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Linking the knowledge-capital model of foreign direct investment with national knowledge systems

By HENK L.M. KOX¹

The paper models the links between public and firm-level knowledge processes. The knowledge-capital (KC) theory assumes that firms use their private knowledge assets to set up foreign subsidiaries. Countries with large outward FDI stocks should have a relative abundance of proprietary knowledge assets. This has not yet been adequately tested. Our model allows to test it by concentrating on national public knowledge inputs that are encapsulated in proprietary knowledge assets of firms. Using a rich international dataset we confirm the basic tenet of the KC theory and show the important role of public knowledge production for outward FDI.

(JEL D22, D25, D83, F23, O31, O34)

The paper tests the validity of the KC model of foreign direct investment (FDI). The KC model assumes that firms own footloose knowledge assets that may be exploited in other countries via foreign direct investment. Firm-level KC may include intangible assets like patents, in-house know-how, blueprints, procedures, reputations and trademarks. Many of such knowledge assets are geographically separable and they may be applied at low or zero additional costs for production in foreign subsidiaries without decreasing their value.² FDI may thus increase the returns to such assets, and may form the basis for scale effects in the international operations of a firm. In the KC interpretation, it forms the key explanation for the foreign direct investment. This assumption on the role of KC assets has not been

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² Markusen, 2002, 2001, 1984; Carr *et al.*, 2001; Markusen and Maskus, 2003.

tested in an adequate way so far. The present paper provides a new way to test it empirically, and applies this test to over 200 countries during the period 2000-2020.

If separable KC assets in firm headquarters indeed form the key driver for investing in foreign subsidiaries, it implies that countries with large outward FDI stocks should have a relative abundance of separable KC assets. So far, it has proved difficult to find unambiguous empirical yardsticks for the relative abundance of private knowledge assets. Moreover, reliable and internationally comparable data on firm-level knowledge assets are sparse in supply, which may be due to strategic secrecy reasons, to country-level disclosure rules, and also to the inherently tacit or intangible nature of some proprietary knowledge assets.³ One proposal was to measure the intangible assets of firms via the difference between market value and historic costs (cf. Hall, 2000; Corrado et al., 2009). However, that procedure is problematic in the case of FDI, because data on market values of foreign subsidiaries and their parents are not separately available (McGrattan and Prescott, 2010). Moreover, if the intangible assets can be used both at home and in the foreign subsidiaries, the risk of a bias due to double-counting is looming large.

Several empirical tests of the KC model have restricted themselves to a very narrowed-down empirical measure for KC assets, namely the skill-related wage differences between countries.⁴ The discussion in the literature on this proposal has shown that this was not a lucky choice. Firstly, the difference in skilled labor costs between the origin and host country may give biased results, when national averages are used. Micro-econometric studies with firm-level data have shown that multinational firms often pay premium wages above the national averages.⁵ Secondly, the fact that wage differences form a separate motive for FDI decisions, quite apart from intangible knowledge assets, is even more

³ Morck and Yeung, 1991; Ali and Hwang, 2000; Foster *et al.*, 2012; Chan and Cheung, 2022.

⁴ Carr *et al.*, 2001; Blonigen *et al.*, 2002; Braconier *et al.*, 2005; Tanaka, 2007; Mariel *et al.*, 2009; Chellaraj and Mattoo, 2009; Kristjansdottir, 2010.

⁵ Aitken *et al.*, 1996; Bernard *et al.* 2018; Wagner, 2012; Kox and Rojas, 2010; Egger and Kreickemeier, 2013; Tanaka, 2015.

disturbing.⁶ Wage differences are particularly important in relation to some vertical FDI decisions, to global value-chain investments, and to export-platform types of FDI. For horizontal FDI transactions between developed countries that form the bulk of all FDI transactions⁷, such wage differences may however be next to irrelevant. Using the skill-related wage gap as indicator for the relative abundance of KC assets is likely to give multi-interpretable results. It should therefore be considered as unfit for testing whether separable knowledge assets are an important driver for outward FDI.

McGrattan and Prescott (2009) opt for a more comprehensive interpretation of the knowledge capital of FDI, calling it technology capital ("unique know-how from investing in research and development, brands, and organization capital"). But they do not provide an empirical estimate for it. Later, they show that the available data do not allow a direct test of the model (McGrattan and Prescott, 2010). To demonstrate the plausibility of their model, they use a numeric model exercise, calibrated on FDI stock data of only the USA. Nonetheless, McGrattan (2012: 3-4) remarks that "the main findings of my analysis rely critically on the existence of intangible capital, both technology capital accumulated by multinational parents and plant-specific intangible capital used by their foreign subsidiaries ". Rather than proving and quantifying this precondition, she only uses some scattered evidence from the USA to show the plausibility of her theory. Anderson, Larch and Yotov adopt the technology-capital approach of McGrattan and Prescott, but offer no solution to the attached measurement problems: "Technology transfer in our model can be viewed as a reduced form of a richer model where the details of transfer are linked to equilibrium plant location decisions subject to imperfect property rights. A full treatment is beyond the scope of this paper " (2019: 2).

The present situation is still that we have the KC model of FDI, with an intuitive appeal, but without a thorough empirical test regarding its key assumption. Our paper provides a completely new strategy for testing this. Given the problems with firm-level data on intangible and separable knowledge assets, we leave the firm-

⁶ Wage differences are relevant for unskilled and skilled labor, as the successful rise of software production in India and other emerging countries shows (Arora and Gambardella, 2005).

⁷ Cf. Davies and Markusen (2021); Ramondo *et al.* (2012).

level data for what they are. Instead, we focus on measurable inputs into the firm-level KC assets coming from national knowledge or innovation systems (OECD, 1997).⁸ Multinationals form part of the national knowledge systems in their countries of origin. At a national level, firms benefit from public and semi-public investments in human capital, science and technology. Firms encapsulate knowledge elements from public and semi-public origin and recombine them with their private know-how. On this basis they create proprietary knowledge assets. The latter are applied in the firm's home market and, if the KC assets are footloose and their use is non-rival, also in foreign subsidiaries. Our proposition is that indicators for public KC might effectively capture the relative abundance of knowledge assets of a country's multinational firms. If so, these indicators may be used as predictor for the magnitude of a country's outward FDI. This is the line of investigation that we will pursue here. Our paper only tests the basic assumption of the KC model, not its specificities regarding different types of FDI (horizontal, vertical, global value chains, or export platform). Testing the latter would at least require industry-specific data.

Our paper contributes in several ways to the literature. Firstly, it introduces a new supplement to the KC model that formalizes the interaction between public and private, firm-level knowledge development. It helps to derive a number of testable hypotheses on the validity of the KC model of FDI. Secondly, we solve an identification problem that has so far encumbered empirical tests of the KC model. The problem is that both national knowledge stocks and the volume of outward FDI are intimately linked with the scale of a national economy, thus giving rise to endogeneity problems and measurement bias. We solved this problem by distinguishing between the intensive and the extensive margin of national knowledge creation. Indicators for the intensive margin of knowledge creation are 'de-scaled' and provide a measure of knowledge creation per unit of economic activity. The normalization process uses national aggregates (like total export, total employment, and total GDP) to all national knowledge indicators.

⁸ Freeman (1987) defines them as "*the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies*".

