

Biophysical Constraints on the Bretton Woods System: Embodied Crude Oil Trade and the US Energy Balance

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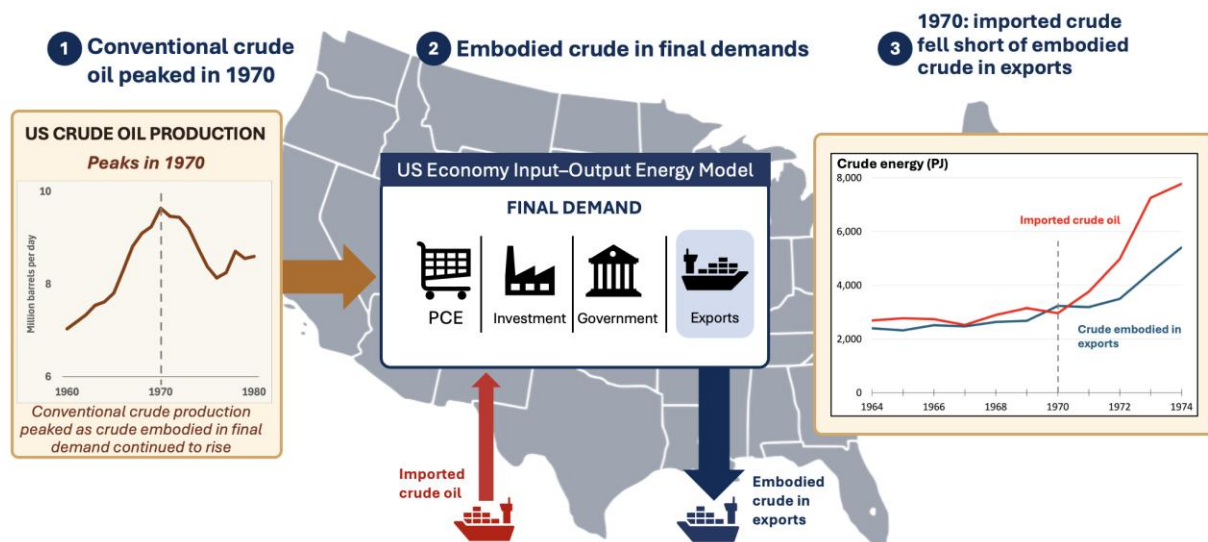
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Highlights:

- Instability of the Bretton Woods system had a biophysical dimension
- End of Bretton Woods convertibility occurred 9 months after US peak conventional oil
- US exports were dependent on imported petroleum energy
- Crude embodied in exports briefly exceeded crude imports in 1970, peak oil year
- The 1971 US trade deficit is avoided under a “no peak” oil counterfactual

Graphical Abstract:



Biophysical Constraints on the Bretton Woods System: Embodied Crude Oil Trade and the US Energy Balance

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Abstract:

The collapse of the Bretton Woods financial system is typically explained as a balance-of-payments deficit, accompanied by other factors such as rising inflation, and the Vietnam War. Alongside these mechanisms the collapse should also be interpreted as a biophysical crude oil energy imbalance that coincided with peak United States conventional crude oil production. Using historical input-output tables, embodied energy intensity vectors, export data, and imported crude oil series, the crude oil embodied in exports is compared to raw imported crude oil. The results show that United States exports were becoming increasingly petroleum-intensive outweighing all other energy carriers. For most of the 1960s the United States operated on a positive imported oil to embodied oil in exports relationship, with a brief reversal in 1970, one year before the collapse of the Bretton Woods system in 1971. After the end of the Bretton Woods system this relationship widened rapidly creating a growing dependence on imported crude oil. The paper creates counterfactual historical scenarios in which there is no domestic crude oil peak in 1970, to test whether the balance of payments could have remained positive. The counterfactual analysis shows that the no peak scenario would have allowed US net exports to remain positive in 1971, thereby potentially avoiding collapse of the financial system. These findings suggest that the end of the Bretton Woods system was influenced by the United States inability to meet crude oil demand to maintain its external monetary position.

1. INTRODUCTION

The breakdown of the Bretton Woods monetary system is usually explained in financial and institutional terms. Standard accounts emphasize the growing US balance-of-payments deficit, how the growth of U.S. dollar liabilities abroad grew faster than the U.S. gold reserves, rising inflation, and the inability of the United States to maintain gold convertibility at the fixed price

of \$35 per ounce (Triffin 1960; Bordo and Eichengreen 1993; Eichengreen 2019; Truman 2017). These explanations leave open the question: was there a material structure underlying the Bretton Woods that deteriorated, requiring the monetary system to end? Standard monetary and institutional accounts tend to treat trade and external imbalance primarily as a financial phenomenon, there is little attention to the energy basis of production and exchange. The late Bretton Woods period coincided with a major shift in the US energy system, most notably the peaking of conventional crude oil production in November 1970 and the growing reliance on imported petroleum afterwards.

