political science or economics although the number of studies that use it to analyse tie formation is growing (Ingold & Fischer, 2014; Kim & Manger, 2017; Manger & Pickup, 2016; Milewicz et al., 2018; Rhue & Sundararajan, 2014)

The RSIENA package uses an objective function to capture the preferences of states with respect to tie formation within the context of the network. This objective function, technically the network objective function, is composed of a combination of network structural effects, dyadic covariate effects, and monadic covariate effects:

$$f_i(\beta, x) = \sum_{k=1} \beta_k S_{ik}(x) + \epsilon(x, z, t, j)$$

$fi(\beta,x)$ is the value of the network objective function for actor *i*. The network objective function is made up of the state of the network (x), parameter estimates (βk), effects (Sik) including network structure, and monadic and dyadic covariates, and a random disturbance term with a Gumbel distribution ($\epsilon(x,z,t,j)$) . The state of the network (x) captures whether a tie exists (1) or doesn't (0).

RSIENA uses a large number of repeated simulations from each wave/time point to model the ministeps that drive network dynamics. Ideally, this produces parameter values for the simulated networks that approximate those of the observed networks. Because the model generates parameter estimates that are approximately normal, it is possible to utilize the traditional tools of statistical inference (Snijders & Pickup, 2016).

Once parameter estimates have been generated, the convergence of the algorithm and individual parameter estimates have to be checked. This requires checking both the t-ratios for individual parameter estimates and the overall maximum convergence ratio (average deviation/standard deviation). In a perfect world, the deviation between simulated value and observed values would be zero. In reality, deviations are not 0 but are very small and good convergence is achieved when the t-ratios for individual parameter estimates are less than |0.1| and overall maximum convergence is (approximately) less than 0.3.

Our network objective function includes endogenous structural covariates – termed effects in network speak – which are required to test our hypotheses as well as a series of covariates (primarily as controls). The first structural effect that we include is the outdegree effect:

$$s_1^{net}(x) = \sum_j x_{ij}$$

The value of the outdegree (or density) effect takes a 1 when a tie exists between *i* and *j* and a 0 if it does not. The value of the effect is not particularly interesting – it is somewhat analogous to an intercept in a traditional regression framework – but does have to be included to control for the number of existing ECA deals in the two networks.

Second, we also control for reciprocity – the tendency of actors to return ties within a network. While we do not expect extensive reciprocity to occur in the network due to the nature of debtor-creditor relationships, it is still important to control for this effect. This effect is defined by the number of reciprocated ties between *i* and *j*.

$$s_1^{net}(x) = \sum_j x_{ij}\, x_{ji}$$

Third, we include a structural effect to capture the extent of triadic closure within each of the two networks and to test **hypothesis 1**. It is important to note that we refer to the ego (network parlance for the country in question) as *i*, a partner as *j* and a third country as *h*.

$$s_1^{net}(x) = x_{ij} \sum_{j,h} x_{ij}\, x_{ih} x_{hj}$$

The value for closure is defined by the number of transitive paths in *i*'s relations with *j* and *h* when *i* is tied to both *h* and *j* (and *i* is the originator of the tie). This effect operationalizes the tendency of creditor countries to invest in the partners of their partners within the fossil fuel and renewable energy networks. Comparing the importance of this effect across the two networks allows us to directly observe if there is support for **hypotheses 1a and 1b**.

Fourth, we include an effect to measure the number of incoming ties to test **hypotheses 2a and 2b**. This effect – preferential attachment – helps to operationalize path dependence in the two networks as it will show whether countries that receive incoming ties make for more attractive partners (from a creditor perspective) relative to countries either without or with lower levels of ties.

$$s_1^{net}(x) = \sum_j x_{ij} \sqrt{\sum_h x_{hj}}$$

This measure is defined by the sum of the square roots of the indegree of *j* to which country *i* is tied to. The square root is included as we assume that the effect of an initial energy deal is larger than subsequent deals.

Fifth, we included an effect to capture the influence of incoming ties in one network on incoming ties in the other network. This measure is defined by centred sum of the *w* indegrees for countries tied to country *i*. *w* Degrees are centred to reduce correlations with other structural variables.

$$s_1^{net}(x) = \sum_j x_{ij}(\sqrt{w+j}) - \sqrt{w}$$

Country dummies could not be included as this would cause problems for estimation and convergence. Year-specific rate parameters, analogous to fixed-effects in a traditional regression framework, were included in order to pick up systemic time-varying trends.

RESULTS

Table 2 (following page) presents our final parameter estimates along with significance levels based on t-statistics. The convergence t-ratios for individual parameter estimates were less than |0.1| and the overall convergence ratio was 0.14. The algorithm is considered to have converged well if convergence ratios for individual parameter estimates are less than |0.1|. A more demanding requirement for excellent convergence is for the overall convergence ratios to not exceed 0.25 (Ripley et al., 2020).