This allows a direct comparison between the knowledge-creation performance of individual countries with different economic scales. Indicators for the extensive margin are purely scale-based and they allow to measure the impact of a country's economic mass on the knowledge-creation process. The third contribution is that we provide a data profile of national knowledge-creation systems (both public and private) for over 200 countries and geographical entities for the period 2000-2020. The database includes about eighty indicators for the intensive and extensive knowledge-creation margin of countries.⁹ By exploiting the international variation among all countries, we achieve a fourth contribution in finding a strong pattern of rank correlation between the indicators for national knowledge creation efforts and the country's outward FDI stocks. It supports the basic assumption of the KC model of FDI. As a fifth contribution we provide several robustness checks for our findings, by redoing the tests for different specifications of the FDI variable and different country samples. One test excludes countries that are intensively involved in tax evasion or tax sheltering. Our results remained standing after removing the tax-sheltering countries from the sample. Finally, we found convincing evidence that knowledge indicators often correlate positively with a country's inward FDI, but that in the far majority of cases the rank correlation between the indicators and outward FDI is stronger than with inward FDI. This may be regarded as indirect evidence in support of the KC model of FDI.

The paper has the following structure. Section I introduces a new module for the KC of FDI that formalizes the relations between national knowledge systems and FDI. It allows to derive testable hypotheses that would be in line with the Markusen approach. Section II deals with the identification problem, the setup of the empirical test, and the dataset of knowledge-creation indicators. Section III presents the main empirical results of the rank correlation analysis with FDI, defined as the outward FDI per unit of GDP. Section IV checks the robustness of the findings by redoing the analysis for three alternative country samples and alternative specifications of the FDI variable. Because FDI patterns might also be driven by tax motives,¹⁰ we

⁹ On request, the database is available for replication studies.

¹⁰ UNCTAD, 2022; Beer *et al.*, 2020; Keen *et al.*, 2022; Damgaard *et al.*, 2019.

remove countries that offer tax-sheltering or tax-evasion facilities. Secondly, we remove the (mostly small) countries that did not have traceable outward FDI in all years of the observation period (2000-2020). Section V investigates test whether the knowledge-creation indicators equally well explain the inward FDI patterns; if so, that would be no good news for our approach to measuring the KC model of FDI. Section VI wraps up the main findings and their implications. The annex provides documents the data sources for the knowledge-system indicators and gives the mathematical proofs. The online appendix holds the detailed rank correlation results per indicator, per FDI definition, and per country sample.

I. Interaction of FDI and national knowledge systems

We specify a formal framework for analyzing the interaction between national knowledge systems and the proprietary knowledge assets of firms. In Markusen's KC model, firms command a unique stock of proprietary technology capital (patents, blueprints, management skills, product recipes, and tacit production knowledge). The production of such assets requires fixed-cost investments by the firm itself, but once created, at least a part of the knowledge assets may also be applied in foreign subsidiaries. From a similar perspective, Burstein and Monge-Naranjo (2009) argue that the international mobility of managerial know-how constitutes the kernel of 'firm-embedded productivity'. A question that the advocates of the KC model do not consider is to what extent private KC assets originate from the individual firms and to what extent the firms build on national knowledge sources of the origin country. In his discussion of location advantages of firms, Markusen (2002:19) fails to appreciate that public knowledge production and closeness to such sources could form an important location advantage for firms with international ambitions. We will argue that this blind spot of the current KC model of FDI is ripe for a reappraisal. Not only that: its correction also provides the possibility to test the basic assumptions of the KC model, as we will show.

A fast-rising volume of literature focuses on the knowledge interaction between individual firms and their environment. It shows that the competitive

edge of individual firms at least partly rests on the knowledge products and knowledge transfers from the public sector, especially the basic science research that it initiates and finances.¹¹ The public and semi-public sector includes universities, specialized scientific, technical and creative institutes, think-tanks, government bodies, higher-education system, and institutional frameworks for knowledge transfer. The public knowledge system can be seen as an input-output process. Its input side accounts for human and material resources that are dedicated to creating new knowledge and to the re-activation of previously created knowledge. The public knowledge system also has a throughput and processing phase where efficiency, focusing, and incentives for creativity matter. And it has an output side where knowledge products, education achievements, technologies, and a learning-oriented institutional environment 'pop out'. Countries can differ a lot in each of these aspects. The public knowledge system forms an important source of free knowledge externalities, by generating and disseminating innovations and discoveries via publications, congresses, staff mobility, intermediary supplier networks, and education-related activities.¹² The commercial exploitation of public-held patents is still a rare phenomenon.¹³ Often, such patents are, before expiration, given away to national firms, or are sold via auctions.¹⁴ Hence, the public knowledge sector tends to be generous with its products. 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, firms work almost exclusively on the basis of proprietary KC. 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. Many of them can be applied in more than one country, at relatively low costs and without negative impacts on domestic production. We proceed by formalizing this process.

¹¹ Sheer, 2022; Arora *et al.*, 2022, 2021; Fagerberg *et al.*, 2012.

¹² Cf. van Elk *et al.*, 2019; Gerbin and Drnovsek, 2016; Audretsch and Stephan, 1996, 1999; Arundel *et al.*, 2013; Breschi and Catalini, 2010; Toole and Czarnitzki, 2010; Verhoogen, 2021; Keller, 2004.

¹³ Agrawal and Henderson, 2002; Calderini *et al.*, 2007; Perkmann *et al.*, 2013.

¹⁴ 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.

M_{it} is the currently active knowledge-capital stock of country i at time t . It is a cumulative product of current and past innovation and knowledge development. "Active" emphasizes that knowledge from the past forms a perishable 'good', requiring constant refreshment, re-education, reappropriation, re-transfer, documentation and dissemination actions by the current generation, otherwise it decays and becomes dead knowledge.¹⁵

The interactions between FDI and the public knowledge-generation system in a country are complex and manifold. We develop a model that, although sketchy, may assist in formulating testable hypotheses regarding the KC model of FDI. The model zooms in on the interaction between FDI and national knowledge systems. Knowledge has no self-evident dimension of measurement; it is complex and multi-dimensional. We perceive the knowledge re-production process as an economic input-output system, counting the material efforts used in that process. We assume that a national economy has just two sectors, the public sector (suffix p) and the firm sector (suffix f). The public sector produces all public, non-proprietary knowledge, while the firm sector accounts for all proprietary or private knowledge. For simplicity, we assume that all foreign knowledge assets are sourced and acquired via the public knowledge sector. The essential production process in the public knowledge sector is described in Table 1.

<TABLE 1 about here>

The parameters β_{it} , φ_{it} and ψ_{jit} all deal with net growth and upgrading of national knowledge-capital in the current period. The input side of all sub-processes are dimensioned by expressing their costs as a fraction of domestic GDP. $\beta_{it} > 0$ represents the GDP fraction dedicated to domestic knowledge creation (e.g. university research, public R&D, basic research).

¹⁵ Many historic examples can be found for this. On lost knowledge, cf. Debenham, 2002; Liu and Kuan, 2016.