The paper follows a biophysical economic understanding that macroeconomic systems are not independent of the material throughput within them and are sustained by continuous flows of high-quality energy. These high-quality energy flows, such as crude oil, support production, transport, trade, and capital accumulation within an economy (Ayres 1998; Ayres and Warr 2005; Melgar-Melgar and Hall 2020; Kennedy 2024). When the energy base of an economy changes, there can be cascading economic effects which can undermine the financial order. For the United States, the late 1960s and early 1970s marked such a tipping point in the internal production and external trade of crude oil. The postwar US economy had been built around an abundance of domestic petroleum. This abundance enabled large industrial production, highway transportation networks, suburbanization, and military capacity all of which required crude oil either directly or indirectly. In the 1970s the country remained a dominant industrial and monetary power, but its domestic oil abundance was no longer growing with peak conventional production in 1970. The US exports were deeply embedded in petroleum-dependent production structures, requiring large amounts of crude to develop capital. Imported crude oil had for a long time been able to meet the requirements of the oil embodied in the exports. When peak oil production coincided with an inability of imported crude to cover embodied exports the US economy was at a tipping point. The Bretton Woods created a ridged financial system susceptible to energy transition disturbances. The weakening of the US external balance under Bretton Woods reflects not only financial pressures, but this worsening physical energy relationship between the United States and the rest of the world.

The primary method of the paper uses historical input output (IO) tables from the US Bureau of Economic Analysis (BEA) and preexisting embodied energy intensity estimates to track energy flows throughout the economy. Primarily the work focuses on embodied crude oil flows in the exported final demand sector of the US economy. The IO model treats the US economy as a domestic system and the embodied crude exports are compared to the imported crude oil energy during the late Bretton Woods era. The use of a counterfactual “no peak” domestic crude oil production estimates what would have happened if domestic production followed a pre-1970 linear trend line. This was undertaken to examine how continued domestic oil

availability and different allocation mechanisms might have altered total output and net exports. Exploring how the rigid US monetary organization under Bretton Woods rested on an increasingly dependent import and export crude oil structure. Reconstructing the crude oil embodied in US exports and comparing it with imported crude oil during the late Bretton Woods period provides a way to examine US external performance not only in nominal trade terms, but also in physical energy terms.

2. LITERATURE REVIEW

2.1. Energy, Macroeconomics, and Systemic Constraints

Biophysical economics suggests that macroeconomic systems cannot be understood independently of their material and energetic foundations. This means production, trade, and capital accumulation are sustained by continuous flows of low-entropy matter and energy. Melgar-Melgar and Hall argue that ecological economics was originally founded on the premise: that social and economic systems are embedded within the biophysical world, and that economic activity depends fundamentally on energy and material throughput rather than existing as a self-contained exchange system (Melgar-Melgar and Hall 2020).

This idea was developed further in work that helped link energy use directly to macroeconomic performance. Ayres argued that economic systems should be understood as thermodynamically open systems which operate on the transformation of energy and materials, rather than as solely circular exchange systems governed only by the prices and preferences of those who exist in them (Ayres 1998). Ayres and Warr (2005) found that a large share of modern economic growth can be better explained by the increases in useful work within economies rather than by increases in capital and labour alone. Their work challenged conventional macroeconomic approaches which would treat energy as a small transitional input and in its place suggested that the changes in energy quality and conversion efficiency have played a major role in explaining economic development (Ayres and Warr 2005).

Kennedy (2024) extended this line of argument from economic growth to the macroeconomic policy paradigm shifts. He pointed out that there were distinct energy regime shifts during major US macroeconomic eras in the twentieth century. The pre-Keynesian era (up to 1929) was dominated by coal, the Keynesian era (1930-1973) had abundant domestic crude oil, and afterwards the Monetarist era (1973 onwards) was increasingly energy constrained. This indicated that the macroeconomic policy regimes were rooted in changes of energy supply and dominate energy systems. Within this framework, Kennedy contends that the collapse of the Bretton Woods system coincided with the peak of US conventional oil production and suggests

that declining domestic energy availability formed part of the structural transition leading to the First Oil Crisis of 1973 (Kennedy 2024).

This argument is consistent with earlier research on oil and macroeconomic disruption. Hamilton showed that, with one exception, every US recession after the Second World War up to the early 1980s was preceded by an increase in oil prices (Hamilton 1985). He went further to point out that these oil shocks were largely exogenous to the US economy itself, and that they arose instead from global disruptions in the petroleum supply. Hamilton's work is not a general theory of macroeconomic paradigms, but it does provide strong evidence that oil supply and markets are tightly linked to and macroeconomic performance. If the US economy depended on abundant domestic oil during the height of the Bretton Woods era, then the peaking of conventional crude oil production may have had consequences extending beyond the energy sector and into trade, external balance, and finally monetary leadership.

2.2. Historical Energy Transitions and US Peak Oil

Since the 1930s, the US had seen steady increases in domestic crude oil production. The peak domestic crude oil production in 1970 confirmed predictions that the US conventional reserves were entering a plateau phase. The peak was predicted by M. King Hubbert in the 1950s (Hubbert 1956) and signaled the end of a long period of increasing domestic supply and a shift towards growing import dependence. For the US to maintain its industrial and transportation base, it increasingly turned to foreign suppliers. The majority of the imports came from the Organization of the Petroleum Exporting Countries (OPEC). As domestic crude oil production reached its peak, the US lost the ability to meet rising demand through expanding domestic production (Kennedy 2024). This took away the ability of the United States to stabilize petroleum prices internally and left it susceptible to price fluctuations as it increased its dependence on imported crude oil. This was seen with the 1973-1974 embargo which left the economy exposed to foreign supply disruptions and price shocks. Smil (Smil 2017) and Yergin (Yergin 2012) have highlighted how historical energy transitions have corresponded with shifts in the economy and geopolitics. This suggests that the 1970 peak production should be treated as both a biophysical turning point and a moment of vulnerability of the macroeconomic order.

