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Testing an Extended Knowledge-Capital Model of Foreign Direct Investment: The Role of Public Knowledge Inputs

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ABSTRACT

The knowledge-capital model explains outward foreign direct investment (FDI) of a country from its relative abundance of its knowledge assets. Early versions of the knowledge-capital theory model these assets as if they were only the results of knowledge investments by private firms. We extend the theory by a formal model of the public-private interaction in knowledge development. This sheds light on the role of the origin country of multinationals. The paper extracts four testable predictions from the model. We use the inter-country variation in national knowledge-creation systems and FDI performance to test the model using a new dataset; it holds knowledge-creation indicators for about 200 countries over the period 2000-2020. Based on a range of non-parametric tests, we can corroborate that the basic tenet of the knowledge-capital model is correct. Moreover, the results show the important role of public knowledge production for outward FDI.

KEYWORDS

Knowledge-Capital Theory of FDI; Foreign Direct Investment; National Innovation Systems; Non-parametric Test

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1. Introduction

The knowledge-capital theory explains outward foreign direct investment (FDI) from the firms' drive to exploit their internal knowledge assets as broadly as possible. Multinational firms have a knowledge capital that at limited costs may also be applied in foreign subsidiaries (Markusen, 2002). Firms may exploit this knowledge capital through exports, but in the presence of trade costs or due to lower resource costs abroad, firms may profitably exploit it via local subsidiaries in other countries. The knowledge-capital theory of FDI predicts different structures of multinational firms in the presence of different cost parameters.[1]

To become a multinational firm must have a proprietary knowledge asset that can also profitably be applied in at least one foreign subsidiary. A problem for the theory is that this assumption has not yet been empirically proved in a convincing way. Reliable and internationally comparable data on firm-level knowledge assets are sparse in supply. Companies are reticent to publish the true value of a strategic item like their intangible knowledge assets. Commercial international datasets with company-level data are handicapped by comparability issues, and by different national disclosure and reporting rules regarding knowledge assets.

We propose an empirical test for the knowledge-capital (KC) theory by reformulating it in a way that is testable at the national level: *if the knowledge-capital theory is correct, countries with relatively large outward FDI stocks should have a relative abundance of firm-specific knowledge assets*. Our paper sets out to deliver this empirical test.

Before unfolding our approach, let us first look at some stylised facts that pertain to this topic. We rank all countries by their outward FDI stocks and by their performance on the Global Innovation Index (WIPO, 2022).[2] Because country size may blur the comparison, we normalise both performance indicators with the GDP size of countries, and then re-determine the country ranks for both indicators. Figure 1 plots the correlation between both indicators at country level with their mean performance for the period 2000-2019. Outward FDI and national innovation performance indeed appear to be closely related. This correlation gets more profile when the same plot is made for the Global Innovation Index in combination with the inward FDI performance of countries: here the correlation is almost fully absent.[3] However, the question is whether the correlation is driven by the relative abundance of *firm-specific* knowledge assets or by a relative abundance of *country-specific* knowledge assets. This is what this paper will explore in much more detail. In Markusen's knowledge-capital theory of FDI, firms are considered as island-like entities in their home countries. However, it matters a lot whether a company's headquarter is in Britain or in Zambia. This location-specific advantage of home countries deserves more attention. The proprietary knowledge capital of firms may to a considerable extent draw on the contributions of the public sector (universities, education, public research institutes) in their home country.

What we need is an extended version of the KC theory that models the interaction between public and firm-based knowledge development activities. We develop a formal model of national knowledge systems that allows to derive falsifiable hypotheses as to the knowledge-related drivers of outward FDI by firms. The model is also the first contribution of the paper to the literature. The second contribution is our identification procedure that allows to test the extended knowledge-capital model. The third contribution of our project is the new dataset that we developed for this purpose. It holds about 80 empirical indicators covering seven components of national knowledge systems. It covers up to 200 countries over the period 2000-2020. The dataset will be made available for replication purposes.

1 Cf. Markusen, 2002; Chen et al., 2012; Carr et al. (2001); Davies and Markusen (2024).

2 Published annually since 2007, the Global Innovation Index (GII) provides performance measures and ranks 132 economies on their innovation ecosystems. It is developed by the World Intellectual Property Organisation (Geneva), in cooperation with Cornell University (USA) and the INSEAD (France). Their annual publication provides the full documentation with regard to the sources and the construction of the Global Innovation Index.

3 See Annex VI of this paper.

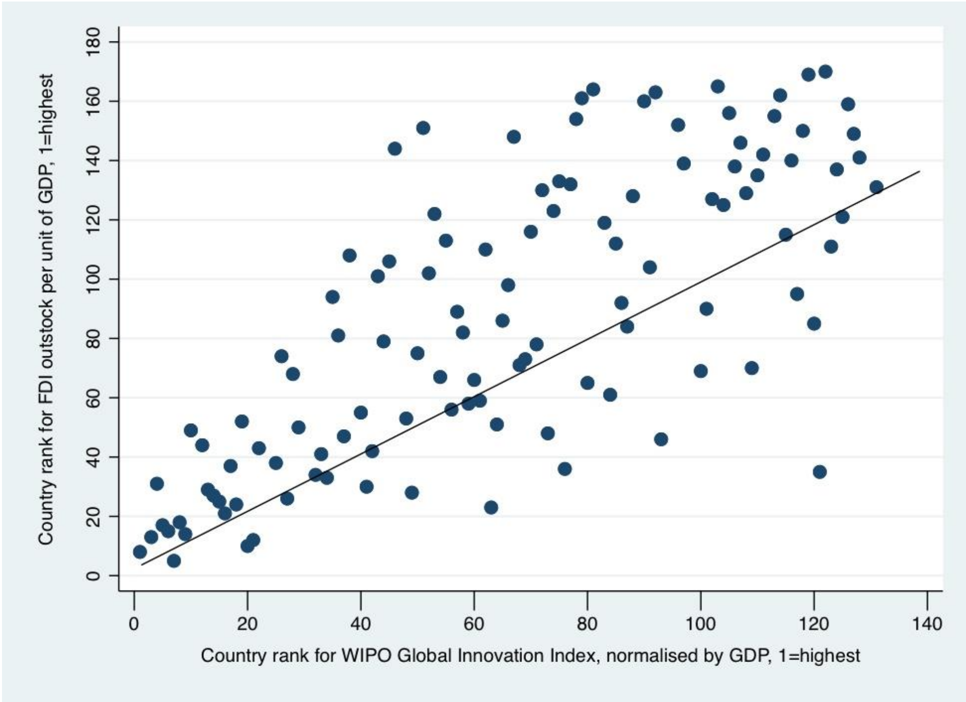

Figure 1. Rank correlation between outward FDI stocks per unit of GDP and Global Innovation Index score per unit of GDP, 2000-2019.

We find unequivocal empirical support for the knowledge-capital theory of outward FDI, based on indicators for firm-specific knowledge assets. A country's outward FDI position correlates even stronger with indicators for national public knowledge-creation efforts. It supports our extended version of the knowledge-capital (KC) theory for explaining outward FDI.

The paper has the following structure. Section I reviews the relevant literature on the knowledge-capital theory of FDI. Section II presents a formal model of the interaction between public and private knowledge creation and FDI. The model is used to derive testable hypotheses that allow to test the predictions of the KC model. Section III deals with the identification problem, the setup of the empirical tests, and describes the dataset of knowledge-creation indicators. Section IV presents the main empirical results based on non-parametrical rank correlation analysis. Section V checks the robustness of the findings by redoing the analysis for three alternative country samples and alternative specifications of the FDI variable. Section VI wraps up the main findings and their implications for the KC model and for public policy. The Appendices provide the mathematical proofs of some model elements, they documents the data sources for the knowledge-system indicators, and they provide the detailed rank correlation results per indicator, per FDI definition, and per country sample. Two abbreviations will return often in the paper: *KC* for knowledge-capital, and *FDI* for (outward) foreign direct investment.

2. Literature review

The knowledge-capital theory of the multinational company is synthesised in Markusen (2002) but was further developed earlier in several articles.[4] Firms command a unique stock of proprietary knowledge or technology capital. The production of these assets is a fixed-cost investment by the firm itself, requiring a relatively intensive use of skilled labour. There is no regard for any outside inputs, and the firm is treated as an entity that is independent of its national environment. Once created, this knowledge capital creates firm-level scale effects,

[4] See Markusen, 2001, 1984; Markusen *et al*, 1997; Markusen and Venables (2000); Carr *et al.*, 2001; Markusen and Maskus, 2003.

because it can also be used -at no or relatively low additional costs- in foreign subsidiaries. It explains outward FDI for all cases where trade or market-entry costs make expansion via exports less attractive.

To test the validity of the theory it was necessary to prove that countries with relatively much outward FDI also had a relative abundance of firm-based proprietary knowledge assets. The FDI data form the smallest part of the problem. The real challenge was to find an empirical measure for the relative abundance of national knowledge assets. Carr *et al*. (2001) proposed a narrow indicator for knowledge assets, namely the skill-related wage differences between countries. That they only used the USA's inward and outward FDI data as benchmark was a weak element, because a general test can only be convincing if it uses the variation across countries. But their choice for the skill-related wage differences was also soon put into question. Blonigen *et al*. (2002) argued that this indicator may give multi-interpretable results with respect to the FDI drivers, especially in the case of vertical (resource-seeking) FDI. Several others joined this debate (Feenstra, 2004; Braconier *et al*., 2005; Tanaka, 2007, 2015), but without providing the required empirical evidence for the knowledge-capital theory of FDI. With the benefit of hindsight, the choice for skill-related wage differences as indicator was not a lucky one. Firstly, wage differences form a separate motive for FDI decisions, and matter for both unskilled and skilled labour. Secondly, multinational enterprises tend to pay premium wages above the national averages (Aitken *et al*., 1996; Bernard *et al.* 2018; Wagner, 2012), so that the use of national averages for the wages differences is not appropriate. Thirdly, for so-called horizontal FDI, which is mainly motivated by acquiring foreign market shares, the international wage differences may be next to irrelevant. And the latter type of FDI forms the bulk of all FDI transactions, as shown by Ramondo *et al.* (2012).

But what alternatives are available? Hall (2000) proposed to measure the intangible assets of firms via the difference between market value and historic costs. Indeed, Chen *et al.* (2005) find that market value and intellectual capital of firms tend to be positively related. However, the valuation itself may be difficult due to the inherently tacit nature of knowledge and the uncertainty that surrounds its contant value.[5] Accounting practice often excludes the intangibles component of this knowledge capital.[6] Belo et al. (2022) calculated for US firms that intangible knowledge capital constitutes as large part of the value of firms.[7] However, the proposal to use the market value as yardstick for knowledge capital used in outward FDI is problematic. Separate data on market values of foreign subsidiaries and their parents are not available, not even for the USA (McGrattan and Prescott, 2010). When intangible knowledge assets can be used both at home and in the foreign subsidiaries, a double-counting bias is looming large when using the indicator that Hall proposes. The present situation is that the KC theory of outward FDI is still largely untested regarding the role of firm-based knowledge assets.[8]

A fast-rising volume of new literature focuses on the knowledge interaction between individual firms and their environment, particularly in their origin countries. Multinationals form part of the national knowledge systems in their countries of origin.[9] Skilled labour is to a large extent the product of national education systems. The competitive edge of individual firms at least partly rests on the use they make of knowledge products and knowledge transfers from the public sector, especially the basic science research that national states initiate and

[5] Cf. Chan and Cheung, 2022; Foster *et al*., 2012; Ali and Hwang, 2000; Morck and Yeung, 1991.
[6] See Corrado *et al*., 2009; Lev, 2001.
[7] They estimate a structural model using firm-level data on US firms and find that (on average and differing by industry) installed labour force accounts for 14–21% of firms' market value, physical capital accounts for 30–40%, knowledge capital accounts for 20–43%, and brand capital accounts for 6–25%.
[8] For instance, McGrattan and Prescott (2009, 2010) did not provide a convincing empirical estimate for the central variable in their knowledge-capital model. To demonstrate the plausibility of their model, they use a numeric model exercise, calibrated on FDI stock data of only the USA, while a real test should use the inter-country variation. Anderson *et al*. (2019) adopt the McGrattan and Prescott approach, but they offer no solution to the measurement issue.
[9] Freeman (1987) defines national knowledge systems as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies".

finance.[10] The public and semi-public sector includes universities, specialized scientific, technical and creative institutes, think-tanks, government bodies, higher-education system, and technology transfer mechanisms that are at least partly financed from tax receipts. Firms benefit from public and semi-public investments in human capital, science and technology. They 'encapsulate' knowledge elements from public and semi-public origin; they recombine them with their private know-how. Such inputs are measurable at the national level. If our conjecture is correct, indicators for public knowledge-creation activities in country A will at least partially capture the relative abundance of knowledge assets of multinational firms with headquarters in country A. This results in a testable hypothesis. The public knowledge sub-system tends to be generous with its products, forming a source of free knowledge externalities. The knowledge transfers occur through generating and disseminating innovations and discoveries via publications, congresses, staff mobility, intermediary supplier networks, and education-related activities.[11] Commercial exploitation of public-held patents is still a rare phenomenon in most countries.[12] Public-held patents are, often before expiration, given away or transferred to domestic firms at favourable conditions.[13] Effectively, this means that most knowledge products from the public and semi-public sector can be characterized as non-proprietary and outside the market domain. By contrast, the private firm-based innovation sub-system operates almost exclusively on the basis of proprietary knowledge capital (Llerena and Millot, 2020). After absorbing free knowledge produced by the public and semi-public sector, firms 'encapsulate' and recombine these input elements with firm-specific knowledge, thus creating marketable products, technologies, brands, and even new business models.[14]

3. Modelling the interaction with national knowledge systems and outward FDI

We propose to measure the relative abundance of firm-specific knowledge assets by focussing on their measurable public inputs. We model the connections between public and private knowledge development in a small dynamic input-output framework, with behavioural parameters that may differ by country. The model serves to generate testable predictions.