Table 1 *The production process of the public knowledge sector in country i*

Sub-processes	Input resources, expressed as fraction of GDP (Y_{it})	Throughput efficiency	Output aggregates
creation new domestic knowledge	β_{it}	v_{it}	M_{piit} (new-created public knowledge)
obtaining foreign (R) proprietary knowledge	φ_{it}	v_{it}	M_{fRit} (new-acquired foreign proprietary knowledge)
obtaining foreign (R) public knowledge	ψ_{it}	v_{it}	M_{pRit} (new-acquired foreign public knowledge)
re-activation of earlier obtained old knowledge	ε_{it}	v_{it}	M_{io} (re-activated old knowledge)
All public effort	$\beta_{it} + \varphi_{it} + \psi_{it} + \varepsilon_{it}$	v_{it}	$M_{pit} = M_{piit} + M_{fRit} + M_{pRit} + M_{io}$

Parameter φ_{it} quantifies the costs of public efforts to attract foreign proprietary knowledge assets M_{fRit} through the channel of inward FDI.¹⁶ Similarly, ψ_{jit} represents the input costs of accessing and using foreign public, non-proprietary knowledge (M_{pRit}). Finally, a very important part of the national knowledge system is formed by all activities that are focused on keeping 'old' knowledge assets active through education, knowledge transfer, documentation, idea diffusion and dissemination activities.¹⁷ This effort is represented by GDP fraction $\varepsilon_{it} > 0$. Quantity M_{io} represents country i's KC stock that was built up before the current period t. It represents the path-dependent historical continuity in a country's national knowledge system.¹⁸ The older knowledge assets are subject to a depreciation rate δ_{it} . A higher depreciation rate can be regarded as a form of creative destruction; it reduces the weight of older knowledge stocks, contributing to rejuvenation of public

¹⁶ Cf. Vujanovic *et al.*, 2022; Lu *et al.*, 2017.

¹⁷ The parameters φ_{it} and ψ_{jt} deal with international diffusion. We do not require a fixed international knowledge frontier; it may differ by knowledge sub-domain. The frontier is constantly moving; domestic frontiers may even collapse due to negative shocks in Y_{it} , ε_{it} or β_{it} . Benhabib *et al.* (2021) elaborate on the aspect of knowledge diffusion.

¹⁸ M_{io} is important for knowledge diffusion; it may reach all domestic firms that operate below the productivity and innovation frontiers, thus potentially narrowing gaps in domestic productivity and KC distributions.

knowledge stocks. The relation $(\beta_{it} + \varphi_{it} + \psi_{it}) \delta_{it}$ thus determines the speed of annual knowledge-rejuvenation.

The final row of Table 1 gives the aggregated knowledge-producing inputs into the public knowledge system and their joint results in the form of M_{pit} . In between the columns of inputs and outputs is conversion or throughput process, quantified by a factor $v_{it} > 0$, measuring national throughput efficiency, or the efficiency with which financial inputs are converted into knowledge outputs. This may for instance depend on knowledge-absorption capabilities, creativity incentives, legal and institutional framework, labor productivity, connectivity, and overall national efficiency.¹⁹ For model simplicity and transparency, we assume v_{it} to be identical for all sub-processes of a national knowledge system.

The present-day state of international statistics does not allow to calculate the monetary weights (expressed as GDP fraction) for all individual elements of the national knowledge system as proposed in the second column of Tables. However, it seems plausible that the national knowledge re-activation efforts (ε_{it}) represent the largest GDP share, certainly in the OECD countries.

Table 2 describes the production function of firm-owned knowledge assets. Country i has $s \in 1, \dots, S$ firms that differ by organisational creativity, productivity, and management capabilities. These elements are embodied in fixed effect $z_s > 0$. Firms in country i are subject to the same national throughput efficiency v_{it} , but at firm level this is mitigated by their z_s factor.²⁰ Hence the country- and firm-specific throughput factor becomes $z_s \cdot v_{it}$.

<TABLE 2 about here>

¹⁹ The throughput efficiency is assumed to be a dimensionless scalar, implying that the value of the knowledge outputs is a function of its input costs (comparable to the treatment of many government activities in the system of national accounts).

²⁰ A typical result from micro studies at firm level 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; Kox and Rojas, 2010; Bernard *et al.*, 2018, 2013; Helpman *et al.*, 2004.

Table 2 *Production of proprietary knowledge by firms in country i*

Sub-processes	Input resources, as fraction of GDP (Y_t)	Throughput efficiency	Output aggregates
internal creation of new private knowledge assets	a_{ist}	$Z_s \cdot v_{it}$	G_{siit} (internal, newly-created private knowledge)
absorbing of public knowledge inputs	ω_{ist}	$Z_s \cdot v_{it}$	$G_{spit} = f(\omega_{ist} M_{pi,t-1})$ (newly encapsulated domestic public knowledge inputs) ²¹
re-activation of 'old' private knowledge	ε_{ist}	$Z_s \cdot v_{it}$	G_{iso} (re-activated 'old' private knowledge)
aggregate effort of firms	$\sum_s \alpha_{ist} + \omega_{ist} + \varepsilon_{ist}$	$Z_s \cdot v_{it}$	$G_{fit} = \sum_s G_{siit} + G_{spit} + G_{iso} = \sum_s G_{sit}$

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_{iso} summarizes older proprietary knowledge stocks of a firm. The parameters ($a_{ist}, \omega_{ist}, \varepsilon_{ist}$) are firm-specific and strictly positive; they depict the inputs into the sub-processes of the firm's knowledge-related activities. 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 firm behavior. Firstly, the costs of absorbing recent knowledge developments from the public sector; it may include networking activity, setting up learning projects, or the hiring of specialists to master new knowledge areas. Moreover, ω_{ist} also captures the costs of turning the firm-modified public knowledge inputs into excludable private assets, e.g. through patenting or secrecy measures.²² The older cohorts

²¹ Note that firms use not the very latest public knowledge, but a recent knowledge consort as input. This is not only plausible but it also prevents endogeneity loops within the model.

²² Cf. Crouset et al., 2022.

of the firm's intangible assets (G_{iso}) are subject to depreciation rate δ_{ist} and a phasing-out process after N years, similar to the public knowledge system.

G_{fit} represents the aggregate active proprietary knowledge of all firms in country i at time t. It can be expressed as a function of the throughput efficiency and real input costs. Following Markusen (2002), it is assumed that the inputs of G_{fit} mainly consist of fixed-cost items with an investment nature. National knowledge stocks consist of public and proprietary elements and may now be defined as:

$$(1) \quad M_{it} \equiv G_{fit} + M_{pit} \quad (1)$$

Both G_{fit} and M_{pit} are decomposable. Tables 1 and 2 describe the components of the right-hand-side variables. Each of them contains a lagged component (M_{io}, G_{io}) as path-dependent component of, respectively, public and firm-level knowledge capital. They have a vintage structure, to which each year a new knowledge 'cohort' is added while older 'cohorts' are depreciated and eventually discarded.²³ The vintage structure creates a historical inertness of a country's knowledge stocks with respect to real-time GDP changes. Time dynamics of knowledge stocks can be complicated due to the time variance of GDP and behavioral parameters (specified in Tables 1 and 2). We may take out the time variance of the behavioral parameters to clarify the basic time dynamics.

²³ Annual cohorts of country i 's stock of older knowledge capital can be consistently aggregated by a CES aggregator, as proposed by Benhabib (2019): $M_{io} = [a_1 M_{i,t-1}^{1-\sigma} + a_2 M_{i,t-2}^{1-\sigma} + \dots + a_{N-1} M_{i,t-(N-1)}^{1-\sigma}]^{1/(1-\sigma)}$ in which $\sigma > 1$ is the elasticity of substitution and $a_1 \dots a_n$ represent the size shares of the annual knowledge stock cohorts, summing up to one. The aggregation of G_{io} may be more problematic, because the firm-level 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.

Proposition 1 *If behavioral parameters are time invariant, the development of public knowledge stocks (M_{pit}) has the following dynamics:*²⁴

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

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 behavioral parameters are time invariant, the development of proprietary knowledge stocks of firms (G_{fit}) has the following dynamics:*

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

The term A_{is} abbreviates the amortization and re-activation module for older proprietary knowledge cohorts at the level of firms: $A_{is} \equiv \{1 + \varepsilon_{is} (1 - \delta_{is}) X_{Yt}\}$. The proof is given in Annex II. Proposition 2 formalizes the crux of our extension to Markusen's knowledge-capital model of FDI, i.e. how proprietary knowledge assets of firms form a joint product of the firms' interaction with the public sector in their origin country.

