Global Financial Chains

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*

Abstract

The use of global financial hubs and tax havens to move capital internationally obfuscates ultimate international investment positions in available data. We provide a network model of global capital positions where capital can be sent indirectly from origin to destination through one or multiple third countries (chains) in a manner which minimizes transaction costs. The model can be embedded in common classes of international finance general equilibrium models. We use the model to microfound recent empirical restatement procedures and formalize their assumptions. We estimate our model, generating a set of theory-consistent bilateral positions which trace investments back to ultimate issuers as well as forward to ultimate global investors. The model also produces a set of bilateral financial frictions. Our results uncover a substantial intermediation role for the United Kingdom in intra-European investments and allows us to identify the ultimate owners of investments ostensibly originating in tax haven countries. The implicit cost matrix we recover exhibits a strong gravity relationship. Our estimation produces four data products: a restated matrix of global capital positions, a matrix of bilateral transfer costs, a matrix of bilateral network frictions, and an enlarged version of the IMF Coordinated Portfolio Investment Survey (CPIS).

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1 Introduction

Cross-border asset claims now constitute twice the value of global GDP (Florez-Orrego, Maggiori, Schreger, Sun, and Tinda, 2023). However, international capital positions are obscured through arrangements which move assets internationally through sometimes complex ownership chains structures, making them difficult to measure (Angulo and Hierro, 2017; Avdjiev, Everett, and Shin, 2019). This challenge has consequences for the study of financial stability,[1] the understanding of portfolio choice and home bias,[2] and the assessment of global wealth inequity.[3]

Consequently, a bevy of attempts have restated data on international capital positions to reflect relationships between *ultimate* investors, the initial source of funds, and the *ultimate* issuers, the real economy firms putting funds to use (Felettigh and Monti, 2008; Pellegrini and Tosti, 2011; Alstadsæter, Johannesen, and Zucman, 2018; Coppola, Maggiori, Neiman, and Schreger, 2021; Tørsløv, Wier, and Zucman, 2023; Fonseca, Nikalexi, and Papaioannou, 2023). This empirical literature is limited by the availability of data on investment ownership and the fungibility of financial investments, which makes it difficult to disentangle ownership relations from observable financial flows. As such, a global restatement that traces investments back to ultimate investors remains elusive, despite a growing need from a literature that uses ultimate investment relationships as a research input.[4]

We present a model of global capital allocation in which international ownership chains form transfer networks that reduce the transaction costs associated with international investment. The model micro-founds empirical restatements, formalizing their assumptions. Using the data moments underpinning the Coppola, Maggiori, Neiman, and Schreger (2021) (henceforth CMNS) restatements, we estimate the model. Our estimation generates two new key datasets: a set of bilateral investment frictions and a complete set of bilateral positions. Our estimates shed light on where investments in offshore tax havens such as the Cayman Islands originate, as well the role of the UK as a large global financial intermediary. Further, our bilateral frictions reveal global financial investments abide by a network-based gravity relationship.

In our model, financial assets are sold internationally through an endogenous network

[1] For example, the role of regional and global imbalances, exchange rates and global financial stability (Lane and Milesi-Ferretti, 2003, 2007; Hale and Obstfeld, 2016; Gopinath, 2019; Maggiori, Neiman, and Schreger, 2020; Jiang, Richmond, and Zhang, 2024).

[2] E.g. Adler and Dumas (1983); French and Poterba (1991); Lewis (1999); Portes and Rey (2005); Bacchetta, Tieche, and Van Wincoop (2023).

[3] A large literature has documented the out-sized role of tax havens as intermediaries for these transactions (Huizinga, Laeven, and Nicodeme, 2008; Desai and Dharmapala, 2009; Zucman, 2014; Hanlon, Lester, and Verdi, 2015; Alstadsæter, Johannesen, and Zucman, 2018; Bertaut, Bressler, and Curcuru, 2019).

[4] E.g. Miranda-Agrippino, Nenova, and Rey (2020); Jiang, Richmond, and Zhang (2024); Kleinman, Liu, Redding, and Yogo (2023).

of intermediaries. Moving capital internationally is costly because transactions incur wedges, potentially a combination of pecuniary and non-pecuniary transfer costs. Intermediaries across countries form ownership chains which allow claims to be sold to international borrowers in a cost minimizing fashion. Because bilateral frictions vary both by country and by security, complicated chains can emerge in equilibrium to avoid more costly direct bilateral transfers. Financial hubs arise as locations where transfers minimize taxes or other costs, e.g. information frictions. The model, which builds on the transportation model of Allen and Arkolakis (2022), recovers analytic relationships between the observables, the ultimate positions, and the structure of the network formed by the bilateral wedges.

The model is in partial equilibrium: we show that the model's key result are invariant to a variety of general equilibrium settings, including major alternatives to model asset demand (Markowitz, 1952; Martin and Rey, 2004; Lane and Milesi-Ferretti, 2008; Okawa and Van Wincoop, 2012; Koijen and Yogo, 2019). Importantly, this allows us to estimate the model without taking a stand on the determinants of asset supply and demand. In particular, this approach does not assume a gravity relationship in bilateral holdings, which we will later test for using our model estimates.

The model microfounds previous empirical restatements. In particular, we formalize the CMNS restatements in the context of our model, and show how the restatements recover the bilateral positions under three additional (formal) assumptions: first, investor country microdata observes the final step in each chain; second, data (CPIS) correctly identifies investors; and third, intermediary usage is homogeneous across investors. Further, we identify the bias that emerges when these assumptions do not hold.

We then use the data moments underpinning the CMNS restatement to estimate the model. The intuition behind our estimation is that even when assumptions are relaxed, CMNS-reported ratios give information on both the relative attractiveness of "sending" positions from one country to another and (more indirectly) the relative volumes of ultimate bilateral positions. In particular, data on the ultimate destination of bonds from particular investor countries at intermediaries gives us information on the relative network proximity of those intermediaries to those destinations, allowing us to identify the network structure; data on the global usage of intermediaries for investments bound for each destination allows us, in conjunction with the network structure, to identify the bilateral positions. The latter relationship is strongly analogous to the estimation of bilateral trade cost frictions where the typical data, trade shares, are the unknowns.

Our estimation results provide a close fit to our targeted moments ($R^2 > 0.98$). Our estimates are also largely in line with the model-free algorithmic restatements, which

tend to restate bilateral positions in the same direction and with similar magnitude. However, by construction, existing global algorithmic restatements reallocate investments across issuers but not across investor countries, a degree of freedom afforded in our estimation. These outward restatements are similar to those for European Economic Area countries Beck et al. (2023), and are new for global data.

These results highlight the trade-off of the theory-driven approach to restatement: by accepting certain key assumptions in the model, we are able to relax others. As a result, we can leverage the existing data moments to reassign ownership of investments made from financial hubs where ownership data is lacking. The model estimates restate downward the outward investment positions of major tax havens (Luxembourg, Cayman Islands, Ireland, and the Netherlands) similar to empirical approaches, but also does so for larger financial hub countries (Japan, Switzerland, and United Kingdom) as well as for the US. These countries appear to also play a significant role in international asset intermediation for reasons beyond tax avoidance. Accordingly, the underlying network structure driving these chains may be responsive to more than just tax costs.

Our results also complement recent work by Beck et al. (2023) which uses detailed financial information to extend the CMNS results backwards for European countries. Our results extend these estimates for non-European countries, for which such data does not exist. We find, for example, the UK investments in Luxembourg are largely comprised of US investments as well as Eureopean round-tripping. Furthermore, we find that investments from offshore tax havens are actually attributable to a large set of economies, including the US and Japan as well as Europe.

Our estimates also recover a "gravity relationship" for international asset ownership. As our estimates do not rely on a general equilibrium model of demand, it does not assert or assume a gravity relationship. Yet, estimated link costs generate average wedges (network costs) that display a robust, inversely proportional relationship to our estimated restated bilateral positions. This holds controlling for country fixed effects as in a standard reduced-form gravity estimation. The finding of gravity for these holdings is novel. There is no reason to assume gravity should exist in this setting (Okawa and Van Wincoop, 2012). Furthermore, the robustness of this finding to all three estimated bilateral positions underscores the external validity of these estimated link wedges.

These results also complement current work by Pellegrino, Spolaore, and Wacziarg (2021), who estimate a spatial DSGE model of international investment. Our paper seeks to recover the unobservable ownership structure of globally held assets and the network frictions which rationalize the observed indirectness. A key distinction between the approaches is that our estimates are made without assumptions on the nature of demand. For example, our model does not yield a gravity equation, although

we find that our recovered frictions are gravity-consistent. As such, our estimated positions can be used as inputs into such spatial DSGE models, and our test of gravity confirms the validity of the Pellegrino et al. (2021) approach. Indeed, our endogenous bilateral network frictions are strongly analogous to the exogenous bilateral frictions in their spatial model, and our decomposition of direct wedges show similar results.

2 A Model of Indirect Global Finance

In this section we propose a model that rationalizes the indirect global positions of (debt or equity) capital illustrated by CMNS, via an adaptation of the transportation model in Allen and Arkolakis (2022). We first present the partial equilibrium chain selection problem, where funds can flow directly or indirectly from an ultimate investor to an ultimate security issuer through a chosen global network. This gives us, conditional on equilibrium origin-destination aggregate demand and supply, a relationship between the underlying network structure and the observable cross-border financial positions.

Our model of indirect financial investment is consistent with a large class of models of global finance, and we show how it can be embedded into common general equilibrium frameworks which serve to pin down the value of ultimate positions. In Section 2.2, we propose a demand system that nests several common systems. However, because our subsequent results are invariant to these modeling choices, we will continue in subsequent sections—and in particular, estimate bilateral positions—without taking a stand on the nature of claim demand or supply.

2.1 The Environment

N countries are arranged in a network defined by nodes (countries) and edges (bilateral links). There are two periods: an investment period and a redemption (repayment) period. In each country, in the investment period, there are investors who have funds and use them to buy claims and issuers who supply claims in exchange for funds, domestically or internationally. In the redemption period, issuers pay returns back to investors. Each claim is of a type $\omega \in \Omega$ which denotes a category such as risk or other characteristics of the claim, and pays a gross per-unit return $r_{j,\omega}$. The exact classification system of claims into classes of ω is flexible and can be pinned down in conjunction with a demand system, as we discuss below. For now, we only assume the set Ω is finite but large enough for the law of large numbers to apply. Because we will allow for indirect ownership, claims, which are associated with ultimate issuers and ultimate investors, stand in contrast to *assets*, which correspond to direct holdings. A

claim relationship between an issuer at j and an investor at i can take the form of a *direct* asset ownership relationship between i and j, or can correspond to a series of assets in a more complex ownership structure involving intermediate steps and countries. For example, an investor in the United States could directly purchase equity issued by a company in Germany, or could acquire bonds issued by a subsidiary in the United Kingdom which in turn buys repurchase agreements issued by a fund in the Cayman Islands which ultimately purchases equity in the German Company.[5] Figure 1 provides an illustration.