2.3. Input-Output Energy Analysis and Embodied Energy

Energy-extended input-output analysis (EEIOA) emerged in the 1970s as a method for estimating the energy embodied in goods and services across the economies. Casler and Wilbur explain that EEIOA has the ability to link energy use to interindustry transactions. This makes it possible to identify the total energy requirements associated with production and final demand (Casler and Wilbur 1984). For the US, Hannon et al. developed sectoral energy-intensity

estimates for each input-output sector, providing a practical way to measure the summation of the direct and indirect energy requirements embodied in the economic output hidden in financial exchanges (Hannon et al. 1983). Hannon underlined how input-output methods made it possible to track non-renewable energy flows through the economy and connect traditional economic accounting with ecological economic analysis (Hannon 2010). This approach quantified the different energy sources embedded throughout production networks and showed where that energy was used associated with the final goods and services of that economic system. The approach also identifies the energy use from interindustry exchanges rather than purely a magnitude of direct sectoral energy use.

Since then, IO analysis has matured as more scholarship extended the framework beyond domestic boundaries to capture the energy embodied in international trade flows. Rather than confining energy use to national borders, it tracks the energy consumption displaced through trade (Lenzen 1998). Lenzen's work, amongst others, showed how embodied energy and emissions can be allocated to final consumers rather than producers. This work showed the interconnected nature of net-importing economies and their hidden energy dependencies. This body of work emerged decades after the 1970s, but in retrospection allows for a foundation for the understanding of how energy constraints can be transmitted internationally through trade.

2.4. Bretton Woods and External Imbalances

The Bretton Woods system was signed in Bretton Woods, New Hampshire, US by 44 nations in an effort to create international economic stability post WWII. All nations participating pegged their currency to the US dollar (USD) which had a fixed exchange rate of 35 USD per troy ounce of gold. The intent was to establish trade expansion, exchange rate stability, and aid in domestic economic management. In institutional terms, this made the system a gold-dollar standard rather than a classical gold standard, with the central position of global monetary relations occupied by the United States (Bordo and Eichengreen 1993; Eichengreen 2010).

The system provided monetary stability in its early years but had structural weaknesses. One of the central tensions within the Bretton Wood system was that gold reserves were insufficient to meet the liquidity needs of the expanding world economy. The international system increasingly depended on net outflows of USD to supply reserve assets to other countries. The economist Robert Triffin argued that since the US had to increase supply of dollars to the rest of the world it gradually undermined the confidence in USD convertibility into gold. This contradiction became known as the Triffin Dilemma.

The balance of payments under Bretton Woods can be expressed as:

$$CA + KA + \Delta R = 0$$

where CA is the current account balance, KA is the capital account balance, and ΔR is the change in official reserves. The external deficits had to be covered by increased capital inflows or by change in official reserves. US balance of payment deficits, inflationary pressures, and military spending in the Vietnam War led to growing international doubts about the dollar (National Archives 1971; Truman 2017). As foreign governments and markets increasingly questioned whether the United States could maintain gold convertibility the foundation of Breton Woods began to break. Due to this in 1971 President Richard Nixon suspended the dollar convertibility. In monetary literature this suspension is considered the culmination of tensions that had been building for years (Truman 2017).

A notable sign of deterioration was the external trade relation of the US with the international market. This trade balance is expressed by:

$$NX = X - M$$

where NX is net exports, X is exports, and M is imports. NX greater than zero indicates a trade surplus. In 1971, the US recorded a negative net annual merchandise trade deficit which was its first annual deficit post WWII. The following methodology builds on this by examining the crude oil embodied in US exports and comparing it with imported crude oil energy during the time of this trade deficit.

The deterioration of the balance of payments was not only a retrospective explanation for the end of Bretton Woods; it was recognized by policymakers at the time as a central problem. In the August 1971 memorandum to Secretary of State Rogers, officials noted that “the U.S. balance of payments deficit was worsening” and that this issue was “extremely important” (National Archives 1971). This external imbalance identified by policymakers and its sensitivity to the physical allocation of petroleum through the U.S. economy is tested in counterfactual Scenario A.

3. METHODOLOGY

3.1. Data sources and benchmark IO tables

Benchmark IO tables for 1963, 1967, and 1972 were obtained from the historical IO accounts of the US BEA (US Bureau of Economic Analysis, n.d.). The 85-industry classification for each year was used. The 1972 benchmark is published in make–use format rather than as symmetric industry-by-industry transactions tables like in 1963 and 1967. The 1972 table was converted into a balanced symmetric industry table using the industry-technology assumption and a RAS

balancing procedure to ensure consistency with the 1963 and 1967 tables. The methodology used to convert the 1972 table is described in Appendix A.

3.2. Construction of annual final-demand vectors

Since yearly IO tables do not exist for the non-benchmark years 1964-1974, annual final demand vectors were created using US national accounts data. The annual totals were taken from the National Income and Product Accounts of the United States, 1929 to 1974: Statistical Tables (U.S. Department of Commerce, Bureau of Economic Analysis 1976). Within the statistical abstract Table 2.6 was used for personal consumption expenditures (IO code 91), Table 5.2 for gross private fixed investment (IO code 92), Table 5.8 for change in business inventories (IO code 93), and Table 3.6 for government purchases (IO codes 96-99). Annual merchandise and foreign aid export data was acquired from the Statistical Abstract of the United States and used for exports (IO code 94) (United States Census Bureau 1979).