The national knowledge system can be seen as an input-output process with two compartments, the public and the firm-based sub-system. Countries may differ a lot in the operation of their knowledge systems, and in the balance between the public and private sub-system.[15] Each sub-system has an input side, which accounts for the human and material resources that are dedicated to creating new knowledge and to the re-activation of previously created knowledge. And they have an output side, where knowledge products, education achievements, technologies, a learning-oriented institutional environment or private knowledge assets 'pop out'. Each input-output activity has a throughput and processing phase where efficiency, focusing, and incentives for creativity matter (Akcigit and Goldschlag, 2023).

Let M_{it} be the active knowledge-capital stock of country *i* at time *t*. "Active" emphasizes that knowledge from the past is perishable. M_{it} is a cumulative product of current and past knowledge development. Active knowledge requires constant refreshment, re-education, reappropriation, re-transfer, documentation and dissemination

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10 Sheer, 2022; Arora *et al.*, 2022, 2021; Fagerberg *et al.*, 2012.

11 Cf. Hussinger and Palladini, 2023; Verhoogen, 2021; Gerbin and Drnovsek, 2016; Arundel *et al.*, 2013; Breschi and Catalini, 2010; Toole and Czarnitzki, 2010; Arundel and Geuna, 2004; Keller, 2004; Audretsch and Stephan, 1996, 1999.

12 Cf. Schoen et al., 2014; Perkmann *et al.*, 2013; Carayol, 2007; Calderini *et al.*, 2007; Powell, *et al.*, 2007; Agrawal and Henderson, 2002.

13 Mazzucato, 2014; Arundel *et al.*, 2013; Escalona Reynoso, 2010; Maskus and Reichman, 2004; Boyle, 2003a, 2003b; Carlsson and Fridh, 2002; Cohen *et al.*, 2000; Henderson *et al.*, 1998.

14 There is variation between industries in this type of links. Cohen *et al.* (2002, 2000) show that after controlling for industry, the influence of public research on R&D in manufacturing industries is disproportionately greater for larger firms as well as start-ups. Multinationals are predominant in the first category of both firm types.

15 For the differences between countries in the organisation of national innovation systems and in the interaction of public and private research, see Moncada, 2016 and Moncada *et al.*, 2010; OECD, 1997.

actions by the current generation, otherwise it decays and becomes dead knowledge.[16] Each separate knowledge-development activity is regarded as an economic process that uses inputs and produces outputs. Knowledge has no self-evident dimension of measurement; it is complex and multi-dimensional. But we may express input costs and the value of outputs as a fraction of national GDP (Y_{it}). This approach is like the valuation of public economic activities in the system of national accounts.

The public sector produces all public, non-proprietary knowledge, while the firm sector accounts for all proprietary or private knowledge. We assume that a national economy has just two sectors, the public sector and the firm sector. The national knowledge stock consists of a public component (M_{pit}) and a proprietary firm-based component (G_{fit}):

$$M_{it} \equiv M_{pit} + G_{fit} \tag{1}$$

Both components are decomposable. We start with the public sub-system. The knowledge production in the public sub-system is described in Table 1. It combines four sub-processes: creation new public knowledge, acquiring foreign public knowledge, obtaining foreign proprietary knowledge, and re-activation of earlier obtained (old) public knowledge. All sub-processes require real resource inputs (labour, equipment, premises) which can be expressed as a fraction of GDP (Y_{it}).

Table 1. The knowledge production process in the public sub-system (country i, period t).

Sub-processes	Input resources, expressed as fraction of GDP (Y_{it})	Throughput efficiency	Output aggregates
creation new public knowledge	β_{it}	v_{it}	M_{piit} (newly created public knowledge)
acquiring foreign public knowledge	ψ_{it}	v_{it}	M_{pFit} (newly acquired foreign public knowledge) &)
obtaining foreign proprietary knowledge	φ_{it}	v_{it}	M_{pRit} (newly acquired foreign proprietary knowledge) @)
re-activation of old public knowledge	ε_{it}	v_{it}	M_{io} (re-activated old public knowledge)
Total public in- and output	$\beta_{it} + \varphi_{it} + \psi_{it} + \varepsilon_{it}$	v_{it}	$M_{pit} = M_{piit} + M_{pFit} + M_{pRit} + M_{io}$

Legend: &) For simplicity we assume that all foreign public knowledge assets are sourced and acquired via the public knowledge sector. @) We assume that this public sub-process only focuses on generic knowledge spillover effects from attracting foreign direct investment.

Each row of Table 1 can be interpreted as an equation. For instance, the first and last rows must read as:

$$M_{piit} = v_{it} \,.\, \beta_{it}\,(Y_{it}),\; M_{pit} = M_{piit} + M_{pFit} + M_{pRit} + M_{io} = v_{it}\,(\beta_{it} + \varphi_{it} + \psi_{it} + \varepsilon_{it})\,Y_{it}$$

in which Y_{it} represents country *i*'s GDP at time *t*. The parameters β_{it}, φ_{it} and ψ_{jit} constitute the net GDP expenditure fraction for each current sub-process in creating new public knowledge-capital. $\beta_{it} > 0$ represents the GDP fraction dedicated to domestic knowledge creation (like university research, public R&D, basic research). The parameters φ_{it} and ψ_{jt} deal with international diffusion.[17] ψ_{jit} represents the input costs of accessing and using foreign public, non-proprietary knowledge (M_{pFit}). Parameter φ_{it} quantifies the public costs for attracting foreign proprietary knowledge assets M_{pRit} through inward FDI with positive spillover effects on the domestic economy.[18] Finally, the GDP fraction $\varepsilon_{it} > 0$ represents the costs of all activities that are dedicated to keep 'old' public knowledge assets (education, knowledge transfer, documentation, idea diffusion and dissemination

[16] On historic examples of lost knowledge, see Liu and Kuan, 2016; Debenham, 2002.
[17] We assume an international knowledge frontier that may differ by knowledge sub-domain and a preference for knowledge variety, which precludes a strict country hierarchy in attracting foreign FDI.
[18] Cf. Vujanovic *et al.*, 2022; Lu *et al.*, 2017.

activities) in an active modus. Quantity M_{io} represents the current value of country i's public knowledge stock that was built up in the past. It represents the path-dependent historical continuity in a country's public knowledge system.[19] The older knowledge assets are subject to a depreciation rate δ_{it} and a phasing-out process after *N* years. A higher depreciation rate can be regarded as a form of creative destruction.[20] Between the input and output columns of Table 1, we see the column throughput efficiency, symbolised by dimensionless factor $v_{it} > 0$. It depicts the efficiency with which financial inputs are converted into knowledge outputs. For modelling transparency, we assume that v_{it} is the same for all four sub-processes. It may, for instance, depend on knowledge-absorption capabilities, creativity incentives, legal and institutional frameworks for information exchange, labour productivity, connectivity, and overall national efficiency.[21]

Now consider the input-output system for the firm-based knowledge-development activities. It is depicted in Table 2 and has about the same setup as the public knowledge system. However, because of the emphasis on proprietary knowledge of firms, it has a more distributed structure. Country i has s $\in 1,..,S$ firms, which may differ in terms of organisational creativity, productivity, and management capabilities. These firm-specific elements are embodied in the firm-specific fixed effect $z_s > 0$. Firms in country i are subject to the national throughput efficiency v_{it}, but mitigated at firm level by their z_s factor.[22] Hence, the country-and firm-specific throughput factor becomes $z_s. v_{it}$. The firm-level production process of knowledge has four sub-processes: internal creation of new private knowledge assets, absorbing of domestic public knowledge inputs, acquisition of foreign proprietary knowledge, and re-activation of 'old' private knowledge. G_{siit} is proprietary new knowledge that results from the firm's own activities (R&D, design, in-house specialists, process or product expertise). G_{spit} is the firm-level result from encapsulating knowledge products from domestic public sources. G_{sRit} constitutes the proprietary knowledge that the firm obtains from foreign origins.[23] G_{iso} captures re-activated older knowledge stocks of a firm. The parameters $(a_{ist}, \omega_{ist}, \varphi_{ist}, \varepsilon_{ist})$ are firm-specific and strictly positive; they depict the inputs into the sub-processes of the firm's knowledge-related activities.[24] The first two parameters describe inputs into the creation of new proprietary knowledge assets. Parameter a_{ist} captures firm-level R&D, and the development of new product varieties, marketing concepts or business models. Parameter ω_{ist} deals with two elements of the firm's knowledge production process. The first is the absorption of recent public knowledge developments, which may include networking, setting up learning projects, or the hiring of specialists to master new knowledge areas. Additionally, ω_{ist} also captures the costs of combining the new inputs from the public sector with existing knowledge assets of the firm, and the costs of turning the firm-modified public knowledge inputs into excludable private assets, e.g. through patenting or secrecy measures.[25] The parameter φ_{ist} captures the costs of the firm's

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19 Annual cohorts of country i's stock of older public knowledge capital can be consistently aggregated by a CES aggregator: $M_{io} = [\, a_1\, M_{i,t-1}^{1-\sigma} + a_2\, M_{i,t-2}^{1-\sigma} + \ldots + a_{N-1}\, M_{i,t-(N-1)}^{1-\sigma}]^{(1/1-\sigma)}$ in which $\sigma > 1$ is the elasticity of substitution and $a_1 \ldots a_n$ represent the size shares of the annual knowledge stock cohorts, summing up to one, as proposed by Benhabib (2019). Annex I elaborates on the depreciation method.

20 It reduces the weight of older knowledge stocks and thus contributes to the rejuvenation of public knowledge stocks. The speed of annual knowledge-rejuvenation is determined by $(1{+}\beta_{it} + \varphi_{it} + \psi_{it})/(1 - \delta_{it})$.

21 Carr et al. (2001) and Markusen and Maskus (2003) also included some indicators for public policy features expected positive impact on the efficiency of national knowledge systems (e.g. protection of intellectual property.

22 A typical result from micro-econometric productivity studies is that firms with multinational activities have a higher productivity than most exporting firms, and substantially higher than firms that operate solely on their national market. Cf. Wagner, 2012; Bernard *et al.*, 2018, 2013.

23 Sometimes, large multinationals set up dedicated foreign subsidiaries that have as main activity the 'insourcing' of rare foreign technologies by networking or even industrial espionage (e.g. Song and Shin, 2008). Most firms acquire foreign technologies by subscribing to foreign specialist journals, learning by reverse engineering, learning from foreign patents, hiring foreign specialists, or by visiting foreign trade fairs.

24 Our approach to measuring firm-specific knowledge capital bears some similarity with Belo et al. (2022). They measure firm-level knowledge capital and brand capital by, respectively, accounting data on R&D expenses, and on advertising expenses. Accordingly, we interpret R&D expenses as a firm's investment in generating new or in improve current ideas. They cumulate these expenditures using the perpetual inventory method to obtain the capital stocks for knowledge capital and brand capital.

25 Cf. Crouset *et al.*, 2022.

activities that aim to acquire proprietary foreign knowledge. The older cohorts of the firm's intangible assets (G_{iso}) are subject to depreciation rate δ_{ist} and a phasing-out process after *N* years, comparable to the public knowledge system.[26] The last row in Table 2 describes the aggregation over all *S* firms in country *i*. The implicit equation can be expressed as a function of the throughput efficiency and real input costs:

$$G_{fit} = \sum_{s} G_{siit} + G_{spit} + G_{sRit} + G_{iso} = v_{it} Y_{it} \sum_{s} z_s \left(\alpha_{ist} + \omega_{ist} + \varphi_{ist} + \varepsilon_{ist}\right)$$

G_{fit} represents the aggregate active proprietary knowledge of all firms in country *i* at time *t*. Like in Markusen (2002), the inputs of G_{fit} would mainly consist of fixed-cost items with an investment nature.[27]

Table 2. Knowledge production process in the firm-based sub-system (by firm s, in country i and period t).