Firms exploit their proprietary knowledge assets (G_{sit}) in the domestic market. But they also use it abroad via outward FDI, if this increases their expected profits (ΔR_{is}^*). If the profit condition is satisfied, the firm's willingness to supply its proprietary knowledge assets to foreign subsidiaries is almost unbounded. From this conjecture we derive a simple function for outward bilateral FDI stocks supply (from country i to country j):

²⁴ The proof is given in Annex II.

$$(4) \quad FDI_{ijt}^{outw} = \begin{cases} q_{ij} (G_{fit})^h & \text{if } \sum_s \Delta R_{ijst} \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad \forall i, j, s$$

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. All time-variant bilateral factors like taxes, subsidies, regulations, and country size influence bilateral FDI decisions through their (expected) effects on ΔR_{ijst} . In line with the IMF definition, foreign direct investment are those situations in which the firm uses its G_{sit} for setting up equity-controlled foreign production ('having a controlling interest'). Cumulative bilateral FDI stocks form the summation of all firm-level FDI stocks.

Given the firms' own assessment of the foreign market potential of G_{sit} , the expected profit change depend 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.²⁵ The model's reduced-form equation for outward FDI stocks in case of positive foreign profits can be derived as:

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

This specification offers all elements that are important for our test of the knowledge-capital model. A general zero hypothesis is that h has no statistical significance or has a negative sign. If the general zero hypothesis is rejected, a lot more specific tests become feasible. The right-hand-side specification of equation (5) shows the important role of current and lagged

²⁵ In the words of Arkolakis *et al.* (2018), "trade costs encourage, while MP costs discourage, multi-plant production" [NB: MP = multinational production, HK].

scale effects ($Y_{it}, Y_{i,t-1}$). Another scale effect is hidden in the so far implicit assumption that the number of firms ($s \in 1, 2, \dots, S$) is equal in all countries ($S = S_i = S_j \quad \forall i, j$), 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.

We conclude this modelling section by formulating a set of falsifiable predictions from our model, of which the first and third directly pertain to the knowledge-capital model of FDI:

1. Firm-specific knowledge assets (G_{fit}) have a positive impact on a country's outward FDI.
2. Public knowledge inputs (M_{pit}) into firm-level proprietary knowledge assets have a positive impact on a country's outward FDI.
3. KC elements have a positive separate impact on outward FDI. When made scale-free, empirical indicators for knowledge-capital elements correlate stronger with outward FDI than with domestic GDP.
4. National knowledge-throughput efficiency (v_{it}) has a positive and significant impact on a country's outward FDI.

II. Design of empirical tests and data issues

The test of the predictions requires that we quantify the impact of a country's knowledge-creation performance on its outward FDI. However, the national knowledge system and the volume of foreign direct investment are both affected by a country's economic scale. To compare countries with different economic sizes, it is necessary that the country-scale effect is identified, quantified and filtered out. There are two identification problems. The first problem is to assess what part of outward FDI stocks of any country k is driven by the country's economic scale.

The country variation in the outward FDI stocks can be used to control for such scale effects, using GDP size as a general proxy for overall scale effects.

The second identification challenge is to isolate the role of scale effects on a country's knowledge creation performance. We introduce the concepts of the intensive and extensive margin of knowledge creation to deal effectively with this second identification problem.

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. If the presence of knowledge-creating hotspots in countries is randomly distributed among and within countries, a larger country is likely to have a larger number of these hotspots within its borders compared to a small country, even when the rest of this large country is just middle-of-the-road or relatively backward in terms of developing new knowledge.²⁶ This is the extensive margin of knowledge creation. The scale effects are important, also for the knowledge-capital model of outward FDI.

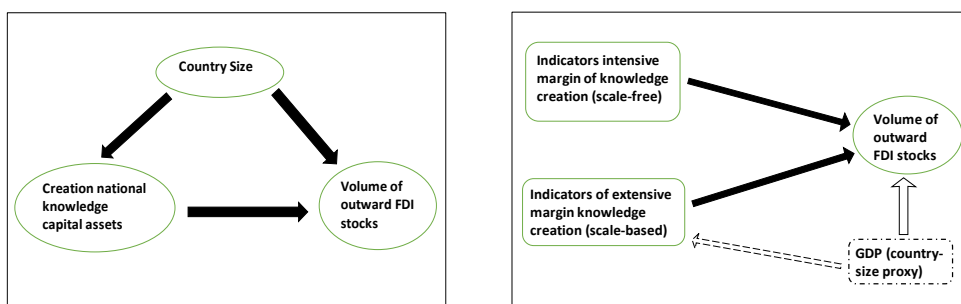
For the intensive margin of knowledge creation we develop scale-free indicators that always measure aspects of knowledge creation per unit of domestic activity.²⁷ The intensive-margin indicators will be normalized by a relevant activity aggregate like total employment, gross domestic product, or total exports. Figure 1 depicts the identification strategy graphically.

<Figure 1 about here >

²⁶ Storper *et al.* , 2019; Crescenzi *et al.* , 2014.

²⁷ In terms of equation 5 it means that we deal with scale effects embodied in the empirical indicators for β_i , φ_i , ψ_i , and ε_{it} (public knowledge system), and similarly for the indicators related to firm-related knowledge aggregates ($\sum_s \alpha_{ist}$, $\sum_s \omega_{ist}$, $\sum_s \varepsilon_{ist}$).

Figure 1 Identifying the roles of knowledge assets and economic scale



The indicators for the extensive margin of knowledge creation are deliberately scale-based. We take the log of scale-dependent measures of knowledge creation to avoid heteroscedasticity effects.

To test the model predictions 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. The empirical indicators measure different, but sometimes partially overlapping elements of a country's knowledge system. Because substantial correlation between several KC indicators of a country may be expected, 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:²⁸

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

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

²⁸ E.g. Agresti (2010). *Tau-b* can be applied if the underlying scale of both ranked variables has the same number of possible values. 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.

(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 i th group of ties for FDI, and u_j is the number of tied values in the j th group of ties for the ranked indicator that is compared with FDI.

Considerable effort was invested in setting up a database with indicators for the private and public knowledge-assets. As discussed in the introduction, it is almost impossible to find reliable and internationally comparable data on knowledge assets that are specific at the country-by-firm level. The best available data on knowledge-creating activities of firms are national aggregates like those on patenting activity, business expenditure on R&D, or investment in high-skilled personnel. Variables that measure aspects of public KC assets are more easy to find. Following equation (5), we searched for empirical indicators with respect to the following model elements: (a) re-activation of existing public knowledge (ε_i) via education system, universities, labor quality; (b) creating of new public knowledge (β_i) through public R&D, state-driven innovation, basic research and scientific output; (c) acquisition of new foreign knowledge (φ_{it}, ψ_{it}) via incoming FDI, imports of knowledge-intensive services and scientific exchange; (d) national productivity and knowledge-throughput efficiency (v_i) with indicators for labor productivity, internet connectivity, legal and governmental efficacy, freedom of movement, and the protection of intellectual property rights; (e) knowledge-creating efforts at firm-level ($\sum_s \alpha_{ist}$) like in-house R&D expenditures, financing of R&D by others, and attracting researchers; and (f) indirect evidence of absorption by firms of public knowledge inputs ($\sum_s \omega_{ist}$) via indicators like high-skilled employment, quality of commercial exports, research networks with public institutions, trade marks, and patenting activity.