The procedure for assigning annual totals to IO sectors depended on the level of category disaggregation available for each final-demand component. Exports were mapped directly to IO sectors because the available trade data provided detailed sectors that the goods and services were attributed to; the mapping used is shown in Appendix B. For personal consumption, private fixed investment, government purchases, and change in business inventories the National Income and Product Accounts (NIPA) did not provide sufficient sectoral detail to be sorted directly into IO categories like the export data. The annual totals of each final demand category from NIPA were consistent with the historical IO table final demand totals. Therefore, the annual totals from the NIPA were used to proportionally scale the nearest previous benchmark IO years (1963 for 1964-1966, 1967 for 1968-1971, 1972 for 1973-1974) final demand vectors for IO codes 91, 92, 93, 96, 97, 98, and 99. All annual final-demand values were retained in current dollars to maintain consistency with the monetary benchmark IO tables. This resulted in a continuous final-demand series for 1964-1974 which was then used in the Leontief analysis.

3.3. Embodied crude oil in exports and imported crude oil energy

The external energy accounting framework is expressed as total primary energy available which is the sum of domestic production E_{prod} and net imports E_{ni} . This total primary energy is allocated among three final demand categories as embodied energy, they are domestic consumption E_{con} , capital investment E_{inv} , and exports E_{exp} . This relationship is expressed as:

$$E_{prod} + E_{ni} = E_{con} + E_{inv} + E_{exp}$$

Embodied energy in US exports was estimated by multiplying the annual export vectors with the corresponding energy-intensity vectors derived from Hannon's work. Hannon's benchmark intensity vectors are available for coal, crude oil, refined petroleum, electricity, natural gas, and total primary energy. The sector and energy carrier type made it possible to estimate annual embodied-energy series in exports by source (Hannon et al. 1983).

Since Hannon's intensity vectors were only available for the benchmark years 1963, 1967, and 1972, two adjustments were made before they were applied to the annual export series. The benchmark intensity vectors were adjusted by the relevant price deflator so that they were expressed in constant dollars. Secondly, the annual intensity vectors for non-benchmark years were estimated by linearly interpolating between the adjacent benchmark year vectors.

Crude oil intensity for the sector i in year t is represented by $e_{i,t}^{crude}$, and exports allocated to the IO sector i in year t are represented by $x_{i,t}^{exp}$. Embodied crude oil in exports was calculated as:

$$E_{i,t}^{crude,exp} = e_{i,t}^{crude} x_{i,t}^{exp}$$

Total embodied crude oil in exports for year t was then obtained by summing across sectors:

$$E_t^{crude,exp} = \sum_i E_{i,t}^{crude,exp}$$

Imported crude oil energy was obtained from the US EIA, Primary Energy Imports by Source (U.S. Energy Information Administration 2026a). The crude oil import heat-content series was used as the annual measure of imported crude oil energy which was then compared to the embodied crude oil in exports series.

3.4. Counterfactual no peak domestic oil supply

To evaluate the macroeconomic implications of US conventional oil production peaking in 1970, a counterfactual assumption was created where the domestic crude oil supply did not peak but followed an increasing linear trend. This linear trend was forecast from 1963 to 1970, shown in Figure 1, and the resulting additional crude oil energy and oil value are shown in Table 1. The projected and historical US crude oil production values were obtained from the US EIA historical petroleum supply statistics, specifically the annual field production of crude oil series (U.S. Energy Information Administration 2026c). Historical crude oil prices were taken from the EIA Annual Energy Review data tables reporting the average US wellhead or refiner acquisition cost of crude oil by year (U.S. Energy Information Administration 2026b).