Sub-processes	Input resources, as fraction of GDP (Y_{it})	Throughput efficiency	Output aggregates
internal creation of new private knowledge assets	a_{ist}	$z_s . v_{it}$	G_{siit} (internal, newly created private knowledge)
absorbing of public knowledge inputs	ω_{ist}	$z_s . v_{it}$	$G_{spit} = f(\omega_{ist} M_{pi,t-1})$ (newly encapsulated domestic public knowledge inputs) [&])
obtaining foreign proprietary knowledge	φ_{ist}	$z_s . v_{it}$	G_{sRit} (newly acquired foreign proprietary knowledge)
re-activation of 'old' private knowledge	ε_{ist}	$z_s . v_{it}$	G_{iso} (re-activated 'old' private knowledge)
aggregate effort of firms	$\sum_{s}(\alpha_{ist} + \omega_{ist} + \varphi_{ist} + \varepsilon_{ist})$	$z_s . v_{it}$	$G_{fit} = \sum_{s} G_{siit} + G_{spit} + G_{sRit} + G_{iso} = \sum_{s} G_{sit}$

Legend: [&]) Firms do not use the very latest public knowledge 'cohort', but a recent knowledge cohort. This is not only plausible but also prevents endogeneity loops within the model.

Both Tables 1 and 2 contain a lagged, path-dependent component (M_{io}, G_{io}) of, respectively, public and firm-level knowledge capital. These variables have a vintage structure, to which each year a new knowledge 'cohort' is added while older 'cohorts' are depreciated and eventually discarded. The vintage structure creates a certain historical inertness of a country's knowledge stocks with respect to real-time GDP changes. The time dynamics of knowledge stocks can be complex due to the time variance of GDP and time variance in the behavioural parameters (as specified in Tables 1 and 2). Without a loss of generality, we take out the time variance of the behavioural parameters to clarify the basic time dynamics in this model of national innovation systems and to arrive at two important propositions. Their mathematical derivation is provided in Annex I.

Proposition 1 *If behavioural parameters are time invariant, the development of public knowledge stocks (M_{pit}) has the following dynamics:*

$$M_{pit} = v_i(\beta_i + \varphi_i + \psi_i) A_i Y_{it} \quad (2)$$

[26] The aggregation of G_{io} may be more problematic than holds for M_{io}, because all firm-specific G_{iso} cannot be added up in a simple way. Their valuation could contain a substantial double-counting bias if knowledge assets are based on ('created from') the same public knowledge assets (cf. Arora *et al.*, 2022). In that case, they are 'variations on a theme' rather than original innovations (cf. Crouset *et al.*, 2022), and their aggregation should contain a nested sub-system that distributes these variations.

[27] The fixedness of costs can be measured by the relative costs of adjusting current activities to changing economic conditions (Barnett and Sakellaris, 1999). Belo *et al.* (2022) estimate for the USA that a firm's annual labour adjustment costs represent, on average, about 6.5% of total annual sales. The average adjustment costs for physical capital and brand capital are, respectively, 0.9% and 0.5% of total annual sales. These are averages for all industries; they are lower for low-skilled industries, while they may be substantially higher for high-tech, high-skilled industries. So, knowledge capital adjustment costs could be proxied by fixing it at e.g. 10% of total annual sales, with variation per industry.

in which A_i is a factor that abbreviates the amortization and re-activation efforts for older vintages of knowledge assets in country i 's public sector: $A_i \equiv \{1 + \varepsilon_i\ (1-\delta_i)\ X_{Yt}\}$, with X_Y as a chain index that links scale (GDP) changes over time.

The time pattern for the development of proprietary knowledge stocks of firms (G_{fit}) is slightly more complicated. The sub-process G_{spit} has our main attention, namely the firm's absorbing of public knowledge inputs. This sub-process adds an additional time lag to the dynamic cycle.

Proposition 2 *If behavioural parameters are time invariant, the time development of aggregate proprietary knowledge stocks of firms (G_{fit}) has the following dynamics*:

$$G_{fit} = v_i\ Y_{it} \sum_s z_s\ A_{is}\big[\ \alpha_{is} + \varphi_{is} + \omega_{is}\ v_i\ (\beta_i + \varphi_i + \psi_i)\ A_i\ Y_{i,t-1}\big] \tag{3}$$

The term A_{is} abbreviates the amortization and re-activation module for older proprietary knowledge cohorts at the level of firms: $A_{is} \equiv \{1 + \varepsilon_{is}\ (1-\delta_{is})\ X_{Yt}\}$. Proposition 2 formalizes the crux of our extension module that can be added to Markusen's knowledge-capital model of FDI.

Individual firms exploit their proprietary knowledge assets (G_{sit}) in the domestic market. But they also use it abroad via setting up a local subsidiary, if this increases their expected profits (ΔR^*_{is}).[28] If the profit condition is satisfied, the firm's willingness to supply its proprietary knowledge assets to a new foreign subsidiary in country *j* is almost unbounded. From this conjecture, and aggregating over all firms, we derive a simple supply function for outward bilateral FDI (from country i to country *j*):

$$FDI^{outw}_{ijt} = \begin{cases} q_{ij}\ \left(G_{fit}\right)^h & if \ \sum_s \Delta R_{ijst} \geq 0 \\ 0 & otherwise \end{cases} \qquad \forall\ i, j, s \tag{4}$$

with q_{ij} as a constant for each country pair that accounts for factors like language, culture, or remoteness, while *h* is a general reaction parameter holding for all countries. Individual firms use their G_{sit} asset for setting up an equity-controlled foreign subsidiary if condition (4) is satisfied. However, this decision is further influenced by (a) relatively time invariant location-specific factors like the presence of natural resources, industrial structure, and country size; (b) time-variant bilateral factors like local input costs (wages, other resource costs), taxes, subsidies, tariffs and non-tariff measures (like regulatory compliance costs); and (c) opportunity costs (e.g. losing export opportunities after setting up a local production subsidiary). The knowledge-capital model (Markusen, 2002; Chen et al., 2012) deals extensively with the intra-firm decision tree that deals with these three factors, and therefore precedes the decision to export or to set up a local subsidiary in a foreign country.

Given the firms' own assessment of the foreign market potential of G_{sit}, the expected profit change depends on bilateral FDI barriers, on the fixed setup costs for a foreign subsidiary, on the value of any investment facilities offered by the host country, and on possible effects for its own export sales after setting up the foreign subsidiary. The model's reduced-form equation for aggregate outward FDI stocks, in the case of positive foreign profits, can be derived as:

$$FDI^{outw}_{ijt} = q_{ij}\ {G_{fit}}^h = q_{ij} \left\{ v_i Y_{it} \sum\nolimits_{s=1}^{S} z_s\ A_{is}\big[\ \alpha_{is} + \varphi_{is} + \omega_{is}\ v_i\ (\beta_i + \varphi_i + \psi_i)\ A_i\ Y_{i,t-1}\big] \right\}^h \tag{5}$$

[28] This assumes that the firm's top management has full knowledge of their proprietary assets. Acemoglu et al. (2007), Rajan and Zingales (2001), and Malenko (2023) show that internal noise about the real value potential of these assets may lead to sub-optimal firm decisions.

The right-hand-side specification of equation (5) shows the important role of current and lagged scale effects (Y_{it}, $Y_{i,t-1}$). Another scale effect is hidden in the (so far implicit) assumption that the number of firms (s∈1, 2, .., S) is equal in all countries ($S = S_i = S_j$ for $\forall\ i, j$), while in reality it holds that the number of firms is always a positive function of economic scale. To keep the model consistent and transparent we will assume henceforth that all national *S* are scale corrected. Note that the term after ω_{is} represents the public inputs into the firm's production process of proprietary assets. It shows that a country's outward FDI depends on private and public knowledge-creation activities, and that firms should not be considered as isolated and self-sufficient entities.

Equation (5) offers all elements that are important for our empirical test of the knowledge-capital model. We regard the model as incorrect and falsified if elasticity *h* would have no statistical significance or has a negative sign. Once the general zero hypothesis is rejected, a lot more specific tests become feasible.

We conclude this modelling section by formulating a set of specific and falsifiable predictions from our model. The first and the third prediction directly pertain to Markusen's knowledge-capital model of FDI, while the second and fourth prediction are important tests for our extended knowledge-capital model of outward FDI:

1. *Firm-specific knowledge assets (G_{fit}) should have a significant and positive impact on a country's outward FDI volume (zero hypothesis).*
2. *Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets should have a significant and positive impact on a country's outward FDI volume.*
3. *At a lower aggregation level, most individual indicators for a country's 'relative abundance of knowledge capital' should have a positive and statistically significant impact on outward FDI volume. When made scale-free, the empirical indicators for knowledge-capital elements are expected to correlate stronger with outward FDI volume than with domestic GDP.*
4. *National knowledge-throughput efficiency (v_{it}) should have a positive and significant impact on a country's outward FDI.*

4. Design of empirical tests and data issues

A country's total knowledge creation is directly affected by its economic scale (GDP), as shown in equation (3). The absolute size of a country's economy magnifies its total knowledge output through the number of firms, available investment funds, number of students, public research budgets, numbers of domestic researchers, total patenting actions or the number of universities. Also, the country's outward FDI volume is partly driven by the economic size (GDP), as equation (5) shows. For an empirical test of the knowledge-capital theory of FDI, we need to use the inter-country variation. However, we don't want the results to be messed-up by the scale effects. Recall that the main target of this paper is to test the following corollary of the KC model: "*if the knowledge-capital theory of foreign direct investment is correct, countries with relatively large outward FDI stocks should also have a relative abundance of firm-specific knowledge assets".* The emphasis should therefore be on "relative". To achieve that, the double impact of economic size should be neutralised. The country-scale effect must be identified, quantified and filtered out, before we can meaningfully compare countries of different economic size with regard to their knowledge stocks and FDI.

The first identification challenge is to assess what part of outward FDI stocks of any country *k* is driven by the country's economic scale. We opt for a simple solution by taking a relative performance measure, the ratio of outward FDI stocks per unit of GDP.[29] This variable is labelled OUTST_GDP. The second identification challenge is to isolate the role of scale effects on country *k*'s knowledge creation performance. We introduce the concepts of the intensive and extensive margin of knowledge creation.

[29] Data on total outward FDI stocks per country are taken from UNCTAD (2022a). The GDP data are from IMF (International Financial Statistics) and World Bank (World Development Indicators).

4.1. Data

For the intensive margin of knowledge, creation we develop scale-free indicators that always measure the *relative* knowledge creation performance, normalized by a relevant scale aggregate (e.g., total employment, gross domestic product, population size, or total exports). Table 3 provides the set of 38 indicators that we will use for the intensive margin of public knowledge creation. The intensive-margin indicators are ordered conform the sub-processes that are distinguished in Table 1. The last category holds eight indicators for the throughput efficiency per country (variable v_{it} in Table 1).

Table 3. Intensive margin of public knowledge-creation: Scale-free indicators.

Sub-processes of the public knowledge system	Variable description	Variable name
Re-activation of existing public knowledge	Females with advanced education, as % of female working-age population	ADEDU_F
	Males with advanced education, as % of male working-age population	ADEDU_M
	Contribution of labour quality to GDP growth (growth accounting)	LQ_CONTR
	Women researchers as % of total researchers	FEM_RESR
	Number of R&D researchers per million people	TOT_RESR
	Number of R&D technicians per million people	TOT_TECH
Creation of new public knowledge: input indicators	Mean score for Global Innovation Indexes 2011-2020, normalized by GDP in PPP$	GII_MAIN
	Global Innovation subindex for inputs 2020, normalized by GDP (in PPP$ 2019)	GII_INPUT
	Research and development expenditure as % of GDP (curr. prices, USD)	GERCGDP
	Gross domestic expenditure on R&D (GERD) as % of GDP (curr. PPP$)	GERPGDP
	Gross domestic expenditure on R&D (in PPP$), per capita of population	GERD_CAP
	Governm. intramural expenditure on R&D (GOVERD) as % of curr. GDP (PPP$)	GVE_XGDP
	Higher-education expenditure on R&D (HERD) as % of current GDP (PPP$)	HED_XGDP
	Total researchers per thousand of domestic labour force	ALLRES_LF
	Total R&D personnel (incl. staff) per thousand of domestic labour force	RDPERS_LF
	Total researchers per thousand of domestic total employment	ALLRES_EM
	Total R&D personnel (incl. staff) per thousand of dom. total employment	RDPERS_EM
	Gross domestic expenditure on R&D (in PPP$), per capita of population	GERD_CAP
Creation of new public knowledge: output indicators	Global Innovation subindex for outputs 2020, normalized by GDP (in PPP$ 2019)	GII_OUTPUT
	Number of papers in economics, normalized by size of domestic GDP	ECONPAP
	Number of articles in scientific journals, normalized by size of domestic GDP	JRN_ART
	Judicial independence of government, mean score 2000-2019	JUDINDEP
	Impartiality of legal courts, mean score 2000-2019	IMPART_C
	Impartiality of public administration, mean score 2000-2019	IMP_PUBL
	Protection of property rights, mean score 2000-2019	PROTPROP
	Effectiveness legal enforcement, mean score 2000-2019	LEG_FORCE
Acquisition of foreign knowledge	Total inward FDI stocks, normalized by size of domestic GDP	INFDI_GDP
	Import of business and financial services, as % of total services import	BF_IMSRV
	Import of knowledge-intensive business services, as % of total services import	KIBS_IMSRV
	Number of patent applications by non-residents, normalized by GDP	PAT_NRES
National productivity and knowledge-throughput efficiency	Individuals using the Internet, as % of population	INT_USER
	Number of secure Internet servers, per million people	INTSECUR
	Number of fixed broadband subscriptions, per million people	BBND_SUB
	Contribution of ICT assets to GDP growth (growth accounting)	ICT_CONTR

	Labour productivity p. person employed, converted to 2020 PPP$	LP_EMPL
	Labour productivity p. hour worked, converted to 2020 PPP$	LP_HOUR
	Freedom of foreigners to visit, mean score 2000-2019	FORGN_MV
	Freedom to setup up a business, mean score 2000-2019	STARTABUS

Sources: Annex II provides more information on the sources of each indicator. The normalisation with a relevant scale aggregate (separate for each country) is in most cases done by this author.

