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Cross-border technology investments in recessions

Juliana Yu SUN
Singapore Management University, YUSUN@smu.edu.sg

Huanhuan ZHENG

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Juliana Yu Sun* Huanhuan Zheng†

Abstract

Utilizing industry-level foreign direct investment (FDI) from 72 source markets to 122 destination markets between 2003 to 2018, we evaluate the sensitivity of technology FDI to economic recessions. We find that research and development (R&D) intensive FDI drops when the destination market is in recession and the source market is in a normal state, and recovers to the pre-recession levels when both destination and source markets are in recession. The result is particularly pronounced in deep and long recessions, during the propagation stage of recessions, and in destination markets with stronger intellectual property protection, looser FDI regulation, and higher financial development. These recession impacts are limited to R&D intensive FDI between advanced markets: there is no evidence that R&D intensive FDI from or to emerging markets respond to either destination or source market recessions.

Keywords: Technology, R&D, Recession, FDI, Multinational Corporations

JEL: F21, F23, F44, E32

*Juliana Yu Sun is from School of Economics, Singapore Management University, 90 Stamford Road, Singapore 178903. Email: yusun@smu.edu.sg.

†Huanhuan Zheng is from Lee Kuan Yew School of Public Policy, National University of Singapore, 469C Bukit Timah Road, Singapore 259772. Email: sppzhen@nus.edu.sg.

1 Introduction

How do multinational corporations (MNCs) allocate technology investments during recessions? Technology investments require considerable amounts of funds not only upon the establishment of new projects but also throughout the long process of research and development (R&D). When the economy is booming and business is flourishing, it is relatively easy to finance technology investments that take a long time horizon to generate returns. During the economic recessions when cash flows are scare, it is both difficult and costly to maintain large expenditures on R&D. Nonetheless, some visionary MNCs strive to sustain R&D even during recessions to boost their comparative advantage for the next boom. Foreign direct investment (FDI) by MNCs transfers technology and knowledge across borders. Whether MNCs expand or cut technology FDI during recessions has important implications for technology spillovers and economic recovery, which are crucial for economies that rely on FDI for growth. Yet how cross-border technology investments respond to recessions is still open for debate.

Investing in technology during recession is challenging and demanding, a litmus test for genuine industry leaders. In fact, firms generally reduce R&D investment during recessions (Barlevy 2007; Aghion et al. 2012; Fabrizio and Tsolmon 2014). Technology investment is highly risky as the probability of success is remarkably low. Even if the project is extraordinarily promising, it could fail if funds are not sustainable in any stage of development. During a recession, corporations typically freeze hiring or even fire employees to preserve cash flow and strengthen their balance sheets; while households, concerned about the risk of unemployment, generally reduce consumption and increase precautionary savings, which reduces aggregate demand. The deterioration of corporate balance sheets and aggregate demand during recessions further increases the risk of technology investment. Firms need both strong balance sheets and strategic foresight to invest in long-term projects that cannot generate immediate cash flows during a recession.

We are interested in cross-border technology investments by MNCs, which represent the most competitive firms (Helpman 2006) and account for the majority of world's R&D (UNCTAD 2005). Compared to their local peers in either destination or source markets, MNCs have higher capacity to invest in technology during recessions. While local firms face credit constraints in recessions, MNCs could utilize their revenues generated from markets that are booming to sustain R&D in the recession markets to boost its rank relative to competitors, which leads to acyclicality or countercyclicality in technology FDI. They also have greater flexibility and skills to diversify their risk during recessions. MNCs typically engage in vertical FDI in several markets to mitigate uncertainty (Aizenman 2003). It implies that, when a market is in recession, MNCs can switch the production or distribution to subsidiaries in other markets that are not in recession, which leads to the procyclicality of FDI. If this is the case, MNCs' investment decisions are not subject to the constraints and resources of a single market. It is not clear whether technology FDI is procyclical, acyclical or countercyclical.