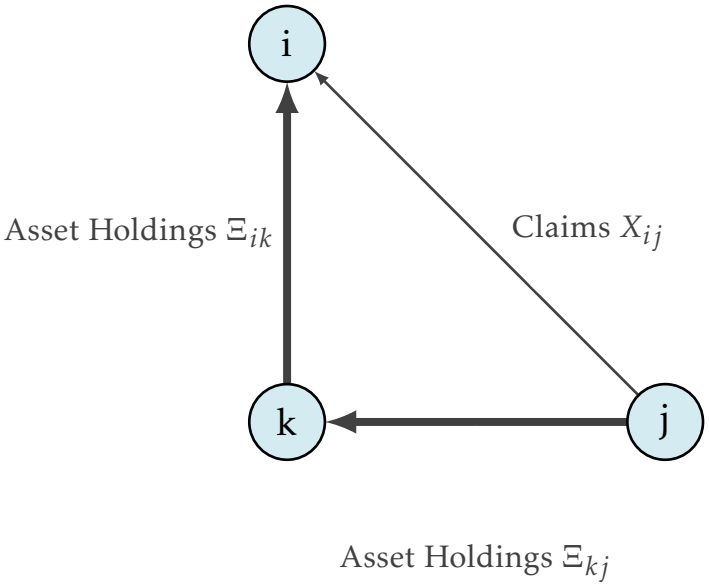


Figure 1: Claims and Assets

Note: The figure shows an example of claims issued in j and held by an ultimately held in i through a financial chain involving asset holdings between k and j and k and i.

Any (domestic or international) asset ownership incurs a transaction investment cost, or wedge. This cost, e_{ij}, is paid when an asset is redeemed in the repayment period. e_{ij} can represent pecuniary costs such as taxes on capital, as well as non-pecuniary costs such as information collections costs, language barriers, or other bilateral frictions. In particular, this cost could include the shadow price of counter-party risk or privacy or disclosure requirements as well. A key aspect is that these costs are incurred for each asset, irrespective of the claim type or ultimate investor or issuer. Claim-type-,

[5]While claims describe an *unobservable* ultimate relationship between investors and issuers, a key question is how do chains correspond to observables in data. Asset ownership in our model, which is always a direct bilateral relationship, corresponds to securities such as bonds and equity as well as subsidiary holdings and custodial accounts. Consider a US investor holding a custodial account in the Bahamas. The account in turn owns bonds issued by a Caymans subsidiary of a Brazilian firm. In the language of our model, the full chain {US, BAH, CYM, BRA} involves three distinct asset ownership relationships, while only the intermediate BAH-CYM asseet may be observable in international accounts. This highlights a key force for identification in our model: because we do not specify modality of ownership, we assume bilateral ownership relationships are equally costly whether they are initiated by investors "downstream" of a given observable security or by issuers "upstream".

borrower-, and investor-specific costs are considered separately below.[6] Edge costs are multiplicative, so that the effective per-unit gross repayment on a claim of type ω from j incurring wedge e_{ij} is $r_{j,\omega}/e_{ij}$. While iceberg costs are traditionally multiplicative in the trade literature, the multiplicative functional form is particularly appealing for taxes on dividends and other such costs. For our purposes, this assumption allows analytical tractability but can be relaxed with additive costs.[7]

Because in some settings financial investment strategies are chosen by ultimate investors or issuers, while in others they may be selected by specialty firms with expertise in cost minimization, we add a third set of agents, *consultants* (e.g. financial tax advisors), which facilitate the ultimate investor-issuer relationship, structuring claims internationally through (potentially indirect) ownership arrangements.[8]

In order to minimize investment transaction costs, ultimate investors pay consultants to set up a cost-minimizing financial chain, where claims are indirectly owned, and funds indirectly channeled, through a series of assets, potentially involving third countries. These financial chains reduce investment costs on an ω-specific basis. Consultants produce these ownership structures for individual asset types through research, and compete with others' chains in order to support international financial investments.

The demand for a claim ω from j at i is denoted by $D_i(j,\omega)$. At present, we do not specify substitutability between claims ω within or across ultimate issuers j.

Lemma 1. *(Chain probability) Under assumptions* **??***-3:*

The probability a chain c is selected for a given claim ω is:

$$\pi_{ij,c} = \frac{\left(\prod_{k=1}^{K} e_{k,k+1}\right)^{\theta}}{\sum_{c\in\mathcal{C}}\left(\prod_{k=1}^{K} e_{k,k+1}\right)^{\theta}} \tag{1}$$

While Bertrand prices depend of the second cheapest supplier, since the lowest cost supplier is the one that will sell the claim, conditional on a claim from j being ultimately owned by investors at i, the probability that it is owned via a chain c is the same as in perfect competition, similar to, e.g., Ganapati et al. (2024).

[6] We assume that $e_{ij} < \infty$ even in the case of autarky: it is possible that the friction from i to j is finite, but the benefits of connecting to j are less than the cost to form a link. In appendix **??**, we provide a potential *centralized* network formation that can microfound this trade-off.

[7] Iceberg transaction costs accord with an interpretation of transaction taxes, while other interpretations, such as intermediation costs, may be more naturally modeled as origination costs, as in Minetti, Romanini, and Ziv (2025). The decision to model frictions as iceberg or costs impacts the factor market clearing conditions.

[8] Our estimation is invariant to alternative approaches where investors or issuers set up ownership structures independently.

To proceed, we adopt the matrix algebra notation in Allen and Arkolakis (2022):

Definition 1. *(Unconditional Edge Intensity) The matrix A is an $N \times N$ matrix where each element is $a_{ij} = e_{ij}^{-\theta}$*

Assumption 1. *(Spectral Radius) Let $\lambda_1, \ldots, \lambda_n$ be the eigenvalues of matrix A. The spectral radius of A is defined as $\rho(A) = \max\{|\lambda_1|, \ldots, |\lambda_n|\}$. We assume that $\rho(A) < 1$, such that we can define $B \equiv (\mathbf{I} - A)^{-1}$.*

The assumption allows us to exploit matrix algebra and obtain the following conditional edge intensities and network expected costs, which summarize the partial equilibrium.

Lemma 2. *(Conditional Edge and Node Intensity) From proposition 1 and assumption 1, we can obtain the conditional edge intensity, i.e. how much an edge kl is relevant in channeling ultimate claims between i and j:*

$$\psi_{kl|ij} = \frac{b_{ik} a_{kl} b_{lj}}{b_{ij}} = \left(\gamma \frac{\tau_{ij}}{\tau_{ik} e_{kl} \tau_{lj}} \right)^{\theta} \tag{2}$$

We can also obtain the conditional node intensity:

$$\psi_{k|ij} = \frac{b_{ik} b_{kj}}{b_{ij}} = \left(\gamma \frac{\tau_{ij}}{\tau_{ik} \tau_{kj}} \right)^{\theta} \tag{3}$$

with network expected cost:

$$\tau_{ij} = \left(\sum_{c \in \mathcal{C}} \left(\prod_{k=1}^{K} e_{k,k+1} \right)^{-\theta} \right)^{-1/\theta} . \tag{4}$$

The unconditional edge intensity, a_{kl}, can be thought - with an abuse of interpretation[9] - as the probability of moving funds from k to l: the cheaper moving funds between k and l is, the more the edge e_{kl} is used for structuring international claims. Expected network intensity b_{lj}, instead, captures the expected transaction costs of a claim originating from country j and reaching the intermediate claim holder at l through all possible chains between l and j; a similar interpretation applies to b_{ik}. Hence, $\psi_{kl|ij}$ measures how much the edge kl is relevant to i's ultimate ownership of claims from j.

Let X_{ij} be the aggregate value of claims issued by j and ultimately held by i. Indirect claims, i.e. the value of such claims channeled through the node k are:

$$W_{k|ij} \equiv \psi_{k|ij} X_{ij} \tag{5}$$

[9] See the discussion on assumption 2.

Moreover, the total outstanding value of asset holdings between k and l is given by:

$$\Xi_{kl} \equiv \sum_{i,j} \psi_{kl|ij} X_{ij} \tag{6}$$

Looking ahead, these definitions are crucial to our ability to map the model to the data by linking unobservable claims to observable assets.

2.2 General Equilibrium

In this section, we close the model, discussing how a variety of demand frameworks can fit with our model of indirect claim ownership.

Claim Demand A number of common asset demand systems conform to the demand assumptions above. Consider investors at each country i maximizing return as well as characteristics of assets, accounting for potential correlation in asset returns across issuers and asset types, as in Koijen and Yogo (2019), e.g. $q_{i,\omega} = D\left(p_{i,\omega}, x_{j,\omega}\right)$. When value of non pecuniary transaction costs such as disclosure requirements are log-additive, they can be expressed as edge costs. With no demand weight on non-pecuniary characteristics and perfectly uncorrelated returns, this system conforms to a neoclassical (Arrow-Debreu security) model, as in Martin and Rey (2004) and Coeurdacier and Martin (2009). In the Appendix, we present an explicit endogenization of the demand system, based on Martin and Rey (2004) and fully solve for the general equilibrium with perfectly elastic claim supply. Under alternative assumptions, this system conforms to Markowitz (1952), where investors chose a vector w of portfolio weights to maximize expected returns r for given level of risk. Here, route c only affects $r_{i,\omega}(c)$, any two chains that deliver identical $r_{i,\omega}$ imply the same portfolio $w_{i,\omega}$, thus satisfying Assumption 3.[10]

Claim Supply We assume the supply of claims of type ω at j, $S_j(\omega)$ is twice differentiable and invertible. We do not take a stance on the source of claim supply. This could, for example, originate from (unmodelled) standard firms' physical capital investment needs or from households' consumption smoothing decisions.

Market Clearing Market clearing is defined by a set of chain draws, quantity of claim supply and demand and gross returns such that there are zero expected profits for entering consultants, and the quantity of claims supplied of each variety ω from

[10] Counterparty risk for assets within a chain can be accommodated conditional on orthogonality to claim issuer risk.

each ultimate issuer j equals the quantity purchased by consultants at the gross return $r(\omega, j)$, and the quantity of such claims sold by consultants equals to the total quantity demanded by ultimate investors at the return $\tilde{r}_{ij}(\omega, c)$ across all i.[11] Across the two periods each country's international payments are balanced.

3 Reconciling Restatement With Theory

In this section, we reconcile the model proposed in Section 2 with theory-free algorithmic restatements. We focus on the popular restatement algorithm of Coppola, Maggiori, Neiman, and Schreger (2021), which provide a global restatement of bilateral financial positions using the IMF CPIS and matrices reporting, for each country k, the proportion of investments that originate in each country j.

3.1 Deriving Restatements

To describe their microdata-derived matrices in the context of our model, we introduce the following definition

Definition 2. *The triplet $s_{k,l,j}$ is the value of assets (securities) owned between k and l for which the ultimate claim issuer is in j.*

In the terminology of CMNS, $s_{k,l,j}$ are securities with residency-based exposure to l and (typically unobserved) nationality based exposure to j.

There are now two cases: in the first, CMNS have access to a dataset (Morningstar) which allows to link an asset to its ultimate investor's nationality - for 9 geographical areas (8 countries and the EMU). We omit a discussion of the EMU investor restatements here. For the remaining several countries in the world, data availability prevents such allocation.

For the eight investor countries, CMNS construct the (8xNxN) tensor $\Omega_{i,k,j}$ for eight investor countries, comprised of elements

$$\omega_{ilj} \equiv \frac{s_{i,l,j}}{\sum_j s_{i,l,j}} \tag{7}$$

[11] For each asset held between countries k and l in any chain, quantities held equal quantities issued at the purchase and sale price, respectively, where the difference between purchase and sale prices is the transaction cost e_{kl}.

where the denominator is the total value of asset holdings at l corresponding to claims held by investors at i. Note that here we maintain the assertion of CMNS that Morningstar data correctly identify investor origin, i.e. $k = i$.[12] For example, consider a US investor with \$20M invested in securities of UK firms. Of those, \$10M are of a firm with a Brazilian parent and \$10M are of a firm with a UK parent. In the aggregate, 50% of US(i)-UK(k) investments are associated with claims issued by UK ultimate issuers and 50% are reallocated as US-Brazil(j) claims.