For the intensive margin of firm-based knowledge creation (per country) we have developed a similar set of indicators, four input-related and eleven output-related indicators for the intensive margin of firm-based knowledge creation. The indicators cover a period of 21 years, from 2000 to 2020. Not all indicators are available for each country and year. A substantial number of annual country observations is missing, especially for the small countries with a limited statistical apparatus. To get a balanced data set, we have calculated, per indicator and country, the mean value of all available annual observations over the full period 2000-2020. An advantage is that annual measurement errors in country data are 'averaged out'. However, it also implies that the period mean for developed countries might be based on more annual observations than holds for the small developing countries. This should not be a big problem, because it is documented that the annual variation for knowledge-system indicators tends to be quite small (Van Elk *et al.*, 2019).[30] The empirical indicators measure different, but sometimes partially overlapping elements of a country's knowledge system. For the indicators in Table 3, the average number of country observations per indicator is 116, with 38 as minimum and 171 as maximum. For the indicators in Table 4 the average number of observations is 97, with 38 as minimum and 160 as maximum.

Table 4. Firm-based knowledge creation: Scale-free indicators of the intensive margin.

Knowledge system sub-processes	Variable description	Variable name
Input-related indicators for knowledge-creation efforts by private business	Total business expenditure on R&D (BERD) as % of current GDP (PPP$)	BERD_GDP
	% of government expenditure on R&D that is performed by the business enterprise sector	BUX_GERD
	% of higher-education expenditure on R&D that is financed by the business sector	BFIN_HERD
	Total business enterprise R&D personnel as a percentage of national total	BRES_TOT
Output-related indicators for knowledge-creation efforts by private business	High-technology exports, as % of total manufacturing exports	HT_MFGEX
	Exports of ICT goods, as % of total merchandise exports	ITPROD_EX
	Exports of ICT services, as % of total services exports	IT_SERVEX
	Export of business and financial services, as % of total services export	BF_SRVEX
	Export of knowledge-intensive business services, as % of total services export	KBS_SRVEX
	No. of patents filed under the PCT (priority yr), per 1000 ppp $ of GDP	PATP_GDP
	No. of ICT patents filed under the PCT (priority yr), per 1000 ppp $ of GDP	PATI_GDP
	No. of biotech patents filed under the PCT (priority yr), per 1000 ppp $ of GDP	PATB_GDP
	Number of patent applications by residents, normalized by GDP	PATP_RES
	Number of trademark applications by direct residents, normalized by GDP	TM_DRES
	Total number of trademark applications, normalized by GDP	TM_TOT

30 This should not be surprising, because the knowledge system is based on long-term processes. It takes some fifteen years to educate engineers or university students with a master's degree.

Note: Annex Table II provides details on the original sources of each indicator. The normalisation with a relevant scale aggregate (separate for each country) is in most cases done by this author.

Finally, the extensive margin of knowledge creation is quite straightforward, because it uses nominal values for all knowledge indicators, including the scale effects that are embodied in them. Annex III gives 25 extensive-margin indicators, thus increasing the total number of separate indicators to 78. The results with the extensive-margin indicators will be compared with those of the intensive-margin indicators; it sheds light on the importance of data normalisation for assessing the relative abundance of a country's knowledge assets.

4.2. Testing methodology

To test the model predictions of Section 2, we apply several non-parametric tests. They focus on the ordinal association between a country's knowledge-creation indicators and the same country's outward FDI.[31] Substantial correlation between KC indicators of a country may be expected, so that they cannot be tested simultaneously. We run the rank correlation tests separately for each indicator. Kendall's *tau-b* rank correlation coefficient tests the strength of the degree of similarity between the two rankings and establishes the statistical significance of this similarity relation. The *tau-b* coefficient is well-suited for small samples like ours (maximum number of country observations is 209), in which ties (equal rankings) may occur. The Kendall *tau-b* coefficient is defined as:[32]

$$\tau_B = \frac{n_c - n_d}{\sqrt{(n_o - n_1)(n_o - n_2)}}$$

in which: $n_o = n(n-1)/2$ is the maximum number of possible pairwise combinations, n_c is the number of concordant pairs (correspondance between rank of FDI and indicator score), n_d is the number of discordant pairs (different rank for FDI and indicator score), $n_1 = \sum_i t_i(t_i - 1)/2$ is the occurrence of ties (equal rankings) for FDI, $n_2 = \sum_j u_j(u_j - 1)/2$ is the occurrence of ties for indicator j, t_i is the number of tied values in the ith group of ties for FDI, and u_j is the number of tied values in the jth group of ties for the ranked indicator that is compared with FDI. *Tau-b* can be applied if the underlying scale of both ranked variables has the same number of possible values. In our case this condition is satisfied, because the rank values refer to the same set of countries. Values of Kendall's *tau-b* range from *−1* (perfect inversed or negative correlation) to *+1* (full perfect positive correlation). A value of zero indicates the absence of any association.

We will also calculate the rank correlation with alternative rank correlation measures (Spearman's *rho*, pairwise correlation). It turned out that these results fully converge with the pattern that displayed by the Kendall *tau-b* scores, but correlation scores are often higher. Since the Kendall's method is the toughest test, only these results will be presented in the main text. The Appendices also provide the results for Spearman's *rho*.

5. Results

We start by using the most stringent rank correlation test, using only variables that have been fully corrected for scale effects. The dependent variable for FDI is outward FDI stocks per unit of GDP (OUTST_GDP). For the knowledge-system variables we only use the intensive-margin indicators. The average number of country observations per intensive-margin indicator is 110. It is important to stress that in case of full randomness, the probability of a matching ordinal rank with 110 observations would be very close to zero: 1/(110*109) $\approx$ 0.000083. The results are split in two parts. Table 5 gives the rank correlation results per knowledge domain and per indicator.

[31] Annex VI offers graphical evidence for a strong correlation between knowledge-creation indicators and outward FDI stocks per unit of GDP. It also shows that this correlation is asymmetric: the correlation with inward FDI stocks is much weaker. T.
[32] E.g., Agresti (2010).

Table 6 aggregates the detailed results for each of the hypotheses formulated at the end of Section 2.

Table 5. Rank correlation between outward FDI stocks per unit of GDP (OUTST_GDP) and each intensive-margin indicator, by knowledge domain.

Knowledge system sub-processes	Indicator name	No. of compared country observations	Rank correlation, Kendall's tau-*b*	Prob>|z|	Confidence code &)
(Re-)activation of existing public knowledge	ADEDU_F	147	0.200	0.000	***
	ADEDU_M	147	0.118	0.033	**
	LQ_CONTR	119	0.106	0.088	*
	FEM_RESR	36	−0.273	0.020	**
	TOT_RESR	118	0.491	0.000	***
	TOT_TECH	107	0.489	0.000	***
Creating of new public knowledge: input-related indicators	GII_MAIN	134	0.539	0.000	***
	GII_INPUT	122	0.570	0.000	***
	GERCGDP	129	0.404	0.000	***
	GERPGDP	42	0.380	0.000	***
	GERD_CAP	42	0.498	0.000	***
	GVE_XGDP	42	0.008	0.948	
	HED_XGDP	42	0.396	0.000	***
	ALLRES_LF	39	0.439	0.000	***
	RDPERS_LF	38	0.440	0.000	***
	ALLRES_EM	39	0.425	0.000	***
	RDPERS_EM	38	0.460	0.000	***
Creating of new public knowledge: output-related indicators	GII_OUTPUT	121	0.482	0.000	***
	ECONPAP	141	0.412	0.000	***
	JRN_ART	160	0.173	0.001	**
	JUDINDEP	146	0.445	0.000	***
	IMPART_C	146	0.462	0.000	***
	IMP_PUBL	144	0.403	0.000	***
	PROTPROP	146	0.428	0.000	***
	LEG_FORCE	146	0.315	0.000	***
Acquisition of foreign knowledge assets	INFDI_GDP	171	0.295	0.000	***
	BF_IMSRV	138	0.130	0.024	**
	KIBS_IMSRV	161	0.181	0.000	***
	PAT_NRES	136	0.102	0.079	*
National productivity and knowledge-throughput efficiency	INT_USER	167	0.504	0.000	***
	INTSECUR	167	0.484	0.000	***
	BBND_SUB	167	0.479	0.000	***
	ICT_CONTR	117	0.210	0.001	***
	LP_EMPL	119	0.579	0.000	***
	LP_HOUR	119	0.595	0.000	***
	FORGN_MV	146	0.233	0.000	***
	STARTABUS	146	0.346	0.000	***
	BERD_GDP	42	0.352	0.001	***
Input-related indicators for knowledge-creation efforts by private business	BUX_GERD	42	0.273	0.011	**
	BFIN_HERD	42	0.059	0.588	
	BRES_TOT	38	0.374	0.001	***
	HT_MFGEX	156	0.330	0.000	***
	IT_SERVEX	160	−0.086	0.105	
	ITPROD_EX	159	0.304	0.000	***
	BF_SRVEX	135	0.320	0.000	***
	KBS_SRVEX	160	0.064	0.229	
Output-related indicators for knowledge-creation efforts by private business	PATP_GDP	42	0.447	0.000	***
	PATI_GDP	42	0.501	0.000	***
	PATB_GDP	42	0.524	0.000	***
	PATP_RES	129	0.077	0.196	
	TM_DRES	130	−0.117	0.050	*
	TM_TOT	139	−0.145	0.013	**

*Legend: &) Coding of confidence levels: *** p<0.01, ** p<0.05, * p<0.10. More details available in the Annex VII.*

Table 6. Overall indicator count statistics with regard to model predictions (full country sample).

Model predictions	Overall count statistics §)
1. Firm-specific knowledge assets (G_{fit}) should have a significant and positive impact on a country's outward FDI volume (zero hypothesis)	11 of 15 indicators (73.3%)
2. Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets should have a significant and positive impact on a country's outward FDI volume.	27 of 29 indicators (93.1%)
3. Most individual indicators for a country's 'relative abundance of knowledge capital' should have a positive and statistically significant impact on outward FDI volume.	36 of 44 indicators (81.8%)
4. National knowledge-throughput efficiency (v_{it}) should have a positive and significant impact on a country's outward FDI.	8 of 8 indicators (100%)

Legend: §) The score reflects the number of rank correlation indicators (Kendall tau-b) that comply with the condition in the first column by being statistically significant and having the predicted sign. The number in brackets gives the share of the total number of indicators that is relevant for that rank correlation. Source: Table 5.

The evidence in Tables 5 and 6 supports the knowledge-capital model of FDI (predictions 1 and 3). The second and fourth predictions deal are specific for our extended KC model. Here the predictions are supported even stronger, namely by 93% (for the role of public knowledge-creation) and 100% (for the role of national and firm-specific productivity indicators). The latter outcome f confirms that national knowledge-throughput efficiency (productivity, connectivity, openness for knowledge circulation) has a strong and positive impact on outward FDI.

Our results show that Markusen's standard KC model has a blind spot by overlooking the large role of the domestic preconditions for knowledge creation by firms. The results would support the view (e.g. Mazzucato, 2014) that private firms derive bounteous knowledge externalities from universities and (semi-)public institutions that they use to for creating proprietary knowledge assets.

5.1. The importance of data normalisation

We applied the same rank correlation approach between GDP per unit of GDP (OUTST_GDP) and extensive-margin indicators of knowledge creation.[33] Overall, we see low support scores for the first three model predictions. Only 44% of the relevant indicators for public knowledge-creation have a significant and positive impact on outward FDI. The impact of public knowledge creation is outshone by the impact of country size. The comparison of the extensive- and intensive-margin results shows the importance of de-scaling the knowledge indicators.

6. Robustness tests

The rest of the paper investigates the stability and robustness of the findings reported in Tables 5 and 6. The first test is about a possible bias due to tax-motivated FDI, which might inflate the outward FDI performance of tax paradises and tax-sheltering countries. The second robustness test is to drop the normalisation of the dependent FDI variable, going from outward FDI stocks per unit of GDP (OUTST_GDP) to total outward FDI stock as basis for the country ranking. The third robustness applies two shocks to the country sample to test the stability of the outcomes.

6.1. Biased FDI data due to tax routing?

The FDI data that we used are based on immediate partner countries. However, there is ample evidence that

[33] Shown in the Annexes IV and V.

FDI patterns may be driven by tax motives.[34] To identify a possible bias, we remove the countries with proven policy reputations as tax paradises and facilitators of tax-sheltering and tax avoiding. It implies that the average number of country observations per indicator falls.[35] Compared to Table 6, the support for the four model predictions becomes, respectively, 67% (was 60%), 86% (was 93%), 80% (was 82%), and 100% (was 100%). So, it is fair to say that the explanatory power of the knowledge-capital theory of FDI is hardly affected by tax routing practices in outward FDI.