It is helpful to think of the network objective function in much the same manner as one would a logistic regression. The estimated parameters of the effects can be used to calculate the probability, ceteris paribus, of an ECA deal in each network. The parameter estimates can be interpreted as log-probability ratios (as in the case of logistic regression) or, exponentiating the estimates, as the multiplicative increase in the probability of tie formation given a one unit increase in a covariate. For example, the exponent of the alliance estimate ($e^{0.366}$) in the fossil fuel network shows that, all things being equal, an alliance between countries increases the probability of fossil fuel investment by 44% (Table 2).

Structural Drivers of ECA Lending: Closure, preferential attachment and cross-network dependencies

The three structural effects – closure, preferential attachment, and cross-network interdependencies – are of substantive interest. The positive and significant parameter estimates for closure across both networks supports the idea that countries will seek to engage in ECA deals with the partners of their existing ECA partners (hypothesis 1a). Confirming hypothesis 1b, there is a stronger closure effect for renewable energy deals relative to fossil fuel investment. The estimate for closure in the renewable energy network was more than ten times as large as in the fossil fuel network, which indicates that the informational and/or trade diversion mechanisms are much stronger with respect to renewable energy deals. This makes sense as renewable energy deals provide more information on trustworthiness and preferences than fossil fuel deals as well as magnifying potential trade diversion in increasingly important economic and strategic industries such as wind and solar.

The parameter estimates for preferential attachment yield mixed results. First, the positive and significant estimate for the fossil fuel network suggests that countries that have received fossil fuel investment make for more attractive investment destinations relative to countries without existing investment. This partially supports hypothesis 2a. However, the parameter estimate for preferential attachment in the renewable energy network was neither positive or significant and does not support hypothesis 2b.

Confirming hypothesis 3a, we find evidence that debtor countries with many fossil fuel investments make for more attractive destinations for renewable energy investment. Confirming hypothesis 3b, we find evidence that creditor countries avoid making fossil fuel investments in debtor countries with many renewable energy investments. Further research is needed to untangle the drivers of the variance between these outcomes.

Table 2: Estimation Results

Fossil Fuel Network			
Effect	par.	(s.e.)	t stat.
Intercept (Density)	−3.637***	(0.274)	−13.273
Reciprocity	−5.869**	(2.241)	−2.619
Indirect ties (transitive triplets)	0.913***	(0.152)	5.999
Popularity (degree, sqrt)	0.308**	(0.110)	2.792
Alliance	0.366*	(0.152)	2.409
Trade-GDP ratio (ego)	0.003***	(0.001)	3.745
GDP (alter)	−0.008	(0.020)	−0.367
Distance (similarity)	0.474	(0.296)	1.599
Democracy (ego)	−0.495	(0.303)	−1.635
Democracy (similarity)	0.402†	(0.231)	1.743
Risk (alter)	0.083	(0.052)	1.615
Clean-network popularity (indegree, sqrt)	−0.394*	(0.156)	−2.521
Clean Energy Network			
Effect	par.	(s.e.)	t stat.
Intercept (Density)	−4.432***	(0.538)	−8.234
Reciprocity	−19.942*	(7.763)	−2.569
Indirect ties (transitive triplets)	10.037**	(3.196)	3.141
Popularity (degree, sqrt)	−0.930	(0.616)	−1.510
Alliance	1.164***	(0.295)	3.948
Trade-GDP ratio (ego)	0.011*	(0.005)	2.182
GDP (alter)	−0.038	(0.047)	−0.824
Distance (similarity)	1.691*	(0.747)	2.263
Democracy (ego)	−2.960**	(0.906)	−3.268
Democracy (similarity)	1.129*	(0.555)	2.034
Risk (alter)	0.178	(0.128)	1.387
Fossil fuel network popularity (indegree, sqrt)	0.594**	(0.193)	3.076

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;
all convergence t ratios < 0.06.
Overall maximum convergence ratio 0.14.

Controls: Reciprocity, Alliances, Geography, Democracy and Trade

The controls reveal several interesting results. First, the negative parameter estimates for reciprocity in both the fossil fuel and renewable energy network suggests that ECA lending is not bidirectional between countries. Second, the result that an alliance makes countries more likely to engage in an energy deal is particularly interesting. The result in the renewable energy network is almost four times as large relative to the fossil fuel network which suggests that the security externalities generated by renewable energy lending are great than for fossil fuels. Third, distance between debtor and creditor countries appears to play an important role in lending decisions in only the renewable energy network. This may reflect both the heterogenous nature of fossil fuel reserves as well as the relative ease with which fossil fuels can be transported. The result could also be interpreted as trend towards regionalism in the renewable energy network. Fourth, our covariate for democracy (ego) and similarity are both significant in the renewable energy network. These results must be interpreted together – the probability of a renewable energy deal increases with the level of democracy but, critically, this only occurs if both countries are democracies. If both countries aren't at least relatively democratic, the probability of a renewable energy deal decreases. This result suggests that ECAs in democracies not only actively engage with other democracies, but that they also tend not to engage with undemocratic countries. Finally, the control for the trade dependence of creditor countries is significant in both networks which speaks to the export promotion purpose of ECAs.