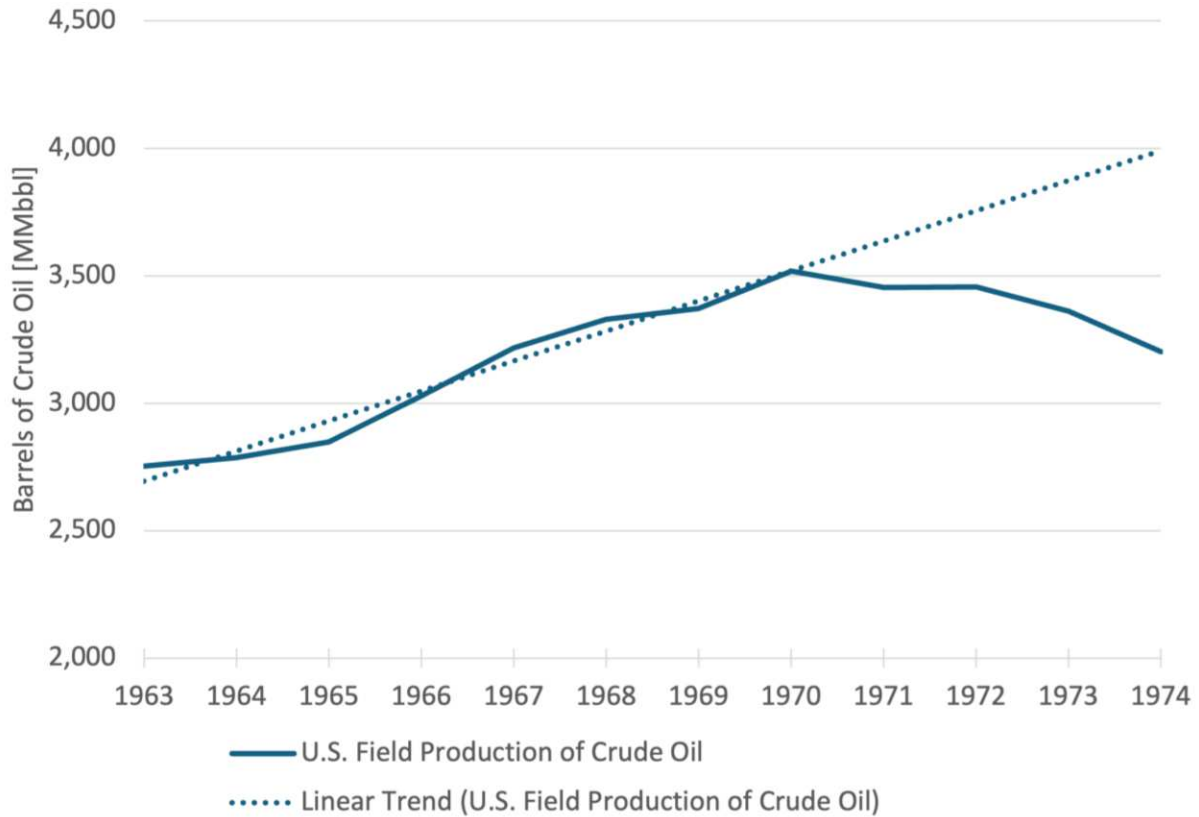


Fig. 1. US field production of crude oil, 1963-1974, with linear projection based on pre-1970 trend.

Table 1. Projected additional US crude oil production under a “no peak” oil linear trend scenario, expressed in physical and monetary terms, 1971-1974.

Year	Projected Total [Mbbbl]	Difference from Actual [Mbbbl]	Difference ΔE^{oil} [PJ]	Price of Crude [\$ /barrel]	Cost of Additional Oil [\$ million]
1971	3,636,973	183,059	1,117	3.17	580
1972	3,754,917	299,549	1,827	3.22	965
1973	3,872,861	511,958	3,123	4.08	2,089
1974	3,990,805	788,220	4,808	12.52	9,869

3.5. Counterfactual allocation scenarios

One of the primary purposes of the “no peak” scenarios was to create bounded counterfactuals to test the sensitivity of the external outcomes of continued domestic crude oil availability. This use of counterfactual reasoning is consistent with arguments made that historical

counterfactuals are most defensible when grounded in causal analysis and indirect evidence (Bunzl 2004). The only difference between each scenario is how the new additional oil is distributed to final demand.

Scenario A: Energy allocation of extra crude oil energy using embodied crude energy shares

In this scenario, the additional crude oil supply is distributed across the final demand categories according to their observed embodied crude-energy shares.

For each final demand category $j \in \{91, \dots, 98\}$ (BEA sectors 91-98) for each year t (1971, 1972, 1973, 1974), the embodied crude oil energy was calculated using the IO intensities calculated earlier. The embodied crude oil energy was only added to domestic final demand consumption, the imports for those years are not changed. The f_j monetary final demand in category j , and e_j is the crude oil intensity of output serving category j , is used to calculate the embodied crude in the category, and E_{total} of the total final demand:

$$E_{j,t} = f_{j,t} \cdot e_{j,t}$$

$$E_{total,t} = \sum_j E_{j,t}$$

The share of crude oil embodied for each final demand category is s_j . This is the fraction of crude oil in each type of final demand:

$$s_{j,t} = \frac{E_{j,t}}{E_{total,t}}$$

The additional “no peak” crude oil energy available for each year is ΔE^{oil} from Table 1. To keep the structure of the oil use consistent with the observed data of the yearly final demand by 91-98 sectors, the additional crude is allocated to each final demand category by the following equation:

$$\Delta E_{j,t} = s_{j,t} \cdot \Delta E_t^{oil}$$

To merge this additional oil into the IO model, the energy increments are converted back into monetary final demand using the crude oil intensities of each category:

$$\Delta f_{j,t} = \frac{\Delta E_{j,t}}{e_{j,t}}$$

and the new final demand vector $f_{j,t}^{cf}$ represents the counterfactual final demand vector with the continued domestic oil availability:

$$f_{j,t}^{cf} = f_{j,t} + \Delta f_{j,t}$$

The “no peak” oil total output vector is calculated using the Leontief production models to find the new counterfactual output; model verification can be seen in Appendix C. This procedure is repeated for each year $t = 1971, 1972, 1973, 1974$:

$$x_t^{cf} = L_{r(t)} \cdot f_{j,t}^{cf}$$

$$r(t) = \begin{cases} 1967, & t = 1971 \\ 1972, & t \in 1972, 1973, 1974 \end{cases}$$

The incremental output difference was then calculated for each final demand vector and summed for the total economic output increase:

$$\Delta x_t = x_t^{cf} - x_t$$

Scenario B: Value-based allocation and Scenario C: Export-only sensitivity

The second scenario was created in which the value of the counterfactual oil increment enters the economy as a monetary increase to final demand at its historical cost per barrel. The monetary increase is added to the final demand categories proportionally to each final demands share of the total final demand.