The dataset for the comparison of national knowledge systems includes 77 empirical indicators that pertain to the input and output vector of

national knowledge systems (cf. Tables 1 and 2). For the intensive margin of knowledge creation we have 52 scale-corrected empirical indicators, subdivided per analytical component of national knowledge systems. They are shown in Table 3, and Annex I provides the data sources and further details per indicator.

<Table 3 about here>

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

Knowledge system component	Variable description	Variable name
Re-activation of existing public knowledge (a)	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 labor 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 (b)	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
	Govern. 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 labor force	ALLRES_LF
	Total R&D personnel (incl. staff) per thousand of domestic labor 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 (b)	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 (c)	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 (d)	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
	Labor productivity p. person employed, converted to 2020 PPP\$	LP_EMPL
	Labor 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
Knowledge-creation efforts by private business (e)	Total business expenditure on R&D (BERD) as % of current GDP (PPP\$)	BERD_GDP
	% of GERD that is performed by the business enterprise sector	BUX_GERD
	% of higher-education expend. 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
Absorbing of knowledge inputs by private firms (f)	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 knowl.-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
Note: *) Classified as elements of institutional and governance-related knowledge output.		

Similarly, Table 4 presents a list of 25 scale-based knowledge-creation variables with a count or value dimension. They allow to assess the impact of the extensive knowledge-creation margin. In order to compact the country scores we took the log of variables.

<Table 4 about here>

Table 4 Extensive margin of national knowledge creation: Scale-based indicators

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

The dependent variable is total outward stocks per country provided by annual UNCTAD statistics (UNCTAD, 2022). Bilateral FDI stock data tend to be more reliable, less volatile and more widely available than FDI flow data.²⁹ Moreover, FDI stocks have a cumulative character like knowledge capital. We use data on total FDI positions with immediate partner countries, irrespective of their financing through debt or equity. We regard the financing decision as a secondary problem that is subsumed under the FDI decision that is explained by the KC model. Current FDI data standards of IMF, OECD and Eurostat advance the concept of the 'ultimate beneficial owner' of foreign subsidiaries, as a response to tax-routing and tax-evasion constructions. However, such

²⁹ Cf. Wacker, 2016; Anderson *et al.*, 2019, 2020.

data refining is still only available for a small set of countries. In the robustness checks, we test the sensitivity of our results to the possible impact of tax routing and tax evasion.

The full data set covers the period 2000 to 2020, but with a substantial number of missing annual observations, especially for the small countries with a limited statistical apparatus. However, the annual variation for knowledge-system indicators tends to be quite small (Van Elk et al., 2019). This should not be surprising, because the knowledge system is based on long-term processes. It takes more than twenty years to educate engineers or university students with a masters degree. In order 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 mean for developed countries is sometimes based on more annual observations than holds for the small developing countries. The period means have been used to calculate the rank the performance of all countries per indicator, which is then compared with their rank in terms of outward FDI.

III. Results

The rank correlation test that applies the identification procedure of Figure 1 in the most stringent way, namely by using only variables that have been corrected for scale effects. First of all this applies to FDI; we use outward FDI stocks per unit of GDP (labelled 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 (minimum 36, maximum 171).³⁰ We also calculated the rank correlation also with alternative rank correlation measures (Spearman's *rho*, pairwise correlation). The latter outcomes converge with

³⁰ The zero hypothesis of a matching ordinal rank between OUTST_GDP and the intensive-margin indicator tends to a zero probability: $1/(110*109) \approx 0.000083$ with 110 observations.

the pattern of Kendall *tau-b* scores, but scores are often higher. The results for pair-wise correlation are at request available from the author.

The evidence in Table 5 provides clear support for the knowledge-capital model. The third model prediction says that indicators for national knowledge assets have a significant and positive rank correlation with outward FDI (here expressed per unit of GDP). This appears to be the case for no less than 36 out of 44 knowledge-asset indicators (81.8%). Prediction two follows the knowledge-capital model more closely, namely that private, firm-specific knowledge assets have a significant and positive impact on outward FDI. This is found to be correct for 9 out of 15 indicators (60%), substantially lower than the overall score for all national knowledge assets.

<Table 5 about here >

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

Knowledge system component	Indicator name	No. of compared country observations	Rank correlation, Kendall's <i>tau-b</i>	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	***	
Private business research and knowledge-creation efforts	BERD_GDP	42	0.352	0.001	***
	BUX_GERD	42	0.273	0.011	**
	BFIN_HERD	42	0.059	0.588	
	BRES_TOT	38	0.374	0.001	***
Absorbing of knowledge inputs by private business	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	
	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	**
<u>Overall count statistics with regard to model predictions:</u>					

1. Indicators for private, firm-specific knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	9 of 15 indicators (60.0%)
2. Indicators for public knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	27 of 29 indicators (93.1%)
3. Indicators for national knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	36 of 44 indicators (81.8%)
4. National knowledge-throughput efficiency has a positive and significant impact on a country's outward FDI.	8 of 8 indicators (100%)
Note: &) Coding of confidence levels: *** p<0.01, ** p<0.05, * p<0.10.	

Our extension to the KC model (Section I) implies that proprietary knowledge assets of firms with outward FDI depend on public knowledge-creation effort in their home countries. Model prediction two is therefore that outward FDI of a country should be positively correlated with public knowledge-creation efforts. This appears to be correct for 93% of the cases: 27 of 29 indicators for public knowledge-creation efforts indicators are statistically significant and have the right sign.

The fourth model prediction is that indicators for national knowledge-throughput efficiency (productivity, connectivity, openness for knowledge circulation) must have a positive impact on outward FDI of a country. The rank correlation for all indicators of knowledge-throughput efficiency confirm this prediction. Especially the national productivity and connectivity indicators appear to be very important. Micro-econometric studies have repeatedly concluded that multinational firms (active with outward FDI) have a higher productivity performance than firms that operate solely in the domestic market,³¹ so the direction of causation from national productivity averages to the FDI decision is not *a priori* clear. However, productivity can to some extent be interpreted as a proxy for national capabilities for process invention and organizational innovation. The high score of productivity indicators in the rank correlation may partly reflect that they also reveal the relative abundance of national knowledge assets with regard to process innovation.

³¹ Battisti *et al.*, 2021; Mataloni, 2011; Bernard *et al.*, 2013; Wagner, 2012; Girma *et al.*, 2005.

Our results show that the standard KC model has a substantial blind spot by overlooking the large role of the macroeconomic preconditions for the private knowledge-creation efforts of firms. The public knowledge-creation efforts and the presence of national knowledge-throughput efficiency appear to have a large role in explaining the outward FDI performance of countries. Our results indicate that private firms derive bounteous positive externalities from universities and (semi-)public institutions that freely create and disseminate knowledge assets.

Firms do contribute to financing of research projects in universities and other institutions of higher education, but the score of the BFIN_HERD indicator in Table 5 indicates that such finance has not a significant impact for explaining the international pattern of outward FDI.