6.2. Changing the specification of the dependent FDI variable

As a further robustness test we change the specification of the dependent variable, using the total value of outward FDI stocks rather than the ratio of outward FDI stocks over GDP. Countries are again ranked by this variable and compared with the country rank for each intensive-margin indicator. The results are shown in the first data column of Table 7. They are quite similar to those in Table 6. Overall, Table 7 reports similar results as those in Table 6. It indicates that the pattern is robust to a different specification of the dependent variable.

6.3. Shocking the country samples

The last three data columns of Table 7 show what happens if we shake-up the country sample. Keeping total outward FDI as the dependent variable, the first shock is to restrict the sample to countries which had non-zero inward and outward FDI during all years over the period 2000-2020. This removes several small countries and island states, which had erratic annual patterns in reported FDI stocks.[36] The second shock removes countries from the sample that have a proven reputation for having policies that facilitate tax routing of FDI (similar to the first robustness test of this Section). The third shock combines both filtering criteria of the first two shocks, thereby reducing the average number of country observations per indicator to 71. All results are shown in Table 7.

The differences are small, so the results are stable across the four country samples. The share of the intensive-margin indicators for firm-based knowledge creation stays within the 67-73% range. The support for the role of public knowledge-creation is even higher, namely in the 86-90% range. The share of indicators that are correlated stronger with outward FDI than with domestic GDP remains in the 75-79% range. The results confirm the earlier found support for the knowledge-capital theory of outward FDI.

Table 7. Comparing rank correlation between total outward FDI and intensive-margin indicators for four different country samples.

Summary statistics in terms of the model predictions	**Full country sample (cases, %)**	**Only countries with all-time outward FDI stocks (cases, %)**	**Full country sample, minus countries with tax evasion / tax-sheltering policies (cases, %)**	**Countries with all-time outward FDI stocks, no tax evasion / tax-sheltering countries**
1. Firm-specific knowledge assets (G_{fit}) should have a significant and positive impact on a country's outward FDI volume (zero hypothesis)	73%	67%	73%	73%

[34] UNCTAD, 2022; Damgaard *et al.*, 2019.
[35] The average number of compared country observations dropped to 102 (was 110), with the minimum and maximum being, respectively, 32 (was 34) and 156 (was 171). Details in Annex Table VII.1.
[36] Reducing of the country sample to those with all-time FDI lowers the number of compared country observations per indicator to an average of 77 (was 110 in Table 5), with the minimum and maximum being, respectively, 34 (was 36) and 126 (was 171).

2. Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets should have a significant and positive impact on a country's outward FDI volume	90%	90%	86%	86%
3. Most individual indicators for a country's 'relative abundance of knowledge capital' should have a positive and statistically significant impact on outward FDI volume	84%	82%	82%	82%
4. National knowledge-throughput efficiency (v_{it}) should have a positive and significant impact on a country's outward FDI outward FDI.	100%	100%	100%	100%
5. The positive and significant correlation of intensive-margin indicators with outward FDI is stronger than their correlation with GDP (prediction 3)	79%	77%	75%	79%

Legend: The score reflects the number of rank correlation indicators (Kendall tau-b) that comply with the condition in the first column by being statistically significant and having the predicted sign. Source: Annex Tables VII.2 and VII.4.

7. Summary and conclusions

The knowledge-capital model of outward FDI by Markusen and some others provides a plausible theory for explaining international patterns of bilateral FDI stocks. If the theory is correct, countries with relatively large outward FDI stocks should also have a relative abundance of firm-specific knowledge assets. This paper presents the first empirical test for this corollary of the theory. To make it empirically testable we extend the knowledge-capital model with a new module that places the knowledge activities of firms in their national context.

This formalisation of Freeman's national innovation systems (1987) allows to derive specific predictions on the public-private knowledge interaction. Firms create new knowledge, but they primarily encapsulate public knowledge; they mix it with internal knowhow and commercial expertise to form proprietary assets. None of our model predictions could be rejected. The empirical tests found robust evidence that firm-specific knowledge assets have a significant and positive impact on a country's outward FDI volume.

Overall, we can confirm the Markusen KC model is correct in predicting that countries with much FDI tend also to have a relative abundance of knowledge assets. The outcomes were stable and robust across several tests. But even stronger was the evidence that public knowledge activities have a significant and positive impact on outward FDI. It is a massive blind spot in the standard KC model that it overlooks the large role of domestic knowledge preconditions for firms with outward FDI. Our analysis and results show that it is incorrect to assume that (large) firms are the sole or even the main innovating force in countries. It calls for much more follow-up studies on the interactions within national innovation systems.

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Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

Author contributions

As sole author, all activities for writing this paper were mine (conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing–original draft, and writing–review & editing.)

Appendices

(Kindly find all the Appendices located after the References Section.)

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Appendices

Annex I. Proofs of Propositions 1 and 2: Time dynamics of national knowledge stocks.

Proof of Proposition 1.

If behavioural parameters described in Table 1 (β_i, ε_i, φ_i, ψ_i and δ_i) are time-invariant, the proof of Proposition 1 (time dynamics of public knowledge stocks) is as follows. Old vintages of public knowledge stocks are fully discarded after N years ($M_{io,t-N} = 0$). Vintages from younger annual cohorts ($\theta < N$) are depreciated by δ_i, hence:

(A1) $M_{io,t-\theta} = (1-\delta_i)\, M_{io,t-(\theta-1)} \qquad \forall\, \theta < N$

From Table 1 we further have:

(A2) $M_{piit} = \nu_i\, \beta_i\, Y_{it}$ (A3) $M_{pRit} = \nu_i\, \varphi_i\, Y_{it}$ (A4) $M_{pFit} = \nu_i\, \psi_i\, Y_{it}$

(A5) $\Delta M_{pit} = \nu_i\, (\beta_i + \varphi_i + \psi_i)\, Y_{it}$

(A6) $M_{pit} = \Delta M_{pit} + \varepsilon_i\, M_{io,t}$

Suppose that the build-up of public knowledge stocks starts in year $t-N$, so that $M_{io,t-N} = 0$, and equation (A6) reduces to: $M_{pi,t-N} = \Delta M_{pi,t-N}$, and that same $\Delta M_{pi,t-N}$ will become the first old vintage knowledge stock that has to be re-activated like in (A6) and depreciated like in (A1) at the end of the next year $t-(N-1)$, so that:

(A7) $M_{pi,t-(N-1)} = \Delta M_{pi,t-(N-1)} + \varepsilon_i\,(1-\delta_i)\,\Delta M_{pi,t-N}$

Because of (A5) that gives:

$$\text{(A8)}\quad M_{pi,t-(N-1)} = v_i\,(\beta_i+\varphi_i+\psi_i)\,Y_{i,t-(N-1)} + \varepsilon_i\,(1-\delta_i)\,v_i\,(\beta_i+\varphi_i+\psi_i)\,Y_{i,t-N}$$
$$= v_i\,(\beta_i+\varphi_i+\psi_i)\left[Y_{i,t-(N-1)} + \varepsilon_i\,(1-\delta_i)\,Y_{i,t-N}\right]$$
$$= v_i\,(\beta_i+\varphi_i+\psi_i)\,Y_{i,t-(N-1)}\left[1+\varepsilon_i\,(1-\delta_i)\,\frac{Y_{i,t-N}}{Y_{i,t-(N-1)}}\right]$$

If we define $X_{Y,t-(N-1)} \equiv \frac{Y_{i,t-N}}{Y_{i,t-(N-1)}}$ as the chain index of GDP, one obtains:

(A9) $M_{pi,t-(N-1)}{=}v_i\,(\beta_i+\varphi_i+\psi_i)\,Y_{i,t-(N-1)}\left[1+\varepsilon_i\,(1-\delta_i)\,X_{Y,t-(N-1)}\right]$

And because this same pattern repeats itself for all later vintages of old public knowledge assets, we may generalize the pattern for all years, thus obtaining:

(A10) $M_{pi,t} = v_i\,(\beta_i+\varphi_i+\psi_i)\,.\left[1+\varepsilon_i\,(1-\delta_i)\,X_{Y,t}\right].\;Y_{i,t}$ QED ■

Proof of Proposition 2.

If behavioural parameters described in Table 2 ($\alpha_{is}, \varphi_{is}, \omega_{is}, \varepsilon_{is},$) and firm-level depreciation parameter δ_{is} are time-invariant, we prove Proposition 2 (time dynamics of proprietary knowledge stocks of firms in country *i*). Old vintages of proprietary private knowledge assets are fully discarded after N years ($G_{iso,t-N}=0$). Stocks from younger annual knowledge cohorts ($\theta < N$) are depreciated by δ_{is}:

(A11) $G_{iso,t-\theta} = (1-\delta_{is})\,G_{iso,t-(\theta-1)} \qquad \forall\,\theta<N\,;\;\forall\,s$

From Table 2 we further have:

(A12) $G_{sit} = v_i\,z_s\,\alpha_{is}\,Y_{it} \qquad \forall\,s$

(A13) $G_{spit} = v_i\,z_s\,\omega_{is}\left(M_{pi,t-1}\right)Y_{it} \qquad \forall\,s$

so that annual new proprietary knowledge of all firms amounts to:

(A14) $\Delta G_{fit} = \sum_s v_i\,z_s Y_{it}\left[\alpha_{is}+\varphi_{is}+\omega_{is}\left(M_{pi,t-1}\right)\right]$

Re-activated older proprietary knowledge assets are the result of the following sub-process:

(A15) $G_{isot} = \sum_s v_i\,z_s\,\varepsilon_{is}\,(G_{iso})\,Y_{it}$

Suppose that in year $t-N$ the knowledge stock of firms starts to build up. There are no old vintages of proprietary knowledge stocks yet ($G_{iso,t-N}=0$) and total knowledge stocks at the end of the first year amount to:[37]

(A16) $G_{fi,t-N} = \Delta G_{fi,t-N} = \sum_s v_i\,z_s\,Y_{i,t-N}\left[\alpha_{is}+\varphi_{is}+\omega_{is}\left(M_{pi,t-N-1}\right)\right]$

That same $\Delta G_{fi,t-N}$ will become the first old vintage of proprietary knowledge that has to be re-activated like in (A15) and depreciated like in (A11) at the end of the next year $t-(N-1)$, so that:

(A17) $G_{fi,t-(N-1)} = \Delta G_{fi,t-(N-1)} + \sum_s \varepsilon_{is}\,(1-\delta_{is})\left\{\Delta G_{fi,t-N}\right\}$

After some substitutions, this becomes:

$$\text{(A18)}\quad G_{fi,t-(N-1)} = v_i\sum z_s\left[\alpha_{is}+\varphi_{is}+\omega_{is}\left(M_{pi,t-N-1}\right)\right]Y_{i,t-(N-1)}\left\{1+\varepsilon_{is}\,(1-\delta_{is})\,\frac{Y_{i,t-N}}{Y_{i,t-(N-1)}}\right\}$$

If we define $X_{Y,t-(N-1)} = \frac{Y_{i,t-N}}{Y_{i,t-(N-1)}}$ as the chain index of GDP, we get:

(A19) $G_{fi,t-(N-1)} = v_i\sum z_s\left[\alpha_{is}+\omega_{is}\left(M_{pi,t-N-1}\right)\right]Y_{i,t-(N-1)}\left\{1+\varepsilon_{is}\,(1-\delta_{is})\,X_{Y,t-(N-1)}\right\}$

And because this same pattern repeats itself for all later vintages of old proprietary knowledge assets of firms, we may generalize the pattern for all years, thus obtaining:[38]

[37] Because $M_{pi,t-N-1}$ is an independent process, we assume that $M_{pi,t-N-1}$ does already exist;

[38] Note that the structure is the same as (A10) in the proof of Proposition 1.

(A20) $G_{fi,t} = v_i \sum z_s \left[\alpha_{is} + \varphi_{is} + \omega_{is} \left(M_{pi,t-1}\right)\right].\{1 + \varepsilon_{is} (1 - \delta_{is}) X_{Y,t}\}.Y_{i,t}$

Finally, using Proposition 1, $M_{pi,t-1}$ can be substituted into (A20):

(A21) $G_{fi,t} = v_i Y_{i,t} \sum_s z_s A_{is}\left[\alpha_{is} + \varphi_{is} + \omega_{is}(\beta_i + \varphi_i + \psi_i) A_i v_i Y_{i,t-1}\right]$

with $A_{is} \equiv \{1 + \varepsilon_{is} (1 - \delta_{is}) X_{Y,t}\}$ and $A_i \equiv \{1 + \varepsilon_i (1 - \delta_i) X_{Y,t}\}$ QED ■

Annex II. Description and sources of national knowledge-capital indicators.