For each final demand category $j \in \{91, \dots, 98\}$ (BEA sectors 91-98, excluding imports) for each year $t = 1971, 1972, 1973, 1974$. The monetary share of each category is defined as:

$$w_{j,t} = \frac{f_{j,t}}{F_{total,t}}$$

The following equation gives the allocation of the additional crude value proportionally to these shares:

$$\Delta f_{j,t} = w_{j,t} \cdot \Delta V_t^{oil}$$

This additional crude value is added to the original final demand vector by the following equation:

$$f_t^{cf} = f_{j,t} + \Delta f_{j,t}$$

Using the piecewise constant technology as before, the counterfactual demand vector gives the new total output:

$$x_t^{cf} = L_{r(t)} \cdot f_t^{cf}$$

$$r(t) = \begin{cases} 1967, & t = 1971 \\ 1972, & t \in 1972, 1973, 1974 \end{cases}$$

The incremental output difference was then calculated for each final demand vector and summed for the total economic output increase:

$$\Delta x_t = x_t^{cf} - x_t$$

This process was repeated for an “export only” variant of Scenario C. Rather than allocating the counterfactual crude value incrementally across all the final demand categories, the full increment was assigned to the export category alone.

3.6. Energy Balance Sign Conventions

The US total crude oil balance is given by:

$$B_t^{total} = P_t^{crude} - C_t^{crude}$$

where B_t^{total} is the balance of domestic crude oil production P_t^{crude} and domestic crude oil consumption C_t^{crude} . In this balance $B_t^{total} > 0$ indicates a domestic surplus and $B_t^{total} < 0$ denotes a domestic deficit.

The crude oil trade energy balance is:

$$B_t^{trade} = M_t^{crude} - E_t^{crude}$$

where M_t^{trade} is imported crude oil energy and E_t^{crude} is crude oil embodied in US exports. The crude oil trade energy balance $B_t^{trade} > 0$ indicates that crude oil imports exceed oil embodied in exports, while $B_t^{trade} < 0$ is an excess of crude oil embodied in exports.

4. RESULTS

The breakdown of the energy embodied in exports by energy source from 1963 to 1974 can be seen in Figure 2. Most notably the total embodied energy in US exports increased from 1963 to 1974 with primary energy increases from 3,524 to 7,934 PJ. There was a large shift in the total primary energy from 1969 to 1974 which was almost exclusively from crude and refined petroleum energy.

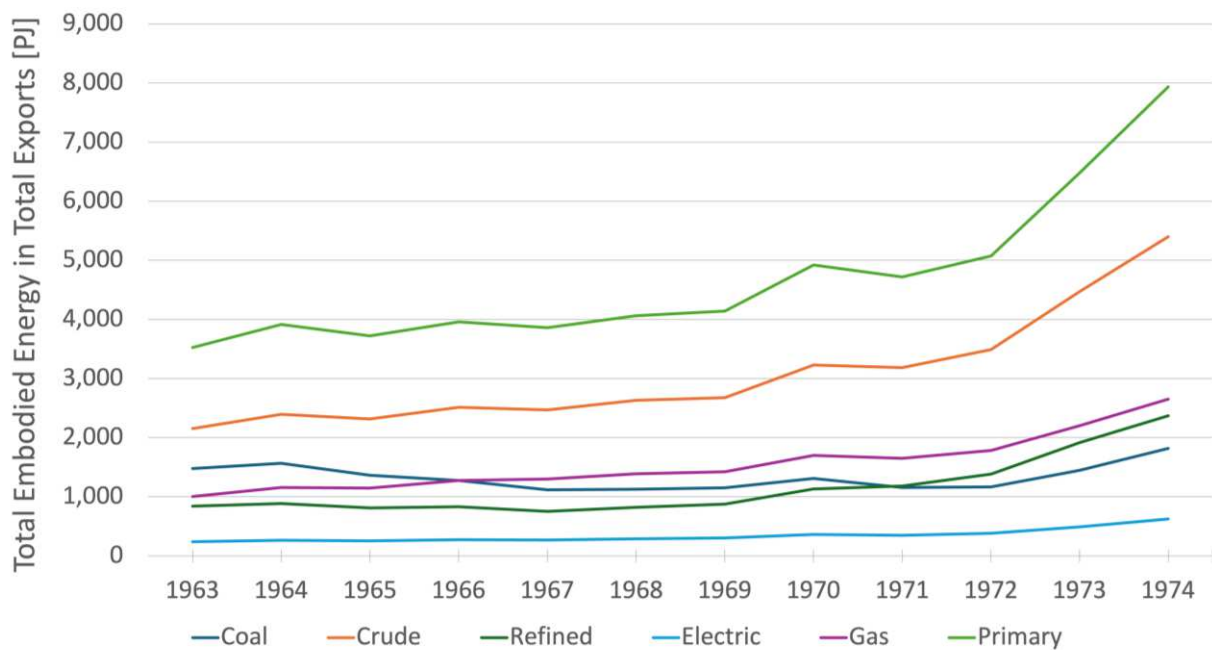


Fig. 2. Total embodied energy in US exports by energy source from 1963 to 1974.

Comparing the exported embodied crude oil energy to the imported crude oil energy resulted in Figure 3. Notably there are three distinct periods in the relationship between oil imports and crude oil embodied in exports between 1963 and 1974. These are three distinct periods are: (1) 1963 - 1969 in where imports and embodied crude track each other closely with imported crude oil always higher; (2) 1970 there is a sign reversal and a momentary -268 PJ crude energy deficit; and (3) post-1970, where there is a rapid increase and divergence of both with most of the increases occurring in crude oil imports. The reversal coincided with peak conventional crude oil production in the US, with gold convertibility being suspended the next year in 1971.