Unlike for the 8 investor countries and the EMU, there is no data source where the financial investments of other countries can be individually identified. Consequently, in order to perform a global restatement, CMNS also generate a matrix $\Omega_{k,j}$ using a sample of bonds where, for securities at each country k, ultimate issuers (j) can be identified, but ultimate investors (i) cannot. The elements of $\Omega_{k,j}$ are thus

$$\omega_{l,j} \equiv \frac{\sum_k s_{k,l,j}}{\sum_{k,j} s_{k,l,j}}.$$

where assets are no longer identified by ultimate investor. Using the definition of, W_{ikj} we are now able to express Ω_{ikj} and Ω_{kj} in terms of our model.

Lemma 3 (CNMS shares)**.** *We can write CNMS investor-specific shares as:*

$$\omega_{i,l,j} \equiv \frac{s_{i,l,j}}{\sum_j s_{i,l,j}} = \frac{\psi_{l|ij} X_{ij}}{\sum_j \psi_{l|ij} X_{ij}} \tag{8}$$

Further, we can express the elements of the global matrix $\Omega_{l,j}$ as

$$\omega_{kj} \equiv \frac{\sum_k s_{k,l,j}}{\sum_{k,j} s_{k,l,j}} = \frac{\sum_i \psi_{l|ij} X_{ij}}{\sum_{i,j} \psi_{l|ij} X_{ij}}.$$

CMNS Restatement CMNS restate residency (asset) exposure observed in CPIS data, which we denote as q_{il}, into nationality (ultimate) claims, X_{ij}. They suggest the following restatement, in matrix notation:

$$X_{ij} = q_{il} \Omega_{lj} \tag{9}$$

and separately, for investor countries i', $X_{ij} = q_{il} \Omega_{i=i',l,j}$.

[12] As discussed in Maggiori, Neiman, and Schreger (2020), "mutual funds domiciled in a particular country primarily invest on behalf of domestic residents," except for the case of the European Monetary Union, where mutual funds in Luxembourg and Ireland aggregate investment from other countries of the EMU (Beck, Coppola, Lewis, Maggiori, Schmitz, and Schreger, 2023). We can also follow an alternative approach allowing for the possibility that these securities do not identify the ultimate investor.

3.2 When Do Restatements Identify Claims?

We first show that under three conditions, the ultimate claim holdings can be directly recovered from the multiplication of the restatement matrices with the asset holdings q_{lj} (e.g. CPIS).

Algorithmic Assumption 1 (Observable Investor-based Ratios)**.** *The investor country i is observable in the data underlying the ratios of Ω. I.e. for all securities $s_{k,l,j}$, $k = i$.*

This assumption is naturally violated in the case of global shares, which are constructed using a sum $s_{k,l,j}$ over all k.

Algorithmic Assumption 2 (First Step Observability)**.** *The triplet $s_{i,l,j}$ corresponds to W_{ilj}, defined such that l is the first step in the chain from i to j:*

$$W_{izj} \equiv \psi_{z|ij} X_{ij}$$

The assumption requires that, conditional on investor in i with transaction happening in l, there is no intermediate step. For example, circuitous chains can violate this assumption. Lemma 4 (see appendix) follows directly from this assumption.

Algorithmic Assumption 3 (Investor Observability)**.** *Observed aggregate data (to be restated) only contain exposures between ultimate investor country i and intermediate countries k, i.e.,*

$$q_{ik} = W_{ik} \equiv \sum_j W_{ikj}$$

Assumption 3 requires that investors are correctly reflected in aggregate statistics. In other words, only the issuer side must be restated.

Theorem 1 reveals that, according to the model, when the above assumptions hold, the results of the CMNS algorithmic restatement procedure recovers ultimate exposures.

Theorem 1. *Assume 1, 2, and 3. Then ultimate claims X_{ij} are recovered by Equation (9).*
Proof:

$$\sum_k q_{ik}\omega_{kj,i} = \sum_k \left(\sum_j W_{ikj} \right) \left(\frac{W_{ikj}}{\sum_j W_{ikj}} \right) = \sum_k W_{ikj} = \sum_z \psi_{z|ij} X_{ij} = X_{ij}$$

where the first step relies on assumption 1, the second on assumption 3, second to last on equation 5, and the last step on lemma 4.

Do Algorithmic Assumptions Hold in the Data? For investor-country restatements, Assumptions 1 and 2 hold if the Morningstar Bond data correctly identifies ultimate ownership, and we can rule out circuitous ownership or consolidated reporting. For non-investor countries, as we discuss above, the construction of the global restatement matrix Ω_{lj} does not conform to these assumptions by definition.

Separately, Assumption 3 requires CPIS data to correctly identify ultimate investors. Table 1 sorts countries by their asset-to-GDP ratio. The top of the list is dominated by major financial hubs including offshore tax havens: Cayman Islands, British Virgin Islands, Bermuda, Luxembourg, Jersey, The Bahamas. These extreme ratios, up to 536-times GDP for the Cayman Islands, makes it unlikely that investments ultimately owned by Caymanians are not commingled in the data with those ultimately owned by offshore nationals and using the Cayman Islands as a pass-through investor. While tax haven investments seem obviously overstated, this raises the potential concern that other gross investment positions are understated. As such, Assumption 3 may fail both for investor-country and global restatements.

All told, Assumptions 1 and 2 may hold for investor-country restatements, but Assumption 3 does not for either investor- or non-investor country restatements. Theorems 2 and 3 explore the consequences of relaxing assumptions 1-3 accordingly.

Theorem 2 (CMNS Investor Restatements)**.** *Assume 1 and 2. Relax assumption 3, i.e. let aggregate data to be restated (e.g. CPIS) corresponding to locational holdings, as in equation 6. Then, CMNS procedure does not recover ultimate positions, and are biased by* $\sum_l \psi_{l|ij} \frac{\Xi_{kl}}{\sum_j W_{ilj}}$ *:*

$$\begin{aligned}\sum_k q_{ik}\omega_{kj,i} = \sum_l \Xi_{kl}\pi_{lj|k} &= \sum_l \Xi_{kl}\left(\frac{W_{ilj}}{\sum_j W_{ilj}}\right) \\ &= X_{ij}\sum_l \psi_{l|ij}\frac{\Xi_{kl}}{\sum_j W_{ilj}} \neq X_{ij}\end{aligned}$$

The magnitude of the bias is higher the more k is confounded for i, i.e. $\frac{\Xi_{kl}}{\sum_j W_{ilj}} = \frac{\sum_{ij} W_{iklj}}{\sum_{kj} W_{iklj}} \geq 1$, weighted by how much l is used as a step between k and j, $\psi_{l|ij}$.[13] In other words, restated positions for investor countries will be biased to the extent to which investor country positions through each intermediary are mislabeled as others' ultimate investments and weighted by that intermediary's share of the total claims.

[13] If both data and share would consist of locational exposures (see appendix **??**, the algorithmic restatement implies:

$$\sum_k q_{ik}\Omega_{kj} = \sum_l \Xi_{kl}\omega_{lj|k} = \sum_l \left(\Xi_{kl}\frac{Y_{klj}}{\sum_j Y_{klj}}\right) = \sum_l \sum_i \psi_{kl|ij}X_{ij}$$

Table 1: Asset to GDP Ratios

Country	Debt assets	GDP	Ratio
Cayman Islands	2,674,595.6	4,989.1	536.1
British Virgin Islands	344,136.8	1,403.0	245.3
Bermuda	547,644.0	6,899.9	79.4
Marshall Islands	13,730.8	201.0	68.3
Luxembourg	3,468,765.6	62,200.0	55.8
Guernsey	187,639.6	3,962.0	47.4
Jersey	235,387.4	5,553.3	42.4
Bahamas, The	205,890.2	11,751.0	17.5
Curaçao	37,033.4	3,122.3	11.9
Barbados	49,869.3	4,833.0	10.3
Isle of Man	65,787.8	6,846.7	9.6
Ireland	2,687,101.2	298,477.0	9.0
Timor-Leste	10,429.8	1,651.0	6.3
Gibraltar	15,961.7	2,660.4	6.0
Malta	69,472.8	11,665.0	6.0
Mauritius	64,191.6	12,594.0	5.1
Singapore	1,528,546.4	319,030.0	4.8
Hong Kong	1,493,405.3	320,860.0	4.7
Brunei Darussalam	50,313.6	11,400.0	4.4
Anguilla	1,363.7	318.8	4.3
Kuwait	445,077.8	109,398.0	4.1
Cyprus	76,689.6	21,041.0	3.6
Netherlands	2,175,386.2	783,844.0	2.8
Bahrain	88,974.2	32,235.0	2.8
China,P.R.:Macao	121,695.6	45,071.0	2.7
United Kingdom	6,427,346.0	2,709,678.0	2.4
Switzerland	1,620,570.7	687,619.0	2.4
San Marino	3,083.5	1,468.0	2.1
Qatar	311,717.9	151,732.0	2.1

Theorem 3. *Relax assumptions 1 to 3. Then, the algorithmic restatement does not recover ultimate claim holdings. In particular:*

$$\sum_k q_{ik}\omega_{kj} = \sum_l \Xi_{kl} \frac{\sum_i W_{ilj}}{\sum_{i,j} W_{ilj}} \neq X_{ij}.$$

4 Estimation of Financial Positions and Frictions

In this section we derive estimating equations from our model, which we match to the micro-data-based moments in CMNS to estimate ultimate positions (claims) and bilateral wedges.

4.1 Estimating Equations

We construct the following sets of equations:

$$m_{ikj} \equiv \omega_{i,k,j} - \frac{b_{kj} X_{ij}}{b_{ij} \sum_{j'} \frac{b_{kj'}}{b_{ij'}} X_{ij'}} = 0 \tag{10}$$

$$m_{lj} \equiv \omega_{lj} - \frac{\sum_{i'} \frac{b_{i'l} b_{lj}}{b_{i'j}} X_{i'j}}{\sum_{i',j'} \frac{b_{i'l} b_{lj'}}{b_{i'j'}} X_{i'j'}} = 0 \tag{11}$$

Equations (10) and (11) link CMNS aggregate (re)allocation shares (respectively $8 \times N^2$ investor-country shares $\Omega_{i,l,j}$ and N^2 moments from global reallocation shares Ω_{lj}) to the aggregate reallocation shares implied by our model.[14] Observe that the moments in equation 10 maintains that Assumptions 1 and 2 hold for $\Omega_{i,l,j}$ while 11 does not maintain as such for $\Omega_{l,j}$. These equations identify the $2N^2$ bilateral unknown parameters $\|X, B\|$ up to $2N$ normalizations: $2N-1$ B-matrix normalizations and 1 scalar for the X matrix.[15]

We estimate the following via minimum-distance estimation with weights λ,

$$Q(X,b) = \lambda_1 \sum_{ikj} \Big(m_{ikj}(X,b) \Big)^2 + \lambda_2 \sum_{kj} \Big(m_{kj}(X,b) \Big)^2$$

Intuitively, for each investor country, the differences in shares of claims using a particular intermediary for two different issuers depends on the relative size of the positions in those issuer countries and the relative network costs of using that intermediate for claims from each ultimate issuer. Differences intermediaries, can net out the position differences and yield information on the network frictions B. On the other hand, the ratios comprising the global restatement matrix depend on the same frictions *as well as* a weighted combination of all global positions, and hence yield information on the entirety of X. We return later to the issue of unpacking the normalizations. In the appendices B.2 and B.3, we formally show the Jacobian of this system is of full rank and hence the model is identified.