Indicator	Description	Source + codename in original source
Intensive knowledge-creation margin		
ADEDU_F	Female with advanced education, as % of female working-age population	WDI (SL_TLF_ADVN_FEZS)
ADEDU_M	Male with advanced education, as % of male working-age population	WDI (SL_TLF_ADVN_MAZS)
LQ_CONTR	Contribution of labour quality to GDP growth (growth accounting)	TED (LQ_contr)
FEM_RESR	Women researchers as % of total researchers	MSTI (TH_WRXRS)
TOT_RESR	Researchers in R&D (per million people)	WDI (SP_POP_SCIE_RDP6)
TOT_TECH	Technicians in R&D (per million people)	WDI (SP_POP_TECHRDP6)
GII_MAIN	Mean score for Global Innovation Indexes 2011-2020, normalized by GDP in PPP$ 2019	WIPO (GII)
GII_INPUT	Global Innovation subindex for inputs 2020, normalized by GDP in PPP$ 2019	WIPO (GII inputs subindex)
GERCGDP	Research and development expenditure (% of GDP, curr. prices, USD)	MSTI (GB_XPDRSDVGD_ZS)
GERPGDP	Gross domestic expenditure on R&D (GERD) as % of curr. GDP (PPP$)	MSTI (G_XGDP)
GERD_CAP	Gross domestic expenditure on R&D (in PPP$), per capita of population	WDI (G_XPOP)
GVE_XGDP	Governm. intramural expenditure on R&D (GOVERD) as % of curr. GDP (PPP$)	MSTI (GV_XGDP)
HED_XGDP	Higher-education expenditure on R&D (HERD) as % of current GDP (PPP$)	MSTI (H_XGDP)
ALLRES_LF	Total researchers per thousand of domestic labour force	MSTI (TP_RSXLF)
RDPERS_LF	Total R&D personnel (incl. staff), per thousand of domestic labour force	MSTI (TP_TTXLF)
ALLRES_EM	Total researchers per thousand of domestic total employment	MSTI (TP_RSXEM)
RDPERS_EM	Total R&D personnel (incl. staff), per thousand of dom. total employment	MSTI (TP_TTXEM)
GII_OUTPUT	Global Innovation subindex for outputs 2020, normalized by GDP in PPP$ 2019	WIPO (GII output subindex)
ECONPAP	Number of papers in economics, normalized by size of domestic GDP	REPEC (r_econpap_n1)
JRN_ART	Number of articles in scientific journals, normalized by size of domestic GDP	WDI (IP_JRN_ARTC_SC)
JUDINDEP	Judicial independence of government, mean score 2000-2019	FRASER (judicialindep)
IMPART_C	Impartiality of legal courts, mean score 2000-2019	FRASER (impartcourt)
IMP_PUBL	Impartiality of public administration, mean score 2000-2019	FRASER (impartpubad)
PROTPROP	Protection of property rights, mean score 2000-2019	FRASER (protpropr)
LEG_FORCE	Effectiveness legal enforcement, mean score 2000-2019	FRASER (legalenforc)
INFDI_GDP	Total inward FDI stocks, normalized by size of domestic GDP	UNCTAD (inst_gdp)
BF_IMSRV	import of business and financial services, as % of total services import	KVL (ocs_impsh_n4)
KIBS_IMSRV	import of knowledge- intensive business services, as % of total services import	KVL (kibs_impsh_n4)
PAT_NRES	Number of patent applications by non-residents, normalized by GDP	WDI (IP_PAT_NRES_n1)
INT_USER	Individuals using the Internet, as % of population	WDI (IT_NET_USER_ZS)
INTSECUR	Number of secure Internet servers, per million people	WDI (IT_NET_SECR_P6)
BBND_SUB	Number of fixed broadband subscriptions, per million people	WDI (IT_NET_BBND_P2)
ICT_CONTR	Contribution of ICT assets to GDP growth (growth accounting)	TED (ICT_contr)
LP_EMPL	Labour productivity p. person employed, converted to 2020 PPP$	TED (LP_eksL)
LP_HOUR	Labour productivity p. hour worked, converted to 2020 PPP$	TED (LP_eksH)
FORGN_MV	Freedom of foreigners to visit, mean score 2000-2019	FRASER (forgn_move)
STARTABUS	Freedom to setup up a business, mean score 2000-2019	FRASER (startabus)
BERD_GDP	Total business expenditure on R&D (BERD) as % of current GDP (PPP$)	MSTI (B_XGDP)
BUX_GERD	% of GERD that is performed by the business enterprise sector	MSTI (G_XEB)
BFIN_HERD	% of higher-education expend. on R&D that is financed by the business sector	MSTI (H_XFB)
BRES_TOT	Total business enterprise R&D personnel as a percentage of national total	MSTI (BP_TTXTT)
HT_MFGEX	High-technology exports, as % of total manufacturing exports	WDI (TX_VAL_TECHMF_ZS)
IT_SERVEX	Exports of ICT services, as % of total services exports	WDI (BX_GSR_CCIS_ZS)
ITPROD_EX	Exports of ICT goods, as % of total merchandise exports	WDI (TX_VAL_ICTG_ZS_UN)
BF_SRVEX	Export of business and financial services, as % of total services export	KVL (ocs_expsh_n4)
KBS_SRVEX	Export of knowledge-intensive business services, as % of total services export	KVL (kibs_expsh_n4)
PATP_GDP	No. of patents filed under the PCT (priority yr), per 1000 ppp$ of GDP	MSTI (P_PCT_n1)
PATI_GDP	No. of ICT patents filed under the PCT (priority yr), per 1000 ppp$ of GDP	MSTI (P_ICTPCT_n1)
PATB_GDP	No. of biotech patents filed under the PCT (priority yr), per 1000 ppp$ of GDP	MSTI (P_BIOPCT_n1)
Extensive knowledge-creation margin		
HERD_S	Log of higher-education expenditure on R&D (curr. PPP$)	MSTI (H_PPP_s)
HRES_S	Log of total no. of researchers in higher-education sector (headcount)	MSTI (HH_RS_s)
HPER_S	Log of total number of higher-education R&D personnel, incl. staff (headcount)	MSTI (HP_TT_s)
HFTE_S	Log of total number of national researchers in higher-education sector (FTE)	MSTI (HP_RS_s)
FEMRES_S	Log of total number of female researchers (headcount)	MSTI (TH_WRS_s)
GII_MAIN_S	log of Global Innovation Index 2020 (not normalized for economic scale)	WIPO (GII)
GII_INPT_S	log of Global Innovation Inputs subindex 2020 (not normalized for econ. scale)	WIPO (GII inputs)
GERD_S	Log of gross domestic expenditure on R&D (curr. PPP$)	MSTI (G_PPP_s)
GOVERD_S	Log of governm. intramural expenditure on R&D (curr. PPP$)	MSTI (GV_PPP_s)
TOTRES_S	Log of total number of researchers (headcount)	MSTI (TH_RS_s)

GVRES_S	Log of total number of researchers in government sector (headcount)	MSTI (GH_RS_s)
TOTPER_S	Log of total number of R&D personnel, incl. staff (headcount)	MSTI (TP_TT_s)
GVPER_S	Log of total number of governm. sector R&D personnel, incl. staff (headcount)	MSTI d (GP_TT_s)
TOTFTE_S	Log of total number of national researchers (FTE)	MSTI (TP_RS_s)
GVFTE_S	Log of total number of national researchers in government sector (FTE)	MSTI (GP_RS_s)
GII_OUTP_S	log of Global Innov. Outputs subindex 2020 (not normalized for economic scale)	WIPO (GII inputs)
PAT_R_S	Log of number of patent applications by residents	WDI (IP_PAT_RESD_s)
JRNART_S	Log of number of articles in scientific journals	WDI (IP_JRN_ARTC_SC_s)
PAT_NR_S	Log of number of patent applications by non-residents	WDI (IP_PAT_NRES_s)
BERD_S	Log of total business expenditure on R&D (curr. PPP$)	MSTI (B_PPP_s)
BRES_S	Log of total number of researchers in busin. enterprise sector (headcount)	MSTI (BH_RS_s)
BPER_S	Log of total number of busin. sector R&D personnel, incl. staff (headcount)	MSTI (BP_TT_s)
BFTE_S	Log of total number of national researchers in business sector (FTE)	MSTI (BP_RS_s)
PCTPAT_S	Log of no. of patents filed under the PCT (priority year)	MSTI (P_PCT_s)
ICTPAT_S	Log of no. of ICT patents filed under the PCT (priority year)	MSTI (P_ICTPCT_s)

Legends: FRASER: Economic Freedom of the World (Gwartney et al, 2021). KVL: World Services Trade Matrix (KVL Economic Policy Research). MSTI: Main Science and Technology database (OECD). TED: The Conference Board Total Economy Database™ (The Conference Board, De Vries, 2022). UNCTAD (2022b), World Investment Report 2021. WDI: World Development Indicators (World Bank). WIPO: The Global Innovation Index (2022, 2020). Full references for the sources are in the main text of the paper.

Annex III. Extensive-margin indicators (scale-based) of national knowledge creation.

National knowledge system component	Variable description	Variable name
(Re-)activation of existing public knowledge	Log of higher-education expenditure on R&D (curr. PPP$)	HERD_S
	Log of total no. of researchers in higher-education sector (headcount)	HRES_S
	Log of total number of higher-education R&D personnel, incl. staff headcount)	HPER_S
	Log of total number of national researchers in higher-education sector (FTE)	HFTE_S
	Log of total number of female researchers (headcount)	FEMRES_S
Creating of new public knowledge: input indicators	Log of gross domestic expenditure on R&D (curr. PPP$)	GERD_S
	Log of governm. intramural expenditure on R&D (curr. PPP$)	GOVERD_S
	Log of total number of researchers (headcount)	TOTRES_S
	Log of total number of researchers in government sector (headcount)	GVRES_S
	Log of total number of R&D personnel, incl. staff (headcount)	TOTPER_S
	Log of total number of governm. sector R&D personnel, incl. staff (headcount)	GVPER_S
	Log of total number of national researchers (FTE)	TOTFTE_S
	Log of total number of national researchers in government sector (FTE)	GVFTE_S
Creating of new public knowledge: output indicators	Log of number of patent applications by residents	PAT_R_S
	Log of number of articles in scientific journals	JRNART_S
Acquisition of foreign knowledge	Log of number of patent applications by non-residents	PAT_NR_S
Business research and knowledge-creation efforts	Log of total number of national researchers in business sector (FTE)	BFTE_S
	Log of total business expenditure on R&D (curr. PPP$)	BERD_S
	Log of total number of researchers in busin. enterprise sector (headcount)	BRES_S
	Log of total number of busin. sector R&D personnel, incl. staff (headcount)	BPER_S
Firms' absorbing of public knowledge inputs	Log of no. of patents filed under the PCT (priority year)	PCTPAT_S
	Log of no. of ICT patents filed under the PCT (priority year)	ICTPAT_S
	Log of no. of biotech patents filed under the PCT (priority year)	BIOPAT_S
	Log of number of trademark applications by direct residents	TMDRES_S
	Log of total number of trademark applications	TM_TOT_S

Note: Annex Table II provides details on the original sources of each indicator.

Annex IV. Rank correlation between OUTST_GDP (outward FDI stocks per unit of GDP) and all extensive-margin indicators, by knowledge domain (full country sample).

Knowledge system component	Indicator name[#)]	No. of compared country observations	Rank correlation, Kendall's *tau-b*	Prob>|z|	Confidence code [&)]
(Re-)activation of existing public knowledge	HERD_S	42	0.194	0.072	*
	HRES_S	37	−0.012	0.927	
	HPER_S	40	0.072	0.522	
	HFTE_S	40	0.087	0.435	
	FEMRES_S	36	0.025	0.838	
Creating of new public knowledge: input-related indicators	GERD_S	42	0.189	0.079	*
	GOVERD_S	42	0.011	0.931	
	TOTRES_S	37	0.048	0.685	
	GVRES_S	37	−0.132	0.255	
	TOTPER_S	38	0.073	0.530	
	GVPER_S	39	−0.107	0.345	
	TOTFTE_S	39	0.082	0.468	
	GVFTE_S	39	−0.128	0.256	
New public knowledge: output-related indicators	PAT_R_S	129	0.241	0.000	***
	JRNART_S	160	0.274	0.000	***
Acquisition of foreign knowledge assets	PAT_NR_S	136	0.222	0.000	***
Input-related indicators for knowledge-creation efforts by private business	BERD_S	42	0.227	0.036	**
	BRES_S	38	0.141	0.218	
	BPER_S	41	0.129	0.238	
	BFTE_S	40	0.151	0.173	
Output-related indicators for knowledge-creation efforts by private business	PCTPAT_S	42	0.308	0.004	***
	ICTPAT_S	42	0.329	0.002	***
	BIOPAT_S	42	0.368	0.000	***
	TMDRES_S	130	0.210	0.000	***
	TM_TOT_S	136	0.197	0.001	***

*Legend: [#)] For description of the extensive-margin indicators, see Annex III, and for the source of the original indicators, see Annex II. [&)] Coding of confidence levels: *** p<0.01, ** p<0.05, * p<0.10.*

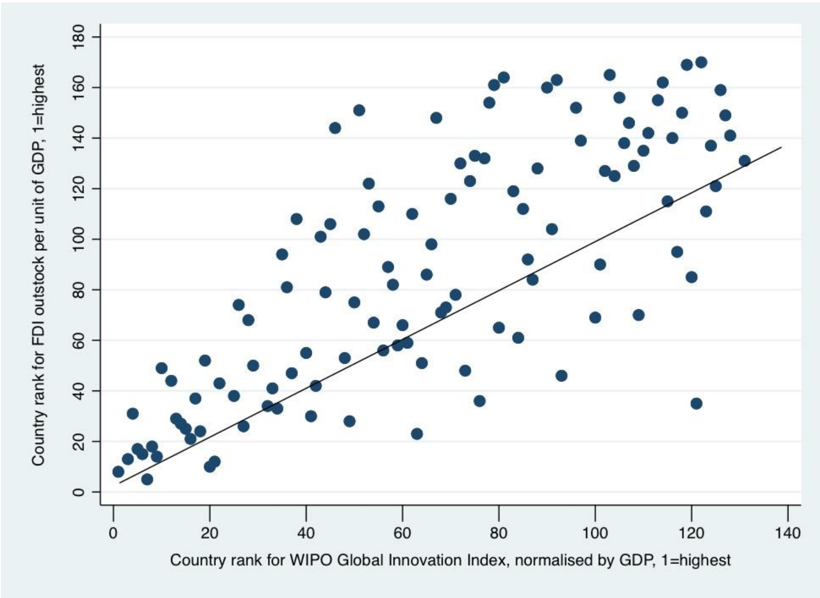
Annex V. Performance for model predictions when extensive-margin indicators are used (full country sample).