< TABLE 6 about here >

In Table 6 we also test the impacts of the extensive-margin of knowledge creation, with 25 scale-based indicators. Extensive-margin indicators could have a significant impact on outward FDI that goes beyond the average de-scaling correction that was already built into the OUTST_GDP indicator for outward FDI. Table 6 shows that six of the nine indicators for private, firm-related knowledge-creation indicators (mostly related to patenting and trademarks) have a significant and positive impact on outward FDI. This finding could capture the fact that multinational firms are generally larger

Table 6 Rank correlation between outward FDI stocks per unit of GDP (OUTST_GDP) and each extensive-margin indicator, grouped by knowledge domain (full country sample)

Knowledge system component	Indicator name	No. of compared country observations	Rank correlation, Kendall's <i>tau-b</i>	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	
New public knowledge: output-related	PAT_R_S	129	0.241	0.000	***
	JRNART_S	160	0.274	0.000	***
Acquisition of foreign knowledge	PAT_NR_S	136	0.222	0.000	***
Private business research and knowledge-creation efforts	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	
Absorbing of knowledge inputs 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	***

Overall count statistics with regard to model predictions:

1. Indicators for private, firm-specific knowledge assets have a significant and positive rank correlation with outward FDI (per 6 of 9 indicators (66.7%)

2. Indicators for public knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP) 7 of 16 indicators (43.8%)
3. Indicators for national knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP) 13 of 25 indicators (52.0%)
-

Note: &) Coding of confidence levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

than average domestic firms. For public knowledge-creation we find that only 7 out of 17 scale-based indicators have a significant and positive impact on outward FDI. This mostly relates to universities and higher education, total R&D budgets, and scientific publication activities where scale matters. The findings on the impacts of scale effects are plausible and strengthen the overall picture that emerged from Table 5.

IV. Robustness tests

The rest of the paper investigates the stability and robustness of the findings so far. The first test checks whether the results are driven by fiscal, tax-routing practices of international firms. If this is the case, then it should make a difference when we remove all countries with well-established reputations for tax-evasion policies or for helping firms with tax-routing constructions from our dataset.³² A simple tool to identify most of such countries is to look at the ratio of incoming or outgoing FDI stocks over total domestic firm-related investment stocks, calculated as total investment minus government investment and housing investment in national accounts.³³ In total, we identified 18 countries and geographical entities: Netherlands Antilles, American Samoa, Bahamas, Bermuda, Switzerland, Cayman Islands, Cyprus, Iceland, Liberia,

³² This can be done by offering excessively low tax rates, or by facilitating tax-sheltering by allowing foreign investors to use their system of bilateral tax treaties.

³³ The median of this ratio for inward FDI stocks for 205 countries in the period 2005-2019 was 0.177 and for outward FDI stocks it was 0.146. Countries below the median level can be regarded as tax neutral. This still leaves a substantial grey zone with countries that apparently have some form of tax-sheltering policies. We concentrated on countries that are in the top decile of the distribution. For the inward FDI ratio the cut-off level was 1.68, and for the corresponding outward FDI ratio it was 1.56. Further, by adding weights for the size of domestic firm-related investment, one may also identify larger tax-sheltering countries like Netherlands, Switzerland or Ireland that themselves may easily attract substantial 'real' (not tax-related) FDI stocks.

Luxembourg, Marshall Islands, Malta, Mauritius, The Netherlands, Panama, Seychelles, British Virgin Islands, and US Virgin Islands. For some of these countries no data were available on outward FDI data or knowledge-creation indicators. By removing these countries from the full country sample, we also 'shock' the country rankings for FDI and knowledge-system indicators. For the countries have data on outward FDI data and knowledge-creation indicators, this test implies that the average number of country observations per indicator falls.³⁴ The result of this robustness check was very small. The full table with the results is not interesting enough for the main text, but Annex Table AIII.1 makes it possible to peruse the results in more detail. The summary statistics that feed back to the four model predictions, and can be compared with the statistics at the bottom of Table 5 are, respectively, 67% (was 60%), 86% (was 93%), 80% (was 82%), and 100% (was 100%). So, it is fair to say that the results of Table 5 remain fully standing.

The next set of robustness tests uses the total value of outward FDI stocks for each country rather than OUTST_GDP (ratio of outward FDI stocks over GDP). The difference with the test in Section III is that we drop the scale-correction (data normalization) for the FDI variable. Countries are ranked by their mean annual outward FDI stocks in the period 2000-2020, and this ranking is compared with the set of indicators of each country's knowledge system. The indicators for the extensive and extensive margin of knowledge creation remain unchanged. To compensate for dropping the normalization of FDI, we add the rank correlation between the knowledge indicators and national GDP as a control variable. This allows to check whether a particular indicator correlates stronger with outward FDI than with domestic GDP. Table 7 presents the rank correlation results with outward FDI stocks for the 52 intensive-margin indicators using the full country sample. We discuss the results by knowledge domain.

< TABLE 7 about here >

³⁴ 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).

Table 7 Rank correlation between total outward FDI and intensive-margin indicators, abbreviated results ^{§)} (full country sample)

Model predictions	Overall count statistics ^{§)}
1. Indicators for private, firm-specific knowledge assets have a significant and positive rank correlation with outward FDI	11 of 15 indicators (73.3%)
2. Indicators for public knowledge assets have a significant and positive rank correlation with outward FDI	26 of 29 indicators (89.7%)
3. Indicators for national knowledge assets have a significant and positive rank correlation with outward FDI	37 of 44 indicators (84.1%)
4. National knowledge-throughput efficiency has a positive and significant impact on a country's outward FDI.	8 of 8 indicators (100%)
5. The positive and significant correlation of Intensive-margin indicators with outward FDI is stronger than their correlation with GDP (prediction 3)	41 of 52 indicators (79 %)

Note: ^{§)} The detailed rank correlation scores per indicator and per knowledge-system sub-domain can be found in the Online Annex, Table AIII.2. ^{§)} The score reflects the number of rank correlation indicators (Kendall *tau-b*) that comply with the condition in the first column, and (in brackets) their share in the total number of indicators.

Most indicators for private business knowledge-creation efforts are positively correlated with outward FDI. This did not hold for BFIN_HERD (percentage of higher-education expenditures on R&D that is financed by the business sector). The average tau-b score of the other three business indicators is 0.356. The 23 indicators for public knowledge creation and reactivation are in most cases significant and positively correlated with outward FDI. In eleven cases, the tau-b for these indicators are higher than the 0.356 average for the three business-related indicators. A few negative results are remarkable, but we do not delve into speculation about the interpretation of these. The FEM_RESR indicator (Women as % of total researchers) has a significantly negative correlation with outward FDI. And GVE_XGDP (Expenditure on in-house governmental R&D) appears not to have any significant impact on outward FDI. Indicators for national productivity and knowledge-throughput efficiency appear to have a strong

positive correlation with outward FDI, with an average *tau-b* of 0.392. The last category of intensive-margin indicators measures how firms use knowledge-creation inputs as proprietary assets. Most items appear to be strongly correlated with outward FDI, but this does not hold for trade-mark registrations.

Table 7 also reports the count results in terms of the four model predictions. They are quite similar to those in Table 5, which shows that the pattern is robust to another test specification. The last column of Table 7 gives also the correlation of the intensive-margin indicators with the home country's GDP. As was to be expected, many indicators are significantly and positively correlated with GDP. This shows the relevance of the earlier de-scaling operation. However, for 41 out of 52 indicators, their positive rank correlation with outward FDI is stronger than their rank correlation with domestic GDP. This result supports the third model prediction of Section I.

Again we test whether the results are perhaps caused by other drivers of outward FDI patterns (like tax routing motives) or by the incidental composition of the country sample.³⁵ Three tests are done to shake-up the country sample. 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 a number of small countries and island states, which had erratic annual patterns in reported FDI stocks. The reduction of the sample to countries with all-time FDI lowers the number of compared country observations per indicator to an average of 77 (was 106 in Table 7), with the minimum and maximum being, respectively, 34 (was 36) and 126 (was 209). The second test 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. Effectively, this second test implies that the average number of country observations per indicator falls to 98. The third test is the toughest one, it combines the preceding two filtering criteria. The average number of country

³⁵ Some indicators have less than fifty country observations (in particular some OECD-derived indicators).

observations per indicator drops to 71. Note that this third test is arbitrary, because the first country filter (only all-time-FDI countries) is not needed for achieving reliable outcomes.