[14] We do not use the information on the EMU aggregate since we want to estimate individual countries exposures. We impose the first step assumption 2 in the case of the investor-specific shares, while we allow for longer chains on the investor side for the global shares: $\psi_{z|ij} = \frac{a_{iz} b_{zj}}{b_{ij}}; \psi_{k|ij} = \frac{b_{ik} b_{kj}}{b_{ij}}$. Note that the assumption does not restrict the first moment, as a_{iz} cancels.

[15] Although we have $7N^2$ more moments than parameters, of the $8N^2$ moments represented by equation 11, there are only $N^2 - 2N + 1$ independent equations. In particular, additional investor country moments beyond the first do not add independent information. The intuition for the redundancy between investor countries' moments is that each gives information on the relative frictions of each intermediary l from each issuer j. Effectively, for each asset issuing country we can estimate the relative transaction costs across asset holding countries; and for each asset holding country we can estimate the relative transaction costs across asset issuing countries.

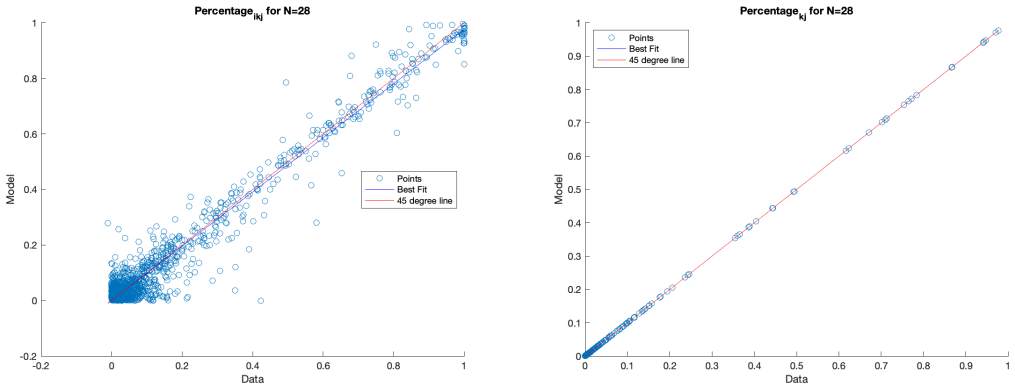
4.2 Results

Our current results include 28 countries: a mix of tax havens, BRICs, and industrialized economies.[16]

Targeted Moments Figure 2 shows the fit between our error-minimizing guess of parameters and the micro-data-derived values. Overall, the optimal guess for X and B fit the moments quite well. Panel 2a reports the fit for for the $8N^2$ equation (10) moments, with $R^2 > 0.96$. The largest source of error comes from the large number of zeros in the data, which the model can approximate well but not perfectly. The fit for the N^2 moment from equation (11) is much stronger ($R^2 > 0.99$). Weights strongly favor these moments, which may be measured in the data with substantially less error, as they are summed over many country's investments.

Note that the targeted moments represent the first two data products of our estimation: a full $N \times N$ matrix of ultimate positions, and associated network costs B. From assumption 1 (Leontief Inverse), we obtain our third data product: the matrix A, which is comprised of estimates of bilateral edge costs of owning (as an intermediary or ultimate partner) foreign assets from any country j in any country i. These wedges correspond to taxes and informational costs of security ownership, for example. To our knowledge, as with the B matrix, there are no such estimates to compare these to.

Figure 2: Fit of Targeted Moments



(a) Triplet Proportion Moment **(b)** Bilateral Proportion Moment

Note: The figure plots the results of the estimation procedure using moments defined by equations (10) and (11).

Untargeted Moments An untargeted moment in our model is the CPIS. Its theoretical counterpart, i.e. the total volume of positions between i and j, including both intermediate and ultimate positions, is given by equation 6, which in matrix algebra

[16] These will be replaced with an estimation of all 86 CPIS reporting countries.

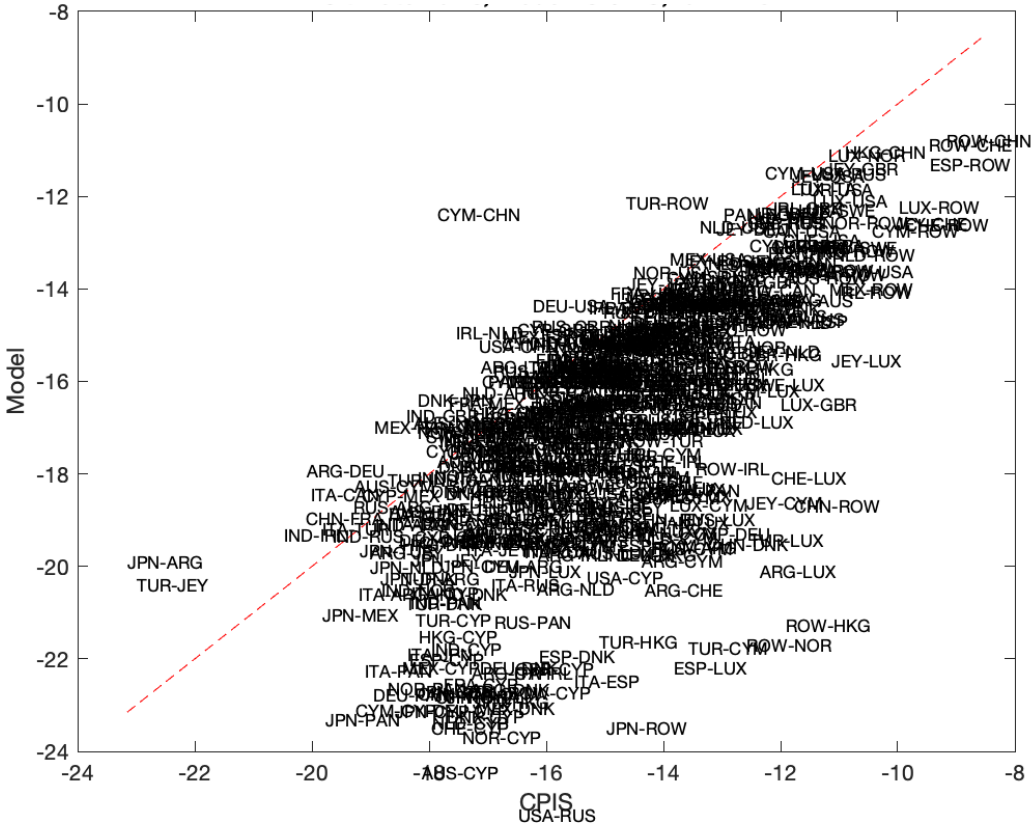
is:

$$\Xi = A \odot B'(X \oslash B)B' \tag{12}$$

where $\odot$ and $\oslash$ are Hadamard product and division, respectively. Given estimates of X, B, and A, we generate a full matrix of Ξ estimates, which represent our fourth data product: a completed CPIS. We check the untargeted fit with respect to the available CPIS: overall, the two line up fairly closely, with $R^2 > 0.93$. Figure 3 assesses the relationship between estimated bilateral positions and those available in the CPIS. On the X-axis are bilateral positions stated in CPIS. On the y-axis are the model-based restated positions. This serves as an untargeted moment test.

Interestingly, the model substantially overestimates the Cayman Island - China bilateral position. Conversely, the model may conclude that the weight of all other bilateral pairs implies that the CYM-CHN CPIS position is under-reported (recall these relationships are not disciplining the model). Second, we see substantial lower estimates for investments and issuance from major tax havens (LUX, CYM, JEY, CYP, IRL) and other financially important countries (JPN, CHE).

Figure 3: Fit of Untargeted Moment: CPIS Observed Positions



Note: The figure plots the results of the estimation procedure using moments defined by equations (10) and (11).

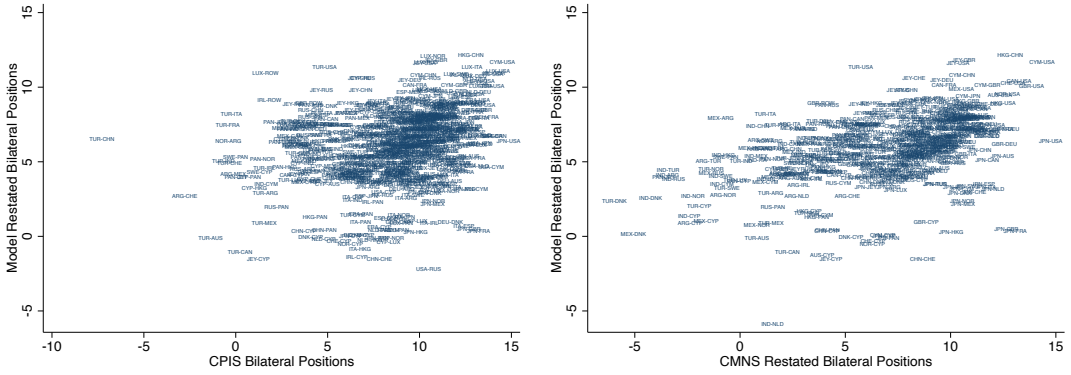
4.3 The Model Restatement

We compare our bilateral restatements to two benchmarks: the CPIS and the algorithmic restatements in CMNS. Figure 4 plots each, respectively, in logs on the x-axis, against model estimates in logs on the y-axis.

In Panel A, the general positive relationship indicates some congruence between the CPIS values and the model's restatement, but also a large number of extreme outliers. Discussing outliers in this context is somehow problematic. Any model with a large number of moments will also generate a large tail of mis-measured moments. Therefore, any particular bilateral element of the graph should be cautiously interpreted. Nevertheless, broader patterns can be detected. A large number of the more extreme positive restatements (upper-left quadrant) are related to middle-income countries, including Turkey and China. In the lower-right quadrant are the model's extreme downward restatements. As expected, a substantial number of bilateral pairs in this column are investments or issuance from tax havens. Indeed tax hubs are represented in the majority of the top 20 largest restatements. More interestingly, many of these are Japanese investments, implying that Japan may be used as an intermediary for many countries' investments. By size, Japanese investment positions constitute about half of the top 20 largest negative restatements. The overall mass of restatements are largely negative.

In Panel B, we compare the estimated restatements with those from the CMNS algorithmic restatements. Overall, the relationship here is tighter. Though the algorithm and the model use the same ratios, they do so in very different ways, which we view as a check on the model's restatement. Focusing again on the negative restatements (lower-right), the negative restatement of Japanese investments in CPIS does not appear in the CMNS restatements, which is due to the fact that the CMNS algorithm re-weights but does not permit overall reductions in outward position volumes. Though more difficult to see, many of the relatively larger negative restatements come from two sources, US-bound investments, and investments or issuance from tax havens, especially the Cayman Islands, but also Luxembourg.

Figure 4: Comparison of Model Estimates to CMNS and CPIS



(a) Model Estimated Positions vs CPIS **(b)** Model Estimated Positions vs CMNS

Note: The figure plots the model implied ultimate positions X against the raw CPIS data and the CMNS restated CPIS (using global shares (**??**)).

5 Implications and Applications

This section re-assesses some of the core debates in the international finance literature through the lens of our restated positions.