Model predictions	Overall count statistics [§)]
1. Firm-specific knowledge assets (G_{fit}) should have a significant and positive impact on a country's outward FDI volume (zero hypothesis)	6 of 9 indicators (66.7%)
2. Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets should have a significant and positive impact on a country's outward FDI volume.	7 of 16 indicators (43.8%)
3. Most individual indicators for a country's 'relative abundance of knowledge capital' should have a positive and statistically significant impact on outward FDI volume.	13 of 25 indicators (52.0%)

Legend: [§)] The score reflects the number of rank correlation indicators (Kendall tau-b) that comply with the condition in the first column by being statistically significant and having the predicted sign. The numbers in brackets gives the share of the total number of indicators that is relevant for that particular rank correlation. Source: Annex IV

ANNEX VI. Stylised facts: Rank correlation for Global Innovation Index and FDI (stocks per unit of GDP), sample without tax-sheltering countries.

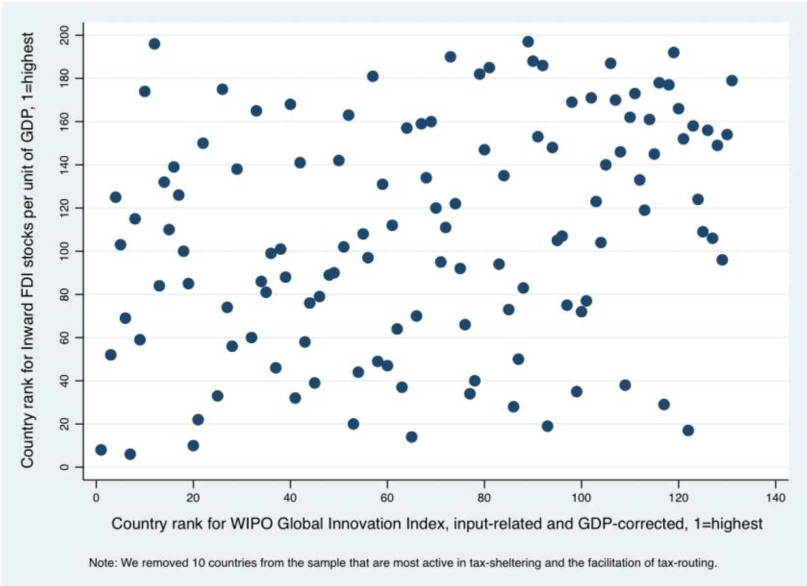
For knowledge assets, we use a well-documented indicator that is annually produced by a consortium of Cornell University, INSEAD, and the World Intellectual Property Organization (WIPO), covering a large set of countries (e.g. WIPO, 2020, 2022). It builds on many sub-indicators for innovation and knowledge-creation per country[39], which are aggregated in a consistent and uniform way. That results in their Global Innovation Index (GII). We plot its country rank against the country ranks in terms of OUTST_GDP (outward FDI stocks per unit of GDP**)**. We use the sample of 114 countries without those countries that are most active in facilitating tax-sheltering and tax avoidance (specified in Annex Table VIII.1). The scatter plot in Graph VI.1 displays how narrow the country rankings for GDP-corrected knowledge assets correlate with the country ranks for outward FDI stocks (per unit of GDP).



Graph VI.1. Rank correlation between outward FDI stocks per unit of GDP and Global Innovation Index, 114 countries, mean scores over period 2000-2019.

In Graph VII.2 we repeat the plot, but now linking the GII to *inward* FDI (stocks per unit of GDP). The picture changes completely. These data suggest that domestic knowledge assets are important for outward FDI, but not - or much less so- for inward FDI. That pattern is confirmed by regression analysis (Table VII.1) using the same data. Panel A displays the results of the OLS regression for explaining the outward FDI rank of countries; the estimated coefficient for the explanatory GII variable is almost one with a just a small standard error. Panel B shows the corresponding regression results for explaining the inward FDI rank of countries; here the estimated coefficient for the explanatory GII variable is less than 0.50. Hence, a country's rank score for the WIPO Global Innovativeness Index almost fully explains a country's rank score for outward FDI stocks over the period 2000-2019. A country's rank score for inward FDI stocks has a much smaller relation with the domestic innovativeness.

[39] Some of their about 80 sub-indicators are the same as the intensive or extensive margin indicators that we have used, so there is overlap. But we have worked independently, and we include three of the GII subindicators in our set of indicators.



Graph VI.2. Rank correlation between inward FDI stocks per unit of GDP and Global Innovation Index, 123 countries, mean scores over period 2000-2019.

Table VI.1. Global Innovation Index (rank_GII) as explanatory variable for outward and inward FDI stocks, country ranks averaged over period 2000-2019.

	estimated coefficient	White-robust S.E.	t-value	P>|t|	95% confid. interval low	95% confid. interval high
Panel A, Dependent variable: country rank with respect to outward FDI stocks per unit of GDP						
* rank_GII	0.9721	0.0705	13.79	0.000	0.8325	1.1117
* constant	23.169	4.6056	5.03	0.000	14.043	32.294
No. of obs = 114; F (1, 112) = 190.3; Prob > F = 0.0000; R^2 = 0.560; White robust OLS						
Panel B, Dependent variable: country rank with respect to inward FDI stocks per unit of GDP						
* rank_GII	0.4161	0.1198	3.47	0.001	0.1790	0.6532
* constant	79.903	9.4718	8.44	0.000	61.152	98.656

No. of obs = 123; F (1, 112) = 12.07; Prob > F = 0.0007; R2 = 0.089; White robust OLS.

Annex VII. Detailed rank correlation results.

Table VII.1. Rank correlation between outward FDI stocks per unit of GDP (OUTST_GDP) and intensive-margin indicators, country sample without tax-sheltering countriese %).

Knowledge system component	Indicator name	No. of compared country observations	Rank correlation, Kendall's *tau-b*	Prob>|z|	Confidence code &)
(Re-)activation of existing public knowledge	ADEDU_F	136	0.161	0.006	***
	ADEDU_M	136	0.090	0.120	
	LQ_CONTR	112	0.076	0.236	
	FEM_RESR	32	–0.250	0.046	**
	TOT_RESR	109	0.497	0.000	***
	TOT_TECH	98	0.454	0.000	***
Creating of new public knowledge: input-related indicators	GII_MAIN	125	0.516	0.000	***
	GII_INPUT	114	0.559	0.000	***
	GERCGDP	119	0.404	0.000	***
	GERPGDP	38	0.408	0.000	***
	GERD_CAP	38	0.482	0.000	***
	GVE_XGDP	38	0.044	0.706	
	HED_XGDP	38	0.408	0.000	***
	ALLRES_LF	35	0.489	0.000	***
	RDPERS_LF	34	0.455	0.000	***
	ALLRES_EM	35	0.492	0.000	***
	RDPERS_EM	34	0.480	0.000	***
Creating of new public knowledge: output-related indicators	GII_OUTPUT	113	0.452	0.000	***
	ECONPAP	134	0.416	0.000	***
	JRN_ART	149	0.194	0.001	***
	JUDINDEP	135	0.420	0.000	***
	IMPART_C	135	0.448	0.000	***
	IMP_PUBL	134	0.389	0.000	***
	PROTPROP	135	0.415	0.000	***
	LEG_FORCE	135	0.320	0.000	***
Acquisition of foreign knowledge assets	INFDI_GDP	156	0.212	0.000	***
	BF_IMSRV	123	0.153	0.012	**
	KIBS_IMSRV	146	0.164	0.003	***
	PAT_NRES	126	0.121	0.047	**
National productivity and knowledge-throughput efficiency	INT_USER	153	0.501	0.000	***
	INTSECUR	153	0.464	0.000	***
	BBND_SUB	153	0.456	0.000	***
	ICT_CONTR	110	0.203	0.002	***
	LP_EMPL	112	0.575	0.000	***
	LP_HOUR	112	0.562	0.000	***
	FORGN_MV	135	0.224	0.000	***
	STARTABUS	135	0.321	0.000	***
Private business research and knowledge-creation efforts	BERD_GDP	38	0.386	0.001	***
	BUX_GERD	38	0.289	0.011	**
	BFIN_HERD	38	0.072	0.530	
	BRES_TOT	34	0.355	0.003	***
Absorbing of knowledge inputs by private business	HT_MFGEX	145	0.301	0.000	***
	IT_SERVEX	149	-0.080	0.148	
	ITPROD_EX	148	0.292	0.000	***
	BF_SRVEX	120	0.305	0.000	***
	KBS_SRVEX	146	0.067	0.206	
	PATP_GDP	38	0.454	0.000	***
	PATI_GDP	38	0.539	0.000	***
	PATB_GDP	38	0.539	0.000	***
	PATP_RES	120	0.105	0.092	*
	TM_DRES	122	–0.103	0.094	*
	TM_TOT	128	–0.144	0.016	**

Continuation of Table VII.1

Overall count statistics with regard to model predictions:	
1. Firm-specific knowledge assets (G_{fit}) should have a significant and positive impact on a country's outward FDI volume (zero hypothesis)	10 of 15 indicators (66.7%)
2. Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets should have a significant and positive impact on a country's outward FDI volume.	25 of 29 indicators (86.2%)
3. Most individual indicators for a country's 'relative abundance of knowledge capital' should have a positive and statistically significant impact on outward FDI volume.	35 of 44 indicators (79.5%)
4. National knowledge-throughput efficiency (v_{it}) should have a positive and significant impact on a country's outward FDI.	8 of 8 indicators (100%)

*Note: %) We dropped the following 18 (tax-sheltering) countries or geographical entities from the full country sample: Netherlands Antilles, American Samoa, Bahamas, Bermuda, Switzerland, Cayman Islands, Cyprus, Iceland, Liberia, Luxembourg, Marshall Islands, Malta, Mauritius, The Netherlands, Panama, Seychelles, British Virgin Islands, and US Virgin Islands (some of them had no reported outward FDI). &) Coding of confidence levels: *** p<0.01, ** p<0.05, * p<0.10.*

Table VII.2. Rank correlation of intensive-margin knowledge-capital indicators with (outward and inward) FDI stock and with GDP, 2000-2020 period, full country sample.