< TABLE 8 about here >

Table 8 Comparing rank correlation between total outward FDI and intensive-margin indicators for four different country samples

Summary statistics in terms of four model predictions	Full country sample (Table 7) (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 (cases, %)
1. Indicators for private, firm-specific knowledge assets have a significant and positive rank correlation with outward FDI	73%	67%	73%	73%
2. Indicators for public knowledge assets have a significant and positive rank correlation with outward FDI	90%	90%	86%	86%
3. Indicators for national knowledge assets have a significant and positive rank correlation with outward FDI	84%	82%	82%	82%
4. National knowledge-throughput efficiency has a positive and significant impact on a country's 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%

Note: The count statistics are based on the number (and percentage) of indicators for which the rank-correlation results comply with the condition that is mentioned in the left-most column. Full results are given in Online Annex Tables AIII.2-3.

Table 8 summarizes the results of the three sample-shocking tests with reference to the four model predictions. The differences are small, so the results are stable across the four country samples. The share of the

intensive-margin indicators for private and public knowledge-creation that have a significant and positive rank correlation with outward FDI is steady between 80-90%. The share of indicators that are correlated stronger with outward FDI than with domestic GDP remains in the 75-81% range. The share of the intensive-margin indicators for private and public knowledge-creation that have a significant and positive rank correlation with outward FDI is steady between 82% and 90%. The share of indicators that are correlated stronger with outward FDI than with domestic GDP remains in the 75-79% range.³⁶

V. The knowledge-capital model and inward FDI

The KC model explains that firm-level separable knowledge assets are important for outward FDI, but it does not say anything about inward FDI.³⁷ A standard assumption in the literature is that market scale, represented by GDP, is the prime driver of inward FDI. Traditional gravity models of FDI mostly confirm this.³⁸ But what about the role of national knowledge assets for inward FDI stocks?

At least six elements of the host country's knowledge system could have a positive impact on inward FDI stocks. A foreign multinational entering the country often needs local complementary skills (education) and knowledge of employees, so it needs at least some public knowledge assets (G_{spit}), depending on industry and conditional on the type of investment (horizontal, vertical, export platform, global value chain). Moreover, to safeguard the firm's proprietary knowledge assets (G_{sit}) it is necessary that the host country has an effective system for the protection of intellectual property rights, like patents and trademarks. The same holds for its need for a legal environment and enforcement of property rights that is not biased against foreign firms. The

³⁶ With regard to the extensive-margin indicators, Tables AIII.2 and AIII.3 in the Online Annex show that the rank correlation results are in all tests comparable with those presented in Table 6. The *tau-b* score per indicator is quite stable between the tests.

³⁷ Cf. Markusen, 2002: Ch.7; Kose *et al.*, 2009.

³⁸ Cf. Tanaka, 2009; Kleinert and Toubal, 2010; Blonigen and Piger, 2014. In more recent structural gravity models of FDI (like Anderson *et al.*, 2019; Kox and Rojas, 2020), the time-variant GDP impact on inward FDI is fully absorbed in the set of estimation dummies (origin-time, host-time).

introduction of the foreign firm's proprietary knowledge assets (G_{sit}) may need occasional assistance of its headquarter employees, so freedom of travel by foreigner personnel is important. Also, the expected profitability of the foreign subsidiary increases by a higher local productivity and a good connectivity infrastructure in the host country. Finally, the non-excludability of public knowledge creation may attract "listening post" subsidiaries of foreign multinationals that are attuned to absorbing the free knowledge externalities created by a country's public knowledge sector. All of the aforementioned influences on inward FDI stocks could be captured by our indicator set.

At a more general level, our set of indicators can also quantify the role of a potential knowledge gap between the FDI origin country i and the FDI host country j . A real bilateral knowledge gap, corrected for GDP size, can be calculated from our model for every possible country pair:³⁹

$$(6) \quad \Delta M_{ij}^* = \frac{1}{Y_j} \left[\frac{M_i}{Y_i/Y_j} - M_j \right] \quad \forall i, j$$

The ex ante effect of a positive knowledge gap ($\Delta M_{ij}^* > 0$) is to increase the probability that host country j has active policies in place to attract and facilitate inward FDI from country i . Such policies are represented by M_{fRit} and quantified by the associated GDP-weight φ_{it} in Table 1.⁴⁰ Current international statistics do not yet allow to calculate and aggregate the bilateral quantity ΔM_{ij}^* , but we should keep in mind that this mechanism related to national knowledge-capital may co-determine the country pattern of inward FDI.

³⁹ Earlier FDI gravity tests (cf. Blonigen and Piger, 2014) often used the bilateral GDP gap between two countries to explain inward FDI, but what they actually estimated was probably the effect of a mix of the scale-corrected bilateral knowledge gap ΔM_{ij}^* and the bilateral GDP gap strictu sensu.

⁴⁰ Using equation 6 and replacing aggregate M by V (for each of the extensive-margin indicators in Table 4) one could calculate a vector containing rough approximations of the knowledge gap at indicator level, but without GDP weights that are necessary for aggregation. The intensive-margin indicators can be used to fill such a vector without eq. 6, via simple subtraction.

We expect that national knowledge creation has a significant and positive impact on inward FDI, but smaller than its impact on outward FDI. We therefore test two additional, falsifiable predictions:

5. Scale-free (intensive-margin) and scale-based (extensive-margin) indicators of domestic KC creation have a stronger ordinal correlation with outward FDI than with inward FDI.
6. The correlation with of scale-free (intensive-margin) KC indicators with inward FDI is stronger than the correlation with GDP.

The fifth prediction implies that national KC assets have a separate role from market size. The test procedure remains the same. Data on total inward FDI stocks per country are also drawn from annual UNCTAD statistics (UNCTAD, 2022). Table 9 provides the summary results for the two most important country samples. The detailed results per indicator can be perused in the Online Annex (Annex Tables III.2 - III.5).

<Table 9 about here>

Domestic KC elements in the host country appear to have a significant positive role for inward FDI stocks, apart from market size considerations. This is new, because the original KC model does not account for this effect. The evidence is further that 65%-75% of indicators correlate stronger with outward FDI stocks than with inward FDI stocks, consistent with prediction 5. This holds for scale-free and scale-based indicators, and for both country samples. Prediction 6 appears to be correct for the intensive-margin indicators, and we consider this as indirect evidence in support of the KC model of FDI. Prediction 6 did not hold for the extensive-margin indicators. The latter correlate stronger with GDP, representing market size.