5.1 The US and the UK Intermediate Global Capital

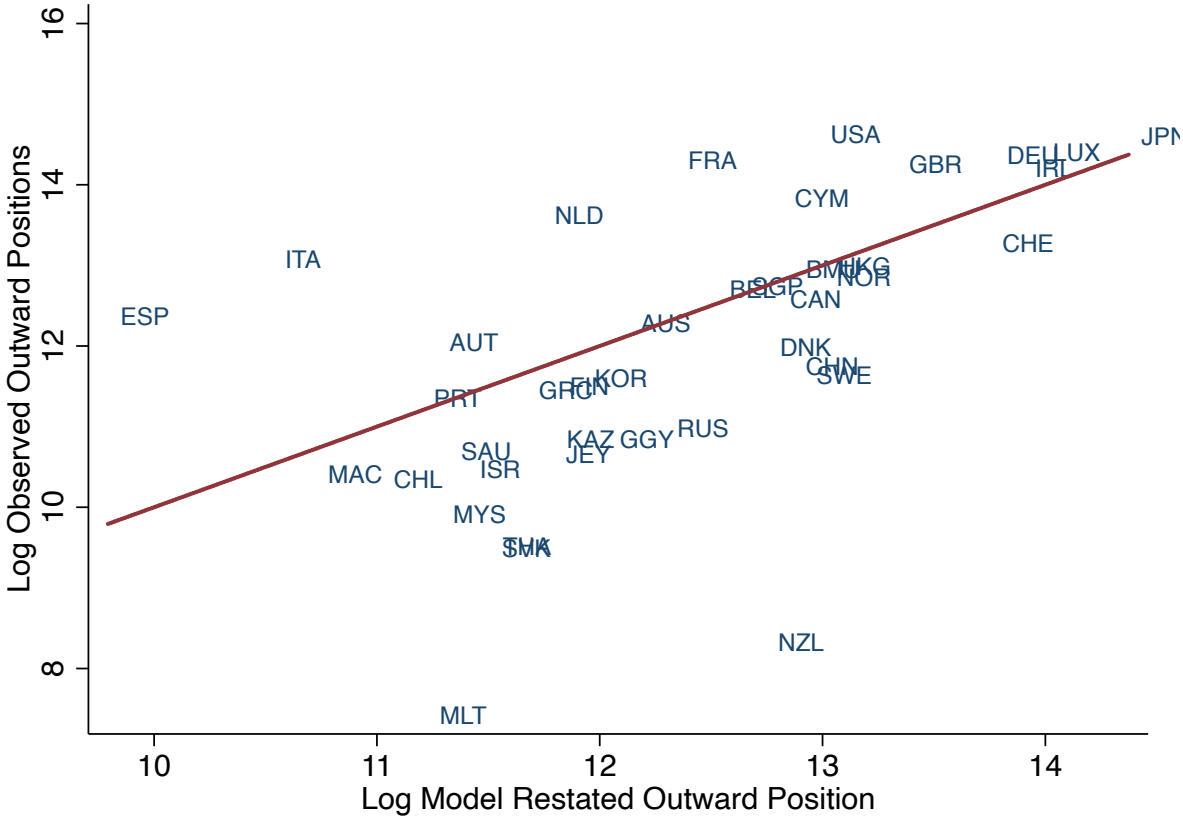
Table **??** reports a selection of the restatements in Figure 7. Of note, Japan's US position is substantially downward restated, although a substantial fraction of this is reallocated by the model to Japanese investments elsewhere, especially Canada. Second, positions invested into global tax havens, such as the Cayman Islands and Luxembourg are restated down, consistent with the CMNS restatement. Unlike the CMNS restatement, the outward positions of these tax haven countries are also restated downward. Further, the outward positions of the United States and Great Britain are restated downward as well, indicating that a substantial portion of their global outward positions are intermediated investments.

Moving to Figure **??**, which plots the total outward position in the CPIS on the Y-axis against the model restated position on the X-axis, we show which countries' positions are restated up and down. As alluded to above, the net positions of the US, UK, Cayman Islands, Luxembourg are restated down, as are those of France, the Netherlands, Italy and Spain (though the log scale overstates the dollar value of these changes). A substantial fraction of this money is reallocated to developing countries: Russia, Israel, Chile, China's outward positions are all restated up.

Table 2: Selected Restatements

Pair	vs CPIS	vs CMNS	Rank
JPN-USA	-902	-934	1
CYM-USA	-536	-509	2
LUX-USA	-334		5
GBR-USA	-192	-212	10
JPN-FRA	-171	-166	13
JPN-CYM	-157	-6	17
BMU-USA	-139	-136	24
CYM-JPN	-33	-40	82
GBR-LUX	-33	2	83

Figure 5: Model-Restated Outward Positions

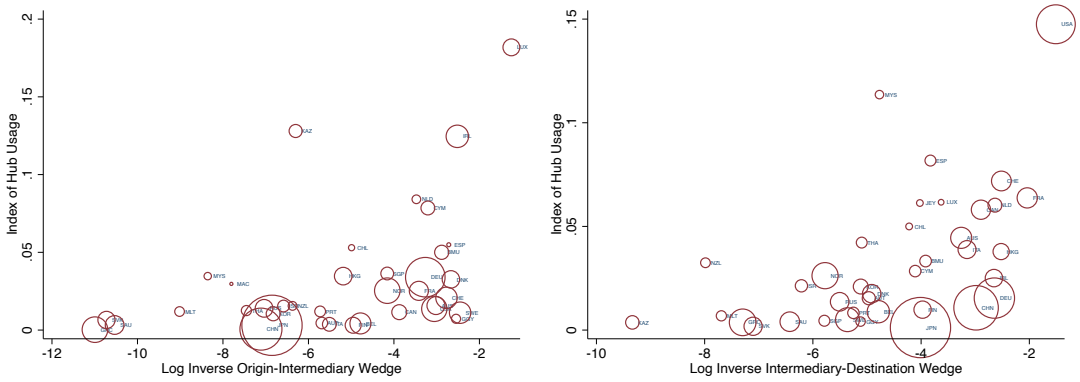


Who invests in the UK? Using the combined wedges a_{kl}, network cost matrix B, and the bilateral position matrix X, we can calculate, for each origin country, for each of its destinations, the percentage of dollars using any particular country as an intermediary. Summing over all destinations, we can recover the dollar amount invested by each country *through* a hub.

Below, we graph the bilateral network distance between all origins and the UK, and the

percent of that country's investments that travel through the UK. The total investment position is given by the size of each circle.

Figure 6: Usage of the United Kingdom as an Intermediary



(a) Sources **(b)** Destinations

From the figure, it's clear that a substantial portion of the funds the UK intermediates come from Europe. Panel (a) identifies the origin country of non-UK investment dollars intermediated by the UK. Luxembourg and Ireland are high up, indicating intensive usage of the UK as an intermediary from those origins, although fewer dollars originate in those countries. Though lower on the Y-axis, other European countries like Germany, France, the Netherlands, and Spain all use the United Kingdom substantially. The positive slope of the scatter indicates the model's rationale for this allocation: these countries enjoy closer connections in 2016 (the year of our estimation) with the United Kingdom, and so a large fraction of their investments are intermediated cheaply through the UK.

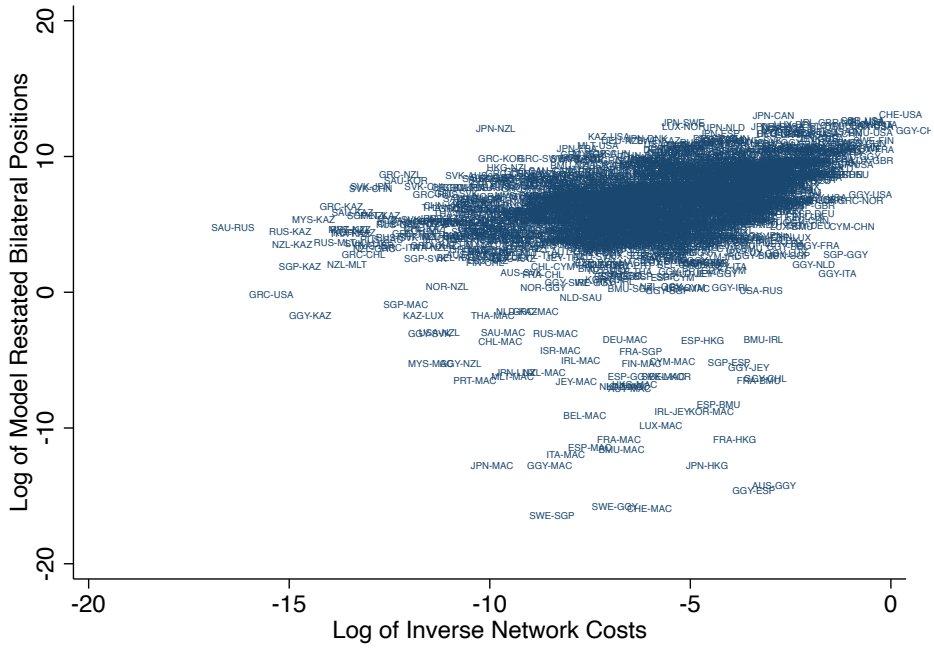
Panel (b) shows the destination of these funds. The US sticks out as a major investment for dollars intermediated by the UK, in large part because of the close network proximity between the two countries. However, a substantial fraction of European money intermediated through the UK returns to Europe. A substantial sum is also destined outward to the rest of the world including to China.

5.2 Financial Gravity

In this subsection, we examine the relationship between bilateral wedges and bilateral positions. Without a specific demand framework, a gravity relationship between claims and wedges is not guaranteed in our class of models (Allen, Arkolakis, and Takahashi, 2020). The case for gravity in international finance is theoretically unclear (Okawa and Van Wincoop, 2012) and with limited empirical support (see Brei and von Peter (2018) for a survey). For example, a diversification motive might increase

demand for financially disconnected assets, and minimize a size-position relationship. In part, the empirical study of gravity in finance has been limited by the unavailability of true bilateral positions as they exist in trade. In addition, because the gravity relationship in trade is driven largely by distance, the empirical relationship existed long before a structural model derived wedges (Eaton and Kortum, 2002). Our model, intentionally agnostic to the origins of the demand for and supply of assets, does not assume a gravity relationship between wedges and positions. As such, our estimated positions and wedges are also gravity-agnostic and do not "bake in" any such relationship.

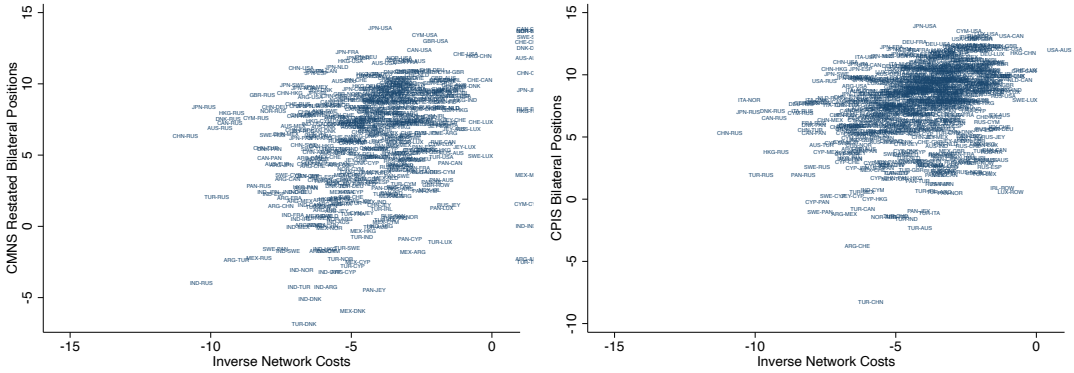
Figure 7: Financial Gravity



Note: The figure plots ultimate positions X and network costs B.