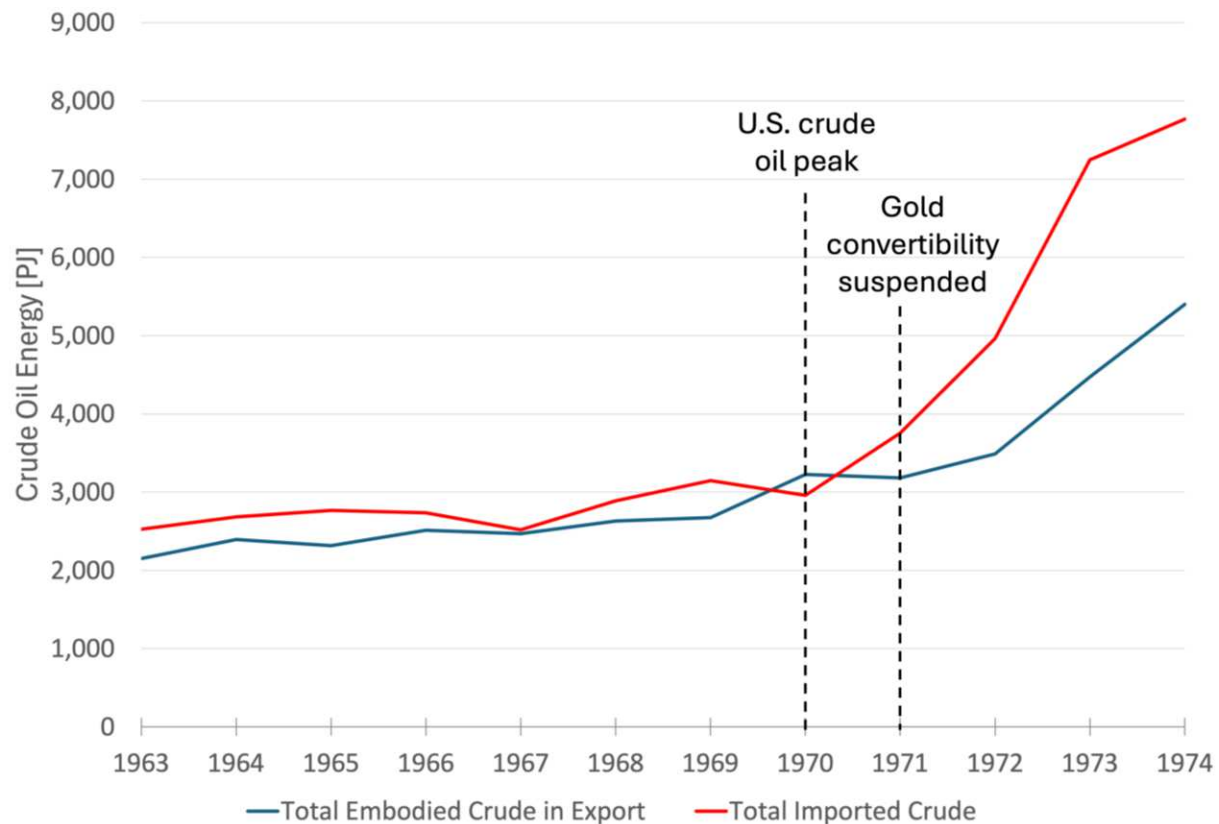


Fig. 3. Embodied crude oil in US exports and imported crude oil in the United States, 1963-1974.

Reconstructing the net exports of the US under the counterfactual, no 1970 peak conventional oil, shows that the allocation method of the additional oil by scenario has different effects on the US ability to maintain a positive monetary net export, Figure 4. Scenario A produces the largest increase in net exports and most importantly is the only scenario of the three where net exports remain positive for 1971. Adding the additional oil as a monetary value we see that Scenario B follows close to the historical trajectory with a minor deviation post 1973. The sensitivity analysis of Scenario B is the “export all” Scenario C. In this sensitivity analysis of the monetary additional oil value all the additional crude oil value is exported instead of distributed amongst the final demand. Despite this treating the additional oil as its monetary value in Scenario’s B and C they were both unable to maintain positive net exports throughout the counterfactual period.