Robustness Checks

We employed several different specifications across our model to check the robustness of our results (available in the online appendix). We included additional controls for the level of development of creditor and debtor countries to test whether income effects drive investment decisions. This specification did not alter any of our substantive results. However, the negative and statistically significant estimate for creditor country GDP per capita in the fossil network suggests that as creditor income level increases, the probability of new fossil fuel investment decreases. We also controlled for OECD membership as OECD members have agreed to certain constraints on fossil fuel lending. Again, the inclusion of these controls did not alter our results. Given the potential of trade agreements on both trade and informational flows, we controlled for the presence of a trade agreement between ECA partners. Again, this did not change our substantive results.

CONCLUSION

The formation of ECA energy deals has important implications for addressing climate change and reducing global inequality – both of which are important for promoting planetary health equity. The formation of ECA energy deals have systemic effects that conventional modelling approaches are not well-suited to capturing. To remedy this, we employed a simulation-based model of the coevolution model network to capture these effects.

We find that ECA energy lending, for both fossil fuels and renewable energy, creates strong incentives for triadic closure. Countries prefer to sign energy deals with the partners of their partners which points the presence of a potential informational mechanism as well as a economic externality mechanism. We also find evidence of path dependence in the fossil fuel network – countries that receive fossil fuel investment make for more attractive destinations of additional investment – but not in the renewable energy network. Our results indicate that renewable energy and fossil fuel investments co-evolve with one another. Existing fossil fuel investment may, somewhat counterintuitively, spur new renewable energy investment while existing renewable energy investment does not support new fossil fuel investment.

Independently of these structural effects, we identify a number of political and economic factors that influence ECA energy investment decisions. Alliances between countries increases the probability of an energy deal, although this effect is stronger for renewable energy investment relative to fossil fuels. Distance plays an important role in the renewable energy investment decisions, but not in fossil fuel decisions. Similarly, democracy positively conditions the probability of a renewable energy deal – democracies prefer to channel ECA renewable energy investment to other democracies. Our analysis also shows that the trade dependency is a correlate, albeit a marginal one, for investment decisions for both renewable energy and fossil fuels.

These findings have several important implications for the achievement of PHE. First, the tendency towards triadic closure highlights the importance of increasing information sharing, particularly for renewable energy investment, and implementing policies, such as loosening local content requirements, that mitigate against potential negative economic externalities for third countries. Failure to do so could hasten the emergence of “renewable energy clubs” composed of countries that are densely tied to one and other relative to the rest of the network. The political and economic factors we identified, lends further credence to this possibility as allies, democracies, and geographically proximate countries sort themselves into these clubs and exclude non-club members – the end result being that non-club members find themselves locked out of the energy transition. Second, the tendency towards path dependency for fossil fuel investment, and concomitant risk of carbon lock-in, points to the importance of ending ECA-provided fossil fuel finance. If ECAs end fossil fuel financing, it would mark an important step away from a future characterized by carbon lock-in and help to support the achievement of PHE outcomes. Third, as our results indicate that renewable energy investments reduce the likelihood of additional fossil fuel investment, policies that expand the exporting capacity for renewable energy goods and services will not only boost enhance the energy transition by providing additional renewable supply, but will also serve as a bulwark against further fossil fuel investment.

Our findings make important contributions to the literature on climate finance and PHE, in which export-credit agencies’ role remains understudied. Energy transition forecasts determine that as much as $USD 1 trillion per year must be invested in climate-compatible infrastructure to avert the worst effects of catastrophic climate change. However, despite recent notable increases in such funding, the majority has been concentrated amongst highly developed countries. Researchers and practitioners should closely consider how barriers to investment, such as a lack of borrower credit history, can be overcome with the considerable financial and informational resources at ECAs’ disposal. Conversely analysts can consider how to further capitalize on the benefits of past transaction experience to accelerate the still relatively miniscule share of renewable energy lending in global export finance.

Looking beyond ECAs, one must ask the question of whether network effects condition energy finance from public bilateral development finance institutions, multilateral development banks, and capital markets? Our approach of simultaneously tracing the structural, monadic, and dyadic determinants of ECAs could be brought to bear on this question. It could also be deployed to examine other areas of International Political Economy such as non-investment provisions (such as health and climate provision) in international investment agreements, international tax agreements, or international environmental agreements.

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ABOUT US

Humanity faces three major and interconnected challenges – climate change, social inequality, and premature death and disease. Governance approaches to date have failed to prevent these problems, and in many cases have made the situation worse.

The Planetary Health Equity Hothouse is here to generate new ways to address these failings. By centring governance goals around planetary health equity, we aim to promote the equitable enjoyment of good health within a stable Earth system.

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