Figure 7 plots the log inverse bilateral network costs against the log of bilateral positions. The striking, positive relationship expresses that according to our estimates, where costs are lower, trade is higher, with an elasticity slightly higher than one. This relationship persists in a specification with individual country fixed effects. The estimated bilateral wedges explain positions, though to a lesser extent, from both the CPIS and model-free restatements. Figure 8 repeats the exercise in Figure 7 using CPIS and CMNS positions. In both cases, the positive relationship persists, though in the case of the CPIS, with a noticeably higher degree of noise.

Figure 8: The Fit of Estimated Network Costs



(a) CMNS Restated Positions vs Net. Costs **(b)** CPIS Positions vs Network Costs

Note: The figure plots CPIS and CMNS-restated CPIS positions against our estimates of network costs B.

5.3 Aggregate Position Restatements

Net Positions Our estimates can also help elucidate countries' global net positions. Because we restate both claims held and claims issued, our estimates are able to restate net positions. Other restatement methods are either globally incomplete (Beck et al., 2023), or only restate claims issued (CMNS).

As our model elucidates, observed bilateral positions should not be conceptual distinct from restatements. Figure 9 illustrates this accounting identity. In the figure, solid lines represent true claims held or issued by k. Claims originating anywhere traveling from country i to k are captured by the top line. Claims issued by k owned by i but subsequently transferred to any other country are represented by the bottom line. All other claims (dotted lines) are "through-claims," those neither destined for or truly issued at k. By construction, these claims wash out. Thus summing over all incoming ik and outgoing kj claims generate the same result, whether including all observed claims or adding unobserved as well.

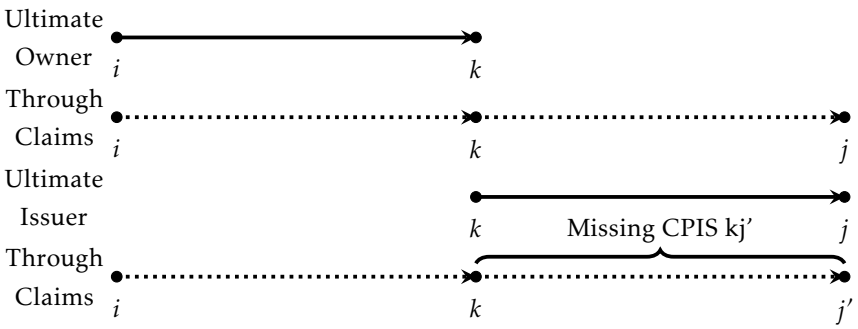


Figure 9: Gross vs Net Positions

Note: The figure draws a schematic representation of gross vs net positions for a country k. Solid lines correspond to claims ultimately issued or held by k. Dashed lines represent claims issued elsewhere and ultimately held elsewhere. The arrows indicate the direction of transaction positions or possible paths.

However, the CPIS is incomplete. In the figure, the through claims and ultimate issuance from k to j' is missing. Without this segment, the inward portion of the claim does not , we cannot place a limit on the size or direction of missing bilateral positions. Figure 10 reports the restated positions, with the CPIS positions on the Y-axis and our model's restatement on the X-axis. The red line is the 45-degree line. For negative CPIS positions, upward restatements (below the red line) reduce the net position. For positive CPIS positions, downward restatements (above the red line) reduce the net position.

Ireland and Luxembourg are positively restated such that their net position is greatly reduced. Strikingly, the net position of the US is substantially revised downward, and the Japanese net position is revised upward. When evaluating the bilateral restatements for both, a substantial amount of claims on Japanese assets are attributed to other ultimate issuers while a substantial amount of US claims are attributed to other claimants. Both countries appear to be used as a hub, though not for tax purposes.

China's net position is also substantially revised upwards, reaffirming the results of CMNS, who do not revise the volume of outward claims.

Inward Position Restatement As Figure 11 shows, the large positive net position revision from China in our estimates are due to a large positive inward restatement. This is reconciles the close results of the algorithmic and model-based restatement.

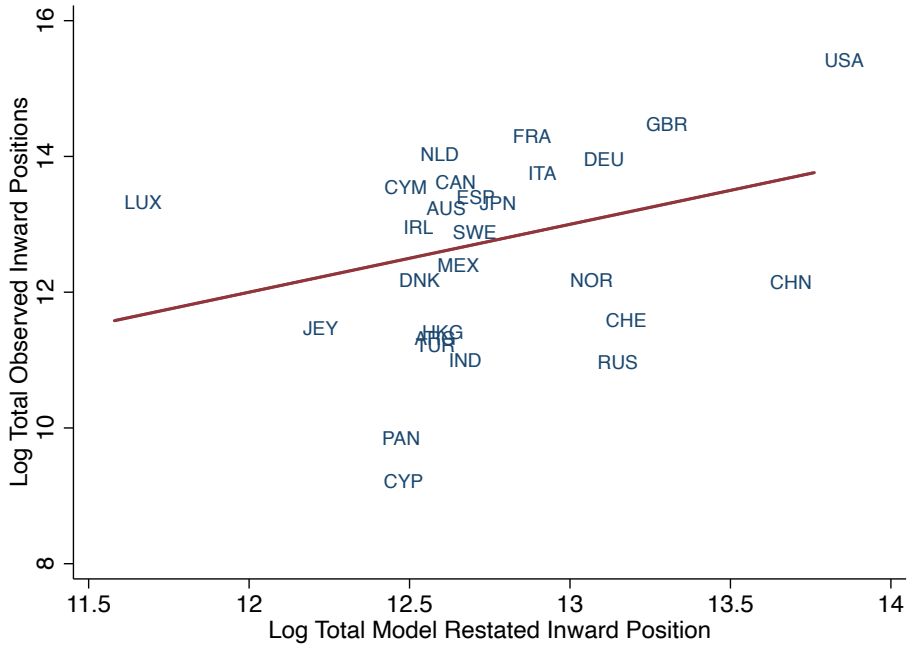


Figure 10: Restating Financial Hub Positions

Note: The figure plots the total inward position from model estimates (x-axis, sum of all inward bilateral positions) vs from the CPIS (y-axis).

Further, the US inward restatement is very negative, as is that of Great Britain, Luxembourg, and the Cayman's. Surprisingly, other financial hubs, Jersey, Cyprus, and Panama have upward revisions to their restatement. These stand in contrast to their algorithmic restatement. Notably, Russia and India inward positions also are substantially revised upward. These positions come largely through the downward restatements of the US and Great Britain, indicating these higher income countries are being used as vehicles for investment into middle income countries.

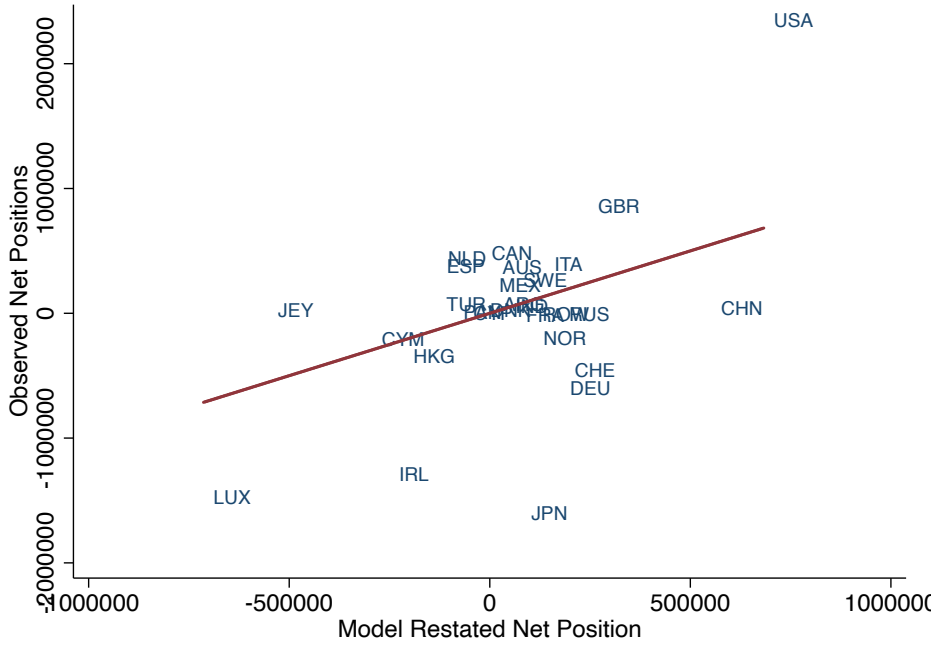


Figure 11: Net Position Restatements

Note: The figure plots aggregates total inward minus outward estimated bilateral positions for each country (x-axis) vs aggregate inward minus outward bilateral CPIS (y-axis).

6 Conclusion

This paper applies model and methods from the literature in international trade to recover estimates of bilateral investment positions in the presence of international transfer methods that result in complex, indirect ownership trains. We leverage the work of algorithmic restatement methods (in particular, CMNS) and estimate our model in a manner which allows us to substantially relax the model-free assumptions of algorithmic restatements. In doing so, we generate four new data products: model-consistent restated bilateral positions, a 'filled in" CPIS and two completely new datasets on bilateral asset transfer costs.

Our results not only build off but also bolster the algorithmic restatements, Our approach allows us to simultaneously restate investments not only within investor countries but across them. Our empirical approach largely confirms and extends algo-

rithmic restatement results. China's net position is restated substantially positive. In addition, we find a substantial role for non-tax-haven intermediaries. These are large, financially sophisticated countries (Japan, US, Switzerland) whose intermediary role was previously masked.

This analysis are preliminary and incomplete. In particular, in the coming month we will expand our estimation to include all 86 CPIS reporting countries.

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A Derivations

A.1 Chain Probabil ity

Conditional on choosing to sell security ω to location i, a firm in location j will choose a chain from i to j to minimize the transaction cost incurred, so that the probability she selects a chain $c \in \mathcal{C}_{ij}$ is:

$$\pi_{ij,c|i} = \frac{\left(\prod_{k=1}^{K} e_{k-1,k}\right)^{\theta_c}}{\sum_{c \in \mathcal{C}_{ij}} \left(\prod_{k=1}^{K} e_{k-1,k}\right)^{\theta_c}}$$

with expected cost

$$\tau_{ij} = \left(\sum_{c \in \mathcal{C}_{ij}} \left(\prod_{k=1}^{K} e_{k-1,k} \right)^{-\theta_c} \right)^{-1/\theta_c}$$

The *unconditional* probability that taking a chain c to lend from country i to j for a given product ω that costs less than a constant τ is:

$$\begin{aligned} H_{ijc\omega}(\tau) \equiv & \Pr\left(\tau_{ij}(c,\omega) \leq \tau \right) \\ = & \Pr\left(\frac{\tilde{\tau}_{ij}(c)}{\xi_{ij}(c,\omega)} \leq \tau \right) \\ = & 1 - \Pr\left(\xi_{ij}(c,\omega) \leq \frac{\tilde{\tau}_{ij}(c)}{\tau} \right) \\ = & 1 - \exp\left\{ -\left[\frac{\tilde{\tau}_{ij}(c)}{\tau} \right]^{-\theta} \right\} \qquad \left[\xi \sim \text{ Fréchet}(1,\theta) \right] \end{aligned} \tag{13}$$

Because the technology is i.i.d across types, this probability will be the same for all goods $\omega \in \Omega$.