VI. Summary and conclusions

The knowledge-capital model of FDI by Markusen, Maskus, McGrattan and Prescott provides a plausible theory for explaining international patterns of bilateral FDI stocks. Its basic tenet is that firms my own proprietary knowledge

Table 9 Correlation of knowledge-creation indicators with inward and outward FDI stocks, and with GDP (count statistics, by country sample)

	Full country sample (% of cases)	Full country sample, minus countries with tax evasion / tax- sheltering policies (% of cases)
Intensive-margin indicators (52)		
5. Rank correlation of the indicators with outward FDI is stronger than their rank correlation with inward FDI	67%	65%
6. Rank correlation of the indicators with inward FDI is stronger than their rank correlation with GDP	69%	63%
Extensive-margin indicators (25)		
5. Rank correlation of the indicators with outward FDI is stronger than their rank correlation with inward FDI	71 %	75 %
6. Rank correlation of the indicators with inward FDI is stronger than their rank correlation with GDP	11%	14%

Note: The count statistics are based on the number (and percentage) of indicators for which the rank-correlation are positive and statistically significant, and for which the results comply with the condition that is mentioned in the left-most column. Full results are given in the Online Annex, Tables III.2 - III.5

assets or technology capital that are not tied to a home-country location and that are non-rival in their use. They constitute a source of firm-level scale effects, because their use in a foreign subsidiary increases the returns to these assets. If separable and non-rival knowledge capital forms the prime driver of outward FDI, one would expect that countries with high outward FDI have a relative abundance of such proprietary knowledge assets. So far, there has not been a convincing empirical test of this prediction.⁴¹ Our paper designs and applies a new way to investigate this matter, focusing on the abundance of public knowledge assets that are encapsulated in the proprietary knowledge assets of firms. First we complemented the KC model with a new module that formalizes this encapsulation process and that allowed us to derive testable

⁴¹ Davies and Markusen (2021): "*The importance of intangible assets to understanding multinationals is acknowledged but remains a conceptual and theoretical curiosity due to the difficulties in observing and measuring the existence and contribution of these assets*".

predictions from it. The test requires one additional step: correcting for the impact that a country's economic mass has on both the scale of domestic knowledge-creation activities and on the magnitude of outward FDI. For that purpose we introduced the distinction between the intensive and the extensive margin of knowledge creation. All indicators for the intensive margin of national knowledge-creation activities are de-scaled, i.e. expressed per unit of economic activity. We created a database with almost 80 empirical indicators that quantify the most important aspects of national knowledge-creation efforts, covering 209 countries over the period 2000-2020. In this way, the wide country variation allows to identify the impact of each aspect of national knowledge creation for explaining outward FDI. We applied international rank correlation analysis to quantify the statistical significance of each indicator's impact. The findings appear robust to using different country samples and alternative specifications of the FDI variable.

The main results are as follows. Like many earlier gravity-based studies, we established that scale effects of national economies have a significant and positive impact on outward FDI stocks. New however, is our assessment that scale-free indicators for a country's knowledge-creation efforts strongly correlate with its outward FDI stocks. More specifically, we find that the impact of public knowledge-creation indicators is often stronger than that of indicators for business-specific knowledge-creation efforts.

Overall, our results do not falsify the predictions of the standard KC model as formulated by Markusen, McGrattan and others. The essentially microeconomic perspective of these authors stresses that firms incur fixed costs for their knowledge efforts, which generates proprietary knowledge assets that help them to set up foreign FDI. This is OK and we find support for such a conclusion. However, the KC model has a substantial blind spot by overlooking the large role of domestic knowledge-system preconditions for the private knowledge-creation efforts of firms. The public knowledge-creation efforts and national knowledge-throughput efficiency appear to have

a large role in explaining the outward FDI performance of countries. Our results suggest that private firms derive bounteous positive externalities from universities and (semi-) public institutions that freely create and disseminate knowledge assets.

Though the KC model of FDI hardly says anything about inward FDI, we checked as a robustness test whether domestic knowledge creation efforts perhaps an equally positive impact on inward FDI. We found that a wide majority of indicators of knowledge-creation indicators correlates stronger with outward FDI stocks than with inward FDI stocks. This result indirectly confirms the validity of the KC of FDI. We also found that inward FDI stocks in a country are significantly and positively correlated with a number of scale-free indicators for national knowledge creation activities. This effect probably differs by industry and by type of FDI, a subject that is open for further investigation.

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Annex Table 1 Description of national knowledge-capital variables

Indicator	Description	Source + codename in original source
Intensive knowledge-creation margin		
AEDU_F	Female with advanced education, as % of female working-age population	WDI (SL_TLF_ADV_N_FEZS)
AEDU_M	Male with advanced education, as % of male working-age population	WDI (SL_TLF_ADV_N_MAZS)
LQ_CONTR	Contribution of labor 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_TECH_RDP6)
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 labor force	MSTI (TP_RSXLF)
RDPERS_LF	Total R&D personnel (incl. staff) per thousand of domestic labor 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 (protprop)
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 knowl.-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	Labor productivity p. person employed, converted to 2020 PPP\$	TED (LP_eksL)
LP_HOUR	Labor 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 knowl.-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)
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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 econ. 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: World Investment Report 2021. WDI: World Development Indicators (World Bank). WIPO: The Global Innovation Index 2020 (Dutta *et al.* 2020)

ANNEX II TIME DYNAMICS OF NATIONAL KNOWLEDGE STOCKS

Proof of Proposition 1

If behavioral 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:

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

From Table 1 we further have:

$$(A2) \quad M_{piit} = v_i \beta_i Y_{it} \quad (A3) \quad M_{frit} = v_i \varphi_i Y_{it} \quad (A4) \quad M_{pRit} = v_i \psi_i Y_{it}$$

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

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

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:

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

Because of (A5) that gives:

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

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:

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

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:

$$(A10) \quad M_{pit} = v_i (\beta_i + \varphi_i + \psi_i) \cdot [1 + \varepsilon_i (1 - \delta_i) X_{Y,t}] \cdot Y_{it} \quad \text{QED} \blacksquare$$

Proof of Proposition 2

If behavioral parameters described in Table 2 (α_{is} , ε_{is} , ω_{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} :

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

From Table 2 we further have:

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

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

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

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

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

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

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:⁴²

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

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:

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

After some substitutions, this becomes:

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

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:

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

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:⁴³

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

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

⁴² Because $M_{pi,t-N-1}$ is an independent process, we assume that $M_{pi,t-N-1}$ does already exist;

⁴³ Note that the structure is the same as (A10) in the proof of Proposition 1.

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

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 ■

FOR ONLINE PUBLICATION

ONLINE ANNEX : DETAILED RANK CORRELATION RESULTS

Table AIII.1 Summary results for the rank correlation between outward FDI stocks per unit of GDP (OUTST_GDP) and intensive-margin indicators, after removing countries with tax-evasion and tax-sheltering policies from the sample ^{%)}

Knowledge system component	Indicator name	No. of compared country observations	Rank correlation, Kendall's <i>tau-b</i>	Prob> z	Confidence code &)
(Re-)activation of existing public knowledge	AEDU_F	136	0.161	0.006	***
	AEDU_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	**

Overall count statistics with regard to model predictions:

1. Indicators for private, firm-specific knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	10 of 15 indicators (66.7%)
2. Indicators for public knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	25 of 29 indicators (86.2%)
3. Indicators for national knowledge assets have a significant and positive rank correlation with outward FDI (per unit of GDP)	35 of 44 indicators (79.5%)
4. National knowledge-throughput efficiency has a positive and significant impact on a country's outward FDI.	8 of 8 indicators (100%)

Note: %) In total, we dropped 18 countries and geographical entities from the full country sample (cf. Section IV in main text for criterion and details). &) Coding of confidence levels: *** p<0.01, ** p<0.05, * p<0.10.

Table AIII.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 AIII.3 Rank correlation of extensive-margin knowledge-capital indicators with total FDI stock (outward and inward) 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	
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 AIII.4 Rank correlation of intensive-margin knowledge-capital indicators with total FDI stock (outward and inward) and with GDP, 2000-2020 period, full country sample, but 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 AIII.5 Rank correlation of extensive-margin knowledge-capital 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 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	
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***