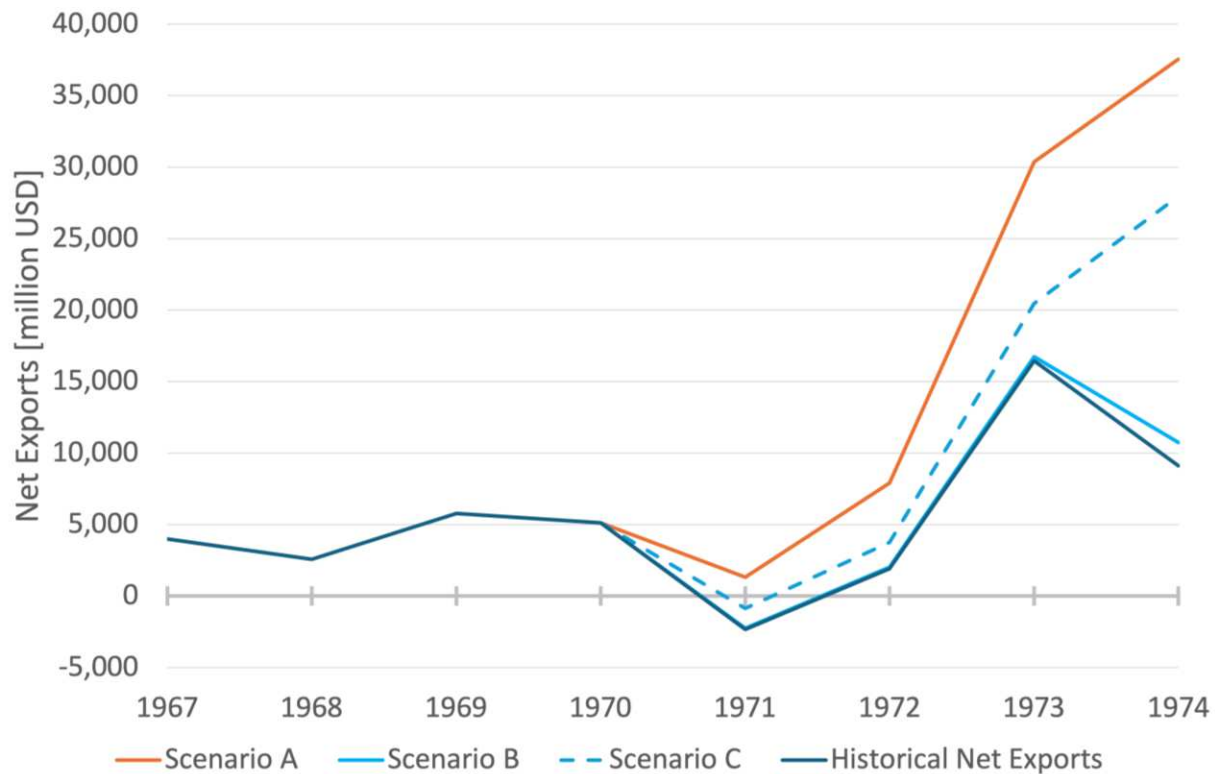


Fig. 4. Historical net exports and counterfactual net exports under “no 1970 peak” domestic crude oil scenarios, 1967-1974.

5. DISCUSSION

A key foundation of this paper is that US exports were not simply energy-neutral bundles of value. Post WWII they were increasingly dominated by petroleum with coal becoming relatively unimportant by the late 1960s, as shown in Figure 2. By 1970, approximately 56% of the embodied energy in exports were from petroleum. This meant that export earnings were generated through production structures that were highly depended on oil-based energy. This changes how the US external monetary balance should be interpreted. The ability of the United States to earn money through foreign exchange depended on a production structure that required considerable petroleum inputs.

Up until 1970 the imported crude oil and the crude oil embodied in exports followed similar trajectories, with the imported oil always equal to or greater than the embodied crude oil in exports. The temporary crossover in 1970, shown in Figure 3, is the first time this relationship was reversed. That reversal occurred in the same year US domestic crude production reached a peaked. The peak meant that production could not simply increase to meet the gap in imported oil and embodied crude oil in exports. Further increases in embodied crude oil domestically

would have to be supplied by imported crude oil or there would need to be a reduction in other final demands such as personal consumption, or private and public investment. This marked the point which the long-standing relationship between export production and domestic crude oil availability entered a regime change.

Counterfactual Scenario A allocates the additional crude oil energy as a physical energy input and is the only scenario which maintains a positive monetary net export balance in 1971. This result suggests that the economic significance of additional domestic crude had a larger role as an energy input than its market value. This is suggested as both Scenario B and C could not mitigate the trade deficit when the additional oil was added as a monetary value. The contrast between these scenarios' points to the biophysical contribution of crude oil was greater than that of its market value.

Together these results extend the conventional explanation for the collapse of the Bretton Woods showing that the monetary system's instability emerged with a structural transition in the energy foundation of the US economy. By reconstructing the crude oil embodied in exports, the paper shows that external energy trade balance in 1970 was constrained. The key contribution of this paper is linking embodied energy, international trade, and monetary stability.

One of the main limitations of the study is that the IO tables for the non-benchmark years do not exist. This means there is an inability to recreate Hannon's energy intensity vectors for those years. To obtain energy intensity vectors the study linearly interpolates between Hannon's benchmark year vectors. This method erases the non-linear fluctuations that would have occurred between these years. The assumption allowed the study to have annual time series data. Another limitation was the counterfactual scenarios did not account for the geopolitical responses, final good price changes, or supply and final demand feedback loops that would have occurred due to an increase in oil supply.

6. CONCLUSION

The breakdown of Bretton Woods should be understood not only as a monetary system collapse. The late 1960s was also a period of a tightening domestic energy paradigm within the US production system. Using historical IO energy intensities, annual export data, and Leontief IO models the paper modelled the crude oil embodied in US exports over the period of the end of the Bretton Woods. The "no 1970 peak" counterfactual models showed how continued domestic crude availability might have altered the US monetary performance and the deficit in the external balance of payments. The deficit in the balance payments was the most important

factor in undermining the Bretton-Woods system and counterfactual Scenario A maintained a net positive (National Archives 1971; Kennedy 2024). The Scenario A results demonstrated that the additional domestic crude oil, when treated as an additional embodied energy input, would have allowed US net exports to remain positive in 1971. This does not show definitively that continued domestic crude could have sustained the Bretton-Woods system, but it does show that one of the destabilizing forces was partly due to the material availability and the allocation of crude oil within the US economy.

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