So far we have considered the potential wedge, however we do not observe bilateral ex-ante cost, but the cost that each country applies ex-post, after choosing the cheapest chain. The probability that, *conditional* on banks choosing the least cost chain, the cost in ω is less than some constant τ:

$$
\begin{aligned}
H_{ij\omega}(\tau) \equiv & \Pr\left(\tau_{ij}(\omega) \leq \tau\right) \\
= & \Pr\left(\min_{c \in \rfloor} \tau_{ij}(c,\omega) \leq \tau\right) \\
= & 1 - \Pr\left(\min_{c \in \rfloor} \tau_{ij}(c,\omega) \geq \tau\right) \\
= & 1 - \Pr\left(\bigcap_{c \in \rfloor} \left[\tau_{ij}(c,\omega) \geq \tau\right]\right) \\
= & 1 - \prod_{c \in \rfloor} \left[\Pr\left(\tau_{ij}(c,\omega) \geq \tau\right)\right] \quad \text{by independence} \\
= & 1 - \prod_{c \in \rfloor} \left[1 - \Pr\left(\tau_{ij}(c,\omega) \leq \tau\right)\right] \\
= & 1 - \prod_{c \in \rfloor} \left[1 - H_{ijc\omega}(\tau)\right] \quad \text{by eq 13} \\
= & 1 - \exp\left\{-\tau^{\theta} \sum_{c \in \rfloor} \left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\} \qquad (14)
\end{aligned}
$$

To summarize, this is the probability that, given that banks choose the lower cost chain, the cost is below a certain value.

Now we derive the probability that a chain c from i to j is selected:

$$
\begin{aligned}
\pi_{ijc\omega} &\equiv \Pr\left(\tau_{ij}(c,\omega) \le \min_{c'\neq c} \tau_{ij}(c',\omega)\right) \\
&= \Pr\left(\bigcap_{c'\neq c}\left[\tau_{ij}(c',\omega) \ge \tau_{ij}(c,\omega)\right]\right) \\
&= \prod_{c'\neq c}\left[\Pr\left(\tau_{ij}(c',\omega) \ge \tau_{ij}(c,\omega)\right)\right] \quad \text{by indep} \\
&= \prod_{c'\neq c}\left[1 - H_{ijc'\omega}\left(\tau_{ij}(c,\omega)\right)\right] \\
&= \int_0^\infty \prod_{c'\neq c}\left[1 - H_{ijc'\omega}(\tau)\right] dH_{ijc\omega}(\tau) \\
&= \int_0^\infty \prod_{c'\neq c}\left[1 - H_{ijc'\omega}(\tau)\right] \frac{d}{d\tau}\left[1 - \exp\left\{-\left[\frac{\tilde{\tau}_{ij}(c)}{\tau}\right]^{-\theta}\right\}\right] d\tau \\
&= \int_0^\infty \prod_{c'\neq c}\left[1 - H_{ijc'\omega}(\tau)\right] \tau^{\theta-1}\theta\left[\tilde{\tau}_{ij}\right]^{-\theta} \exp\left\{-\left[\frac{\tilde{\tau}_{ij}(c)}{\tau}\right]^{-\theta}\right\} d\tau \\
&= \int_0^\infty \prod_{c'\neq c}\left[\exp\left\{-\left[\frac{\tilde{\tau}_{ij}(c')}{\tau}\right]^{-\theta}\right\}\right]\left(\tau^{\theta-1}\theta\left[\tilde{\tau}_{ij}\right]^{-\theta}\right)\exp\left\{-\left[\frac{\tilde{\tau}_{ij}(c)}{\tau}\right]^{-\theta}\right\} d\tau \\
&= \int_0^\infty \prod_{c\in G}\left[\exp\left\{-\left[\frac{\tilde{\tau}_{ij}(c)}{\tau}\right]^{-\theta}\right\}\right]\left(\tau^{\theta-1}\theta\left[\tilde{\tau}_{ij}\right]^{-\theta}\right) d\tau \\
&= \int_0^\infty \left[\exp\left\{-\tau^\theta \sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\}\right]\left(\tau^{\theta-1}\theta\left[\tilde{\tau}_{ij}\right]^{-\theta}\right) d\tau \\
&= \int_0^\infty \left[\exp\left\{-\tau^\theta \sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\}\right]\left(\tau^{\theta-1}\theta\left[\tilde{\tau}_{ij}\right]^{-\theta}\right) d\tau \, \frac{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}} \\
&= \int_0^\infty \left[\exp\left\{-\tau^\theta \sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\}\right]\left(\tau^{\theta-1}\theta\right)\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta} d\tau \, \frac{\left[{}_i\tilde{\tau}_{ij}\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}} \\
&= \int_0^\infty -\frac{d}{d\tau}\exp\left\{-\tau^\theta \sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\} d\tau \, \frac{\left[\tilde{\tau}_{ij}\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}} \\
&= -\exp\left\{-\tau^\theta \sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}\right\}\Bigg|_0^\infty \frac{\left[\tilde{\tau}_{ij}\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}} \\
&= \left[-\frac{1}{\exp(\infty)} + \frac{1}{\exp(0)}\right] \frac{\left[\tilde{\tau}_{ij}\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}} \\
&= \frac{\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}}{\sum_{c\in G}\left[\tilde{\tau}_{ij}(c)\right]^{-\theta}}
\end{aligned}
$$

A.2 Lemma 4

Lemma 4. *Under assumption 2 the edge intensity is defined as*

$$\psi_{z|ij} = \frac{a_{iz} b_{zj}}{b_{ij}}$$

and it equals the proportion of ultimate positions W_{ikj} from k to j, i.e.

$$\sum_z \psi_{z|ij} = 1$$

In other words, if a node k is not the only the first step after the investor, it can be used as hubs by multiple chains, make it so the intensity equal the proportion times the number of times the node is used (Allen and Arkolakis, 2022).[17]

A.3 Relaxing Assumptions

Proposition 1 (First step only)**.** *Let assumptions 1 and 3 hold. Relax assumption 2 such that the node intensity is defined by equation (??) and hence lemma 4 does not hold. Then, the algorithmic restatement does not recover ultimate exposure:*

$$\begin{aligned}\sum_k q_{ik}\omega_{kj,i} &= \sum_k W_{ik}\pi_{kj|i} \\ &= \sum_k \left(\sum_j W_{ikj}\right)\left(\frac{W_{ikj}}{\sum_j W_{ikj}}\right) = \sum_k W_{ikj} \\ &= \sum_k \psi_{k|ij} X_{ij} \neq X_{ij}\end{aligned}$$

Proposition 2 (Global shares, homogeneity only)**.** *Let assumption 3 hold. Let Ω be a $N \times N$ matrix of global shares, i.e. we don't know the investor country i, and each element corresponds to equation (??). Then, the algorithmic reallocation does not recover ultimate*

[17] Whenever k is not the first step, summing over k may double count, since $n_k > 1$: you may use that link twice, making $\sum_k \psi_{k|ij} > 1$.

exposures:

$$\begin{aligned}\sum_k q_{ik}\omega_{kj} &= \sum_k W_{ik}\pi_{kj} \\ &= \sum_k W_{ik}\frac{\sum_i W_{ikj}}{\sum_{i,j} W_{ikj}} = \sum_k \frac{W_{ik}}{W_k}\sum_i W_{ikj} \\ &= \sum_k \frac{W_{ik}}{W_k}\sum_i \psi_{k|ij}X_{ij} \neq X_{ij}\end{aligned}$$

A.4 Endogenization of Aggregate Financial Flows

We present a microfoundation of the aggregate ultimate financial flow between any countries i and j based on the analysis of Martin and Rey (2004). There are two periods. In each country households can carry out divisible projects, indexed by ω. Each investment unit of project ω costs one unit of the consumption good and yields a dividend of D units of the consumption good in state of nature ω, and zero otherwise. There are Ω states of nature, each with equal probability $\pi(\omega) = 1/\Omega$.

The representative household derives linear utility from consumption in the first period (C_{1i}) and CES utility from consumption in the second period (C_{2i}):

$$U = C_{1i} + \beta E\left(\frac{C_{2i}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}\right)$$

Households can purchase securities representing claims on the dividends of investment projects in any country (traded in the stock market or the bond market). We denote securities held in project ω by $s_i^j(\omega)$. Purchase of a security entails an intermediation cost of τ, per unit.[18]

The problem of the representative household thus reads

$$\begin{aligned}\max_{C_{1i},C_{2i},s_i^j(\omega)} \quad U &= C_{1i} + \beta E\left(\frac{C_{2i}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}\right) \\ s.t.\ Y_i &= C_{1i} + \sum_{\omega\in\Omega} p_\omega(1+\tau)s_i^j(\omega) \\ C_{2i}(\omega) &= Ds_i^j(\omega)\end{aligned}$$

where $s_i^j(\omega)$ is the number of securities (units) of project ω in country j held by the representative household of country i, and Y_i denotes the income of the household.

[18] Alternatively, the transaction cost could be on the payment of the dividend.

Substituting the constraints into the objective function, the household's problem can be rewritten as

$$\max_{s_i^j(\omega)} U = Y_i - \sum_{\omega\in\Omega} p_\omega(1+\tau)s_i^j(\omega) + \beta \sum \left(\frac{\pi(\omega)\left[Ds_i^j(\omega)\right]^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} \right)$$

Taking first order conditions with respect to securities holdings, after some algebra, we obtain the demand of the representative household of country i for the securities of project ω in country j:

$$s_i^j(\omega) \quad = \quad D^{\sigma-1}p_\omega^{-\sigma}(1+\tau)^{-\sigma}\Psi, \quad \text{where } \Psi = \left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma}$$

The demand for securities of type ω of country i is thus directly related to the dividend flow and to the discount factor, and inversely related to the price of the security and to the intermediation cost τ.

Under perfect competition, the supply of shares is infinitely elastic at the price of one (the opportunity cost of investment). That is, $p_\omega = 1$. Substituting, and aggregating across securities, the total flows from country i to country j can then be written as

$$\sum_{\omega\in\Omega} p_\omega(\omega)s_i^j(\omega) = \Omega^{1-\sigma}\frac{\left(1-\frac{1}{\sigma}\right)^{-\sigma}}{\beta^{-\sigma}} D^{\sigma-1}(1+\tau)^{-\sigma}$$

.

These are increasing in dividends and in the discount factor, and decreasing in transaction costs.