Indicator name	No. of country observations	Rank correlation with outward FDI		Rank correlation with inward FDI		PM: Kendall rank corr. (tau-b) with own GDP
		Spearman's rho	Kendall's tau-b	Spearman's rho	Kendall's tau-b	
ADEDU_F	175	0.152**	0.101**	0.157**	0.105**	0.042
ADEDU_M	175	0.157**	0.102**	0.153**	0.104**	0.106**
LQ_CONTR	128	0.322***	0.212***	0.352***	0.232***	0.213***
FEM_RESR	36	-0.540***	-0.384***	-0.441***	-0.305***	-0.232**
TOT_RESR	135	0.721***	0.517***	0.659***	0.457***	0.394***
TOT_TECH	121	0.669***	0.478***	0.603***	0.423***	0.345***
GII_MAIN	147	0.751***	0.552***	0.697***	0.504***	0.369***
GII_INPUT	131	0.794***	0.592***	0.731***	0.536***	0.404***
GERCGDP	149	0.642***	0.450***	0.621***	0.438***	0.399***
GERPGDP	42	0.514***	0.336***	0.248	0.164	0.196*
GERD_CAP	42	0.585***	0.375***	0.368**	0.231**	0.171**
GVE_XGDP	42	0.148	0.109	-0.003	0.006	0.108
HED_XGDP	42	0.368**	0.240**	0.237	0.157	0.106
ALLRES_LF	39	0.415***	0.236**	0.141	0.077	0.074
RDPERS_LF	38	0.481***	0.306***	0.179	0.115	0.112
ALLRES_EM	39	0.395**	0.223**	0.120	0.058	0.072
RDPERS_EM	38	0.493***	0.309***	0.194	0.118	0.115
GII_OUTPUT	130	0.749***	0.551***	0.729***	0.537***	0.399***
ECONPAP	164	0.762***	0.569***	0.822***	0.617***	0.545***
JRN_ART	195	0.464***	0.298***	0.478***	0.300***	0.279***
JUDINDEP	165	0.559***	0.390***	0.461***	0.316***	0.231***
IMPART_C	165	0.598***	0.420***	0.524***	0.365***	0.273***
IMP_PUBL	162	0.511***	0.356***	0.441***	0.307***	0.222***
PROTPROP	165	0.579***	0.407***	0.507***	0.351***	0.278***
LEG_FORCE	165	0.465***	0.329***	0.417***	0.290***	0.252***
INFDI_GDP	197	0.110	0.067	.	.	-0.138***
BF_IMSRV	157	0.296***	0.227***	0.307***	0.233***	0.200***
KIBS_IMSRV	193	0.489***	0.350***	0.539***	0.390***	0.312***
PAT_NRES	153	0.122	0.096*	0.121	0.092*	0.011
INT_USER	205	0.664***	0.472***	0.529***	0.365***	0.268***
INTSECUR	209	0.622***	0.441***	0.497***	0.348***	0.219***
BBND_SUB	204	0.633***	0.451***	0.516***	0.366***	0.248***
ICT_CONTR	126	0.255**	0.167***	0.316***	0.204***	0.115*
LP_EMPL	128	0.762***	0.566***	0.649***	0.468***	0.368***
LP_HOUR	128	0.769***	0.575***	0.658***	0.474***	0.373***
FORGN_MV	165	0.171**	0.117**	0.145*	0.102*	0.031
STARTABUS	165	0.498***	0.347***	0.450***	0.319***	0.222***
BERD_GDP	42	0.522***	0.340***	0.269*	0.182*	0.220**
BUX_GERD	42	0.434***	0.299***	0.153	0.182*	0.187*
BFIN_HERD	42	0.153	0.122	0.057	0.043	0.048
BRES_TOT	38	0.592***	0.428***	0.402**	0.300***	0.303***
HT_MFGEX	178	0.504***	0.348***	0.461***	0.323***	0.256***
IT_SERVEX	185	-0.027	-0.019	0.003	0.000	0.056
ITPROD_EX	185	0.396***	0.262***	0.370***	0.242***	0.170***
BF_SRVEX	162	0.537***	0.374***	0.474***	0.338***	0.263***
KBS_SRVEX	196	0.224***	0.149***	0.333***	0.225***	0.238***
PATP_GDP	42	0.600***	0.398***	0.385***	0.254**	0.213**
PATI_GDP	42	0.689***	0.489***	0.488***	0.354***	0.285***
PATB_GDP	42	0.626***	0.429***	0.426***	0.303***	0.201*
PATP_RES	145	0.265***	0.174***	0.297***	0.187***	0.175***
TM_DRES	150	0.115	0.064	0.169**	0.100*	0.073
TM_TOT	159	0.046	0.028	0.104	0.063	0.057

Table VII.3. Rank correlation of extensive-margin indicators with total FDI stock (outward and inward) and with GDP, 2000-2020 period, full country sample.

Indicator name	No. of country observa-tions	Rank correlation with outward FDI		Rank correlation with inward FDI		PM: Kendall rank corr. (tau-b) with own GDP
		Spearman's rho	Kendall's tau-b	Spearman's rho	Kendall's tau-b	
HERD_S	42	0.805***	0.628***	0.792***	0.436***	0.677***
HRES_S	37	0.574***	0.402***	0.539***	0.402***	0.694***
HPER_S	40	0.697***	0.497***	0.675***	0.500***	0.779***
HFTE_S	40	0.693***	0.497***	0.661***	0.495***	0.744***
FEMRES_S	36	0.629***	0.460***	0.574***	0.438***	0.759***
GII_MAIN_S	147	0.751***	0.552***	0.698***	0.504***	0.369***
GII_INPT_S	131	0.794***	0.592***	0.730***	0.536***	0.403***
GERD_S	42	0.806***	0.624***	0.736***	0.559***	0.814***
GOVERD_S	42	0.607**	0.436***	0.570***	0.408***	0.677***
TOTRES_S	37	0.657***	0.487***	0.583***	0.438***	0.734***
GVRES_S	37	0.411**	0.282**	0.374**	0.270**	0.586***
TOTPER_S	38	0.709***	0.514***	0.647***	0.482***	0.787***
GVPER_S	39	0.440***	0.304***	0.407**	0.279**	0.606***
TOTFTE_S	39	0.730***	0.544***	0.666***	0.505***	0.776***
GVFTE_S	39	0.404**	0.282**	0.367**	0.247**	0.584***
GII_OUTP_S	130	0.749***	0.551***	0.729***	0.537***	0.399***
PAT_R_S	145	0.698***	0.514***	0.7690***	0.573***	0.639***
JRNART_S	195	0.803***	0.612***	0.866***	0.686***	0.756***
PAT_NR_S	153	0.720***	0.528***	0.765***	0.578***	0.632***
BERD_S	42	0.806***	0.619***	0.707***	0.540***	0.745***
BRES_S	38	0.748***	0.565***	0.758***	0.502***	0.727***
BPER_S	41	0.748***	0.561***	0.679***	0.510***	0.746***
BFTE_S	40	0.758***	0.569***	0.684***	0.505***	0.728***
PCTPAT_S	42	0.857***	0.677***	0.768***	0.584***	0.686***
ICTPAT_S	42	0.832***	0.642***	0.727***	0.568***	0.656***
BIOPAT_S	42	0.887***	0.728***	0.783***	0.617***	0.668***
TMDRES_S	159	0.765***	0.565***	0.844***	0.654***	0.757***
TM_TOT_S	159	0.760***	0.565***	0.841***	0.654***	0.757***

Table VII.4. Rank correlation of intensive-margin indicators with total FDI stock (outward and inward) and with GDP, 2000-2020 period, sample without tax-sheltering countries.

Indicator name	No. of country observations	Rank correlation with outward FDI		Rank correlation with inward FDI		PM: Kendall rank corr. (tau-b) with own GDP
		Spearman's rho	Kendall's tau-b	Spearman's rho	Kendall's tau-b	
ADEDU_F	163	0.116	0.076	0.123	0.084	0.042
ADEDU_M	163	0.139*	0.090*	0.149*	0.101*	0.129**
LQ_CONTR	121	0.313***	0.209***	0.359***	0.240***	0.243***
FEM_RESR	32	-0.493***	-0.343***	-0.373***	-0.250**	-0.234*
TOT_RESR	125	0.716***	0.515***	0.661***	0.459***	0.415***
TOT_TECH	112	0.658***	0.467***	0.609***	0.423***	0.386***
GII_MAIN	138	0.741***	0.540***	0.704***	0.506***	0.400***
GII_INPUT	123	0.783***	0.581***	0.735***	0.536***	0.433***
GERCGDP	137	0.637***	0.449***	0.625***	0.443***	0.414***
GERPGDP	38	0.525***	0.346***	0.235	0.158	0.218*
GERD_CAP	38	0.599***	0.380***	0.358**	0.226**	0.218*
GVE_XGDP	38	0.212	0.158	0.015	0.021	0.155
HED_XGDP	38	0.386**	0.243**	0.250	0.164	0.110
ALLRES_LF	35	0.457***	0.261**	0.163	0.089	0.103
RDPERS_LF	34	0.500***	0.312***	0.169	0.102	0.159
ALLRES_EM	35	0.446***	0.250**	0.148	0.072	0.099
RDPERS_EM	34	0.518***	0.323***	0.194	0.112	0.169
GII_OUTPUT	122	0.729***	0.533***	0.727***	0.534***	0.433***
ECONPAP	157	0.752***	0.560***	0.818***	0.613***	0.548***
JRN_ART	183	0.471***	0.300***	0.486***	0.305***	0.281***
JUDINDEP	154	0.532***	0.369***	0.445***	0.305***	0.250***
IMPART_C	154	0.580***	0.420***	0.513***	0.354***	0.288***
IMP_PUBL	152	0.480***	0.333***	0.413***	0.289***	0.221***
PROTPROP	154	0.556***	0.389***	0.495***	0.342***	0.287***
LEG_FORCE	154	0.448***	0.320***	0.401***	0.280***	0.251***
INFDI_GDP	181	0.027	0.015	0.108	0.071	-0.136*
BF_IMSRV	141	0.307***	0.231***	0.333***	0.247***	0.238***
KIBS_IMSRV	176	0.486***	0.347***	0.567***	0.409***	0.366***
PAT_NRES	143	0.168**	0.124**	0.174**	0.127**	0.049
INT_USER	189	0.657***	0.466***	0.522***	0.360***	0.288***
INTSECUR	192	0.610***	0.431***	0.489***	0.342***	0.251***
BBND_SUB	188	0.619***	0.441***	0.506***	0.360***	0.282***
ICT_CONTR	119	0.231**	0.151**	0.287***	0.185***	0.107*
LP_EMPL	121	0.748***	0.555***	0.645***	0.463***	0.408***
LP_HOUR	121	0.756***	0.564***	0.658***	0.471***	0.413***
FORGN_MV	154	0.167**	0.114**	0.149*	0.105*	0.045
STARTABUS	154	0.476***	0.331***	0.451***	0.320***	0.251***
BERD_GDP	38	0.542***	0.357***	0.267	0.181*	0.240**
BUX_GERD	38	0.439***	0.306***	0.243	0.181	0.212*
BFIN_HERD	38	0.045	0.061	-0.089	-0.041	-0.056
BRES_TOT	34	0.571***	0.405***	0.368**	0.266**	0.330***
HT_MFGEX	167	0.486***	0.337***	0.455***	0.320***	0.272***
IT_SERVEX	173	-0.034	-0.024	-0.016	-0.013	0.027
ITPROD_EX	174	0.367***	0.242***	0.346***	0.226***	0.173***
BF_SRVEX	145	0.535***	0.374***	0.491***	0.342***	0.290***
KBS_SRVEX	179	0.243***	0.164***	0.324***	0.219***	0.196***
PATP_GDP	38	0.373**	0.403***	0.669***	0.243**	0.240**
PATI_GDP	38	0.668***	0.471***	0.435***	0.317***	0.275***
PATB_GDP	38	0.614***	0.414***	0.393***	0.272**	0.206*
PATP_RES	136	0.278***	0.183***	0.309***	0.194***	0.169***
TM_DRES	142	0.138	0.079	0.192**	0.113**	0.07
TM_TOT	151	0.061	0.038	0.119	0.073	0.063

Table VII.5. Rank correlation of extensive-margin indicators with total FDI stock (outward and inward) and with GDP, 2000-2020 period, full country sample, but without tax-sheltering countries.

Indicator name	Number of country observa-tions	Rank correlation with outward FDI		Rank correlation with inward FDI		PM: Kendall rank corr. (tau-b) with own GDP
		Spearman's rho	Kendall's tau-b	Spearman's rho	Kendall's tau-b	
HERD_S	38	0.830***	0.690***	0.809***	0.650***	0.824***
HRES_S	33	0.636***	0.458***	0.594***	0.443***	0.705***
HPER_S	36	0.723***	0.527***	0.689***	0.518***	0.762***
HFTE_S	36	0.726***	0.533***	0.682***	0.518***	0.724***
FEMRES_S	32	0.678***	0.516***	0.606***	0.472***	0.770***
GII_MAIN_S	138	0.741***	0.541***	0.704***	0.507***	0.400***
GII_INPT_S	123	0.783***	0.581***	0.735***	0.536***	0.433***
GERD_S	38	0.834***	0.662***	0.760***	0.576***	0.795***
GOVERD_S	38	0.688***	0.508***	0.633***	0.457***	0.698***
TOTRES_S	33	0.698***	0.538***	0.603***	0.462***	0.754***
GVRES_S	33	0.471***	0.341***	0.420**	0.303**	0.595***
TOTPER_S	34	0.735***	0.551***	0.657***	0.497***	0.775***
GVPER_S	35	0.524***	0.375***	0.469***	0.324***	0.620***
TOTFTE_S	35	0.771***	0.593***	0.687***	0.529***	0.771***
GVFTE_S	35	0.485***	0.351***	0.425**	0.287***	0.597***
GII_OUTP_S	122	0.729***	0.533***	0.727***	0.534***	0.433***
PAT_R_S	136	0.732***	0.545***	0.799***	0.600***	0.635***
JRNART_S	183	0.835***	0.644***	0.881***	0.705***	0.755***
PAT_NR_S	143	0.757***	0.562***	0.799***	0.609***	0.634***
BERD_S	38	0.821***	0.642***	0.706***	0.539***	0.724***
BRES_S	34	0.782***	0.608***	0.681***	0.523***	0.718***
BPER_S	37	0.765***	0.592***	0.683***	0.523***	0.730***
BFTE_S	36	0.786***	0.606***	0.695***	0.521***	0.718***
PCTPAT_S	38	0.861***	0.684***	0.749***	0.570***	0.664***
ICTPAT_S	38	0.846***	0.556***	0.713***	0.747***	0.718***
BIOPAT_S	38	0.902***	0.747***	0.771***	0.610***	0.642***
TMDRES_S	142	0.800***	0.606***	0.875***	0.689***	0.744***
TM_TOT_S	151	0.786***	0.589***	0.861***	0.675***	0.757***