Proof (algebra details) of the secutities demand derivation.

$$
\begin{aligned}
s_i^j(\omega) \quad &: \qquad -p_\omega(1+\tau) + \frac{\beta\left[Ds_i^j(\omega)\right]^{-\frac{1}{\sigma}} D}{\Omega\left(1-\frac{1}{\sigma}\right)} = 0 \\
\left[Ds_i^j(\omega)\right]^{-\frac{1}{\sigma}} &= \frac{p_\omega(1+\tau)\Omega\left(1-\frac{1}{\sigma}\right)}{\beta D} \Longrightarrow \\
\left[Ds_i^j(\omega)\right]^{-1} &= \left[\frac{p_\omega(1+\tau)\Omega\left(1-\frac{1}{\sigma}\right)}{\beta D}\right]^{\sigma} \Longrightarrow \\
s_i^j(\omega) &= D^{\sigma-1} p_\omega^{-\sigma}(1+\tau)^{-\sigma}\left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma} \Longrightarrow \\
s_i^j(\omega) &= D^{\sigma-1} p_\omega^{-\sigma}(1+\tau)^{-\sigma}\Psi, \quad \text{where } \Psi = \left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma}
\end{aligned}
$$

B Estimation Appendix

B.1 Identification

B.2 Identification

A key feature of these equations is that they depend on the unknown matrices B and X only through ratios. In particular, they are invariant under the following *gauge transformation*:

$$B_{ij} \to \alpha_i \beta_j B_{ij}, \tag{15}$$

where $\{\alpha_i\}_{i=1}^N$ and $\{\beta_j\}_{j=1}^N$ are arbitrary positive scaling factors. Notice that if we multiply all α_i by a constant c and divide all β_j by c, the transformation remains unchanged. Moreover, the moment conditions depend on X only through the ratio

$$\frac{X_{ij}}{\sum_{j'}\left(\frac{b_{kj'}}{b_{ij'}} X_{ij'}\right)},$$

so that a uniform scaling $X \to \gamma X$ leaves both numerator and denominator multiplied by γ and hence cancels out. Thus, aside from the $2N-1$ invariances in B, there is an additional overall scaling invariance in X, yielding a total of $2N$ invariances. To see how this invariance affects identification, we linearize the transformation by writing

$$\alpha_i = 1 + \epsilon_i, \quad \beta_j = 1 + \eta_j,$$

with ϵ_i and η_j being small. Then, to first order, the transformed parameters satisfy

$$\delta B_{ij} = (\epsilon_i + \eta_j) B_{ij}, \qquad \delta X_{ij} = -(\epsilon_i + \eta_j) X_{ij}.$$

Since the moment functions m_{ikj} and m_{kj} are homogeneous functions of B and X, an infinitesimal change along the gauge direction does not alter their values. More precisely, if we denote the full parameter vector by $\theta = (X, B)$ and the corresponding moment functions by $m(\theta)$, then the directional derivative along the gauge direction v, with

$$v = \Big\{ \delta X_{ij} = -(\epsilon_i + \eta_j) X_{ij}, \quad \delta B_{ij} = (\epsilon_i + \eta_j) B_{ij} \Big\},$$

is given by

$$D_v m(\theta) = \lim_{\epsilon \to 0} \frac{m(\theta + \epsilon\, v) - m(\theta)}{\epsilon} = 0.$$

In terms of the Jacobian $J = \partial m(\theta)/\partial \theta$, this means that

$$J\, v = 0.$$

Thus, the vector v lies in the null space (kernel) of J; we say "the derivative vanishes" along v because the change in the moments along this gauge direction is zero.

This nontrivial null space implies that the parameters are not locally identified unless the $2N - 1$ gauge degrees of freedom are removed. In our estimation procedure we eliminate this invariance by imposing normalization restrictions. A convenient and standard choice is to fix one entire row and one entire column of B (which accounts for $2N - 1$ independent restrictions) and to fix one element of X (removing the remaining overall scaling). With these restrictions the gauge transformation in Eq. (15) is uniquely pinned down, the kernel of the Jacobian is eliminated, and the Jacobian (restricted to the remaining free parameters) becomes full rank. This ensures that the mapping from the parameters to the moment conditions is locally one-to-one and that the model is identified.

B.3 Jacobian of the moments

In what follows, δ is the Kroenecker delta.

$$\frac{\partial m_{ikj}}{\partial X_{yz}} = \frac{N_{ikj}}{D_{ik}^2} \delta_{yi} \frac{b_{kz}}{b_{iz}} - \frac{1}{D_{ik}} \delta_{yi} \delta_{zj} \frac{b_{kj}}{b_{ij}} \tag{16a}$$

$$\frac{\partial m_{ikj}}{\partial B_{yz}} = \left[\frac{N_{ikj} X_{iz}}{D_{ik}^2 b_{iz}} \left(\delta_{ky} - \delta_{iy} \frac{b_{kz}}{b_{iz}} \right) - \frac{X_{ij}}{D_{ik} b_{ij}} \left(\delta_{ky} \delta_{zj} - \delta_{iy} \delta_{zj} \frac{b_{kj}}{b_{ij}} \right) \right] \tag{16b}$$

$$\frac{\partial m_{kj}}{\partial X_{yz}} = \left[\frac{N_{kj}}{D_k^2}\frac{b_{yk}b_{kz}}{b_{yz}} - \delta_{zj}\frac{1}{D_k}\frac{b_{yk}b_{kj}}{b_{yj}}\right] \tag{17a}$$

$$\frac{\partial m_{kj}}{\partial B_{yz}} = \left[\frac{N_{kj}}{D_k^2}\left(\delta_{kz}\sum_{j'} b_{kj'}\frac{X_{yj'}}{b_{yj'}} + \delta_{ky}\sum_{i'} b_{i'k}\frac{X_{i'z}}{b_{i'z}} - b_{yk}b_{kz}\frac{X_{yz}}{b_{yz}^2}\right) - \frac{1}{D_k}\left(\delta_{kz}b_{kj}\frac{X_{yj}}{b_{yj}} + \delta_{ky}\delta_{jz}\sum_{i'} b_{i'k}\frac{X_{i'j}}{b_{i'j}} - \delta_{jz}b_{yk}b_{kj}\frac{X_{yj}}{b_{yj}^2}\right)\right] \tag{17b}$$

$$\frac{\partial m_{klj}}{\partial X_{yz}} = \left[\frac{N_{klj}}{D_{kl}^2}\frac{b_{yk}b_{lz}}{b_{yz}} - \delta_{jz}\frac{1}{D_{kl}}\frac{b_{yk}b_{lj}}{b_{yj}}\right] \tag{18a}$$

$$\frac{\partial m_{klj}}{\partial B_{yz}} = \left[\frac{N_{klj}}{D_{kl}^2}\left(\delta_{kz}\sum_{j'}\frac{b_{lj'}X_{yj'}}{b_{yj'}} + \delta_{ly}\sum_{i'}\frac{b_{i'k}X_{i'z}}{b_{i'z}} - \frac{b_{yk}b_{lz}X_{yz}}{b_{yz}^2}\right) - \frac{1}{D_{kl}}\left(\delta_{kz}\frac{b_{lj}X_{yj}}{b_{yj}} + \delta_{ly}\delta_{jz}\sum_{i'}\frac{b_{i'k}X_{i'j}}{b_{i'j}} - \delta_{jz}\frac{b_{yk}b_{lj}X_{yj}}{b_{yj}^2}\right)\right] \tag{18b}$$

$$\frac{\partial m_{lj}}{\partial X_{yz}} = \sum_{k'} b_{yk'}\left[\frac{N_{lj}}{D_l^2}\frac{b_{lz}}{b_{yz}} - \delta_{zj}\frac{1}{D_l}\frac{b_{lj}}{b_{yj}}\right] \tag{19a}$$

$$\frac{\partial m_{kj}}{\partial B_{yz}} = \left[\frac{N_{lj}}{D_l^2}\left(\sum_{j'} b_{lj'}\frac{X_{yj'}}{b_{yj'}} + \delta_{ly}\sum_{i',k'} b_{i'k'}\frac{X_{i'z}}{b_{i'z}} - b_{lz}\frac{X_{yz}}{b_{yz}^2}\sum_{k'} b_{yk'}\right) - \frac{1}{D_l}\left(b_{lj}\frac{X_{yj}}{b_{yj}} + \delta_{ly}\delta_{jz}\sum_{i',k'} b_{i'k'}\frac{X_{i'j}}{b_{i'j}} - \delta_{jz}b_{lj}\frac{X_{yj}}{b_{yj}^2}\sum_{k'} b_{yk'}\right)\right] \tag{19b}$$

C Endogenization of aggregate ultimate financial flows

We present a microfoundation of the aggregate ultimate financial flow between any countries i and j based on the analysis of Portes and Rey (2004). There are two periods. In each country households can carry out divisible projects, indexed by ω. Each investment unit of project ω costs one unit of the consumption good and yields a dividend of D units of the consumption good in state of nature ω, and zero otherwise. There are Ω states of nature, each with equal probability $\pi(\omega) = 1/\Omega$.

The representative household derives linear utility from consumption in the first pe-

riod (C_{1i}) and CES utility from consumption in the second period (C_{2i}):

$$U = C_{1i} + \beta E\left(\frac{C_{2i}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}\right)$$

Households can purchase securities representing claims on the dividends of investment projects in any country (traded in the stock market or the bond market). We denote securities held in project ω by $s_i^j(\omega)$. Purchase of a security entails an intermediation cost of τ, per unit.[19]

The problem of the representative household thus reads

$$\begin{aligned}\max_{C_{1i},C_{2i},s_i^j(\omega)} \quad U &= C_{1i} + \beta E\left(\frac{C_{2i}^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}\right)\\ s.t.\ Y_i &= C_{1i} + \sum_{\omega\in\Omega} p_\omega(1+\tau)s_i^j(\omega)\\ C_{2i}(\omega) &= Ds_i^j(\omega)\end{aligned}$$

where $s_i^j(\omega)$ is the number of securities (units) of project ω in country j held by the representative household of country i, and Y_i denotes the income of the household. Substituting the constraints into the objective function, the household's problem can be rewritten as

$$\max_{s_i^j(\omega)} U = Y_i - \sum_{\omega\in\Omega} p_\omega(1+\tau)s_i^j(\omega) + \beta\sum\left(\frac{\pi(\omega)\left[Ds_i^j(\omega)\right]^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}}\right)$$

Taking first order conditions with respect to securities holdings, after some algebra, we obtain the demand of the representative household of country i for the securities of project ω in country j:

$$s_i^j(\omega) = D^{\sigma-1}p_\omega^{-\sigma}(1+\tau)^{-\sigma}\Psi, \quad \text{where } \Psi = \left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma}$$

The demand for securities of type ω of country i is thus directly related to the dividend flow and to the discount factor, and inversely related to the price of the security and to the intermediation cost τ.

Under perfect competition, the supply of shares is infinitely elastic at the price of one

[19] Alternatively, the transaction cost could be on the payment of the dividend.

(the opportunity cost of investment). That is, $p_\omega = 1$. Substituting, and aggregating across securities, the total flows from country i to country j can then be written as

$$\sum_{\omega\in\Omega} p_\omega(\omega)s_i^j(\omega) = \Omega^{1-\sigma}\frac{\left(1-\frac{1}{\sigma}\right)^{-\sigma}}{\beta^{-\sigma}} D^{\sigma-1}(1+\tau)^{-\sigma}$$

.

These are increasing in dividends and in the discount factor, and decreasing in transaction costs.

Proof (algebra details).

$$\begin{aligned}
s_i^j(\omega) \quad &: \quad -p_\omega(1+\tau) + \frac{\beta\left[Ds_i^j(\omega)\right]^{-\frac{1}{\sigma}} D}{\Omega\left(1-\frac{1}{\sigma}\right)} = 0 \\
\left[Ds_i^j(\omega)\right]^{-\frac{1}{\sigma}} &= \frac{p_\omega(1+\tau)\Omega\left(1-\frac{1}{\sigma}\right)}{\beta D} \Longrightarrow \\
\left[Ds_i^j(\omega)\right]^{-1} &= \left[\frac{p_\omega(1+\tau)\Omega\left(1-\frac{1}{\sigma}\right)}{\beta D}\right]^{\sigma} \Longrightarrow \\
s_i^j(\omega) &= D^{\sigma-1}p_\omega^{-\sigma}(1+\tau)^{-\sigma}\left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma} \Longrightarrow \\
s_i^j(\omega) &= D^{\sigma-1}p_\omega^{-\sigma}(1+\tau)^{-\sigma}\Psi, \quad \text{where } \Psi = \left[\frac{\Omega\left(1-\frac{1}{\sigma}\right)}{\beta}\right]^{-\sigma}
\end{aligned}$$