Technology FDI could also be countercyclical if creative destruction is in force. Investing in technology during recessions is risky yet rewarding. Gulati, Nohria, and Wohlgezogen (2010) present anecdotal evidence that firms that invest comprehensively in R&D and cut operating costs during recessions have a higher probability of outperforming rivals in their industry after the economy recovers. Steenkamp and Fang (2011) and Amore (2015) show empirically that innovation in economic downturns creates higher impact and value. Intuitively, investing more in technology during a recession paves the way to produce innovative products which meet the rising demand as the market rebounds. Firms with new technology may exit the recession stronger, and potentially become the market leaders after the market recovers. When destination and source markets, or in an extreme case global markets, are in recession, it is difficult to do business anywhere. With falling investment efficiency, nonprofitable business will be cut or minimized to spare resources and budgets for core business to strengthen its advantage. To cope with the difficult business environment, some firms may strategically switch investment to technology to boost future productivity while others may downsize or even retrieve their investments.

Utilizing the variations in bilateral FDI flows among more than 100 markets across 28 manufacturing industries with different R&D intensities, we explore the response of technology FDI to economic recessions. The key measure of technology is R&D intensity, which is calculated as the ratio of R&D spending to total capital expenditures. In such a context, technology FDI refers to FDI in R&D intensive industries. We compare the difference in FDI flows to R&D intensive and R&D light industries during recessions relative to that during normal times. The result shows that R&D intensive FDI drops when the destination market is in recession, and the source market is not. It is difficult for a market in recession to attract technology FDI while other markets are normal. We also find that R&D intensive FDI remains robust when only the source market is in recession. Interestingly, when both source and destination markets are in recession, R&D intensive FDI is found to bounce back to the pre-recession levels. The synchronization of recessions in both destination and source markets may dry out alternative investment opportunities and motivate firms to concentrate resources on R&D so as to strengthen their competitiveness when the economy recovers. These findings are robust for FDI between advanced markets (AM)[1]. We find no evidence that R&D intensive FDI responds to recessions in emerging markets (EM), be it a destination or a source market.

We further explore R&D intensive FDI in different types of recessions. Our findings indicate that R&D intensive FDI drops more aggressively when the destination market recession dips deeper and lasts longer. Deep and long recessions are associated with weak aggregate demand, which reduces the rents to innovation and therefore discourages R&D investments (Barlevy 2007). Also, when the destination recession is deep, R&D intensive FDI rises above the pre-recession levels if the source market switches from a normal state to a recession, which provides evidence for creative destruction. To test whether different stages of a recession have heterogeneous effects on technology FDI, we decompose each destination recession into shock and propagation stage, which refer respectively to the first and subsequent periods of a recession following Samaniego and Sun (2015). We find that R&D intensive FDI drops in different stages of a recession, but only recovers to pre-recession levels in the propagation stage. To see whether the impacts of recessions are driven by banking crises that constraint the credit, we examine the episodes of recession with and without banking crises, separately. It turns out that R&D intensive FDI drops during a recession even in the absence of banking crises. The result is consistent with the literature that FDI flows are resilient during financial crises (Alfaro and Chen 2012).

Interestingly, we find that the response of R&D intensive FDI to recessions varies with destination market characteristics. In particular, R&D intensive FDI drops more in markets with weaker institution, looser FDI regulation and higher financial development. The result is intuitive. Weak institution in intellectual property protection and rules of law reduces the rents accrued to innovators, and therefore discourages R&D investments. Loose FDI regulation facilitates the movements of FDI, which lowers the cost of downgrading R&D intensive FDI during recessions and expanding it when the timing is right. In addition, recessions are usually accompanied by contractions in credit and liquidity, which is particularly severe in markets with high financial development. A greater contraction in funding availability then leads to more shrinkage in R&D intensive FDI. In markets with

[1] AM and EM is defined according to IMF classification. The list of markets in each categories in our sample is presented in Appendix Table A2.

looser regulation and higher financial development, we also find that R&D intensive FDI restores to pre-recession levels when the source market is also in recession.

Our results that R&D intensive FDI falls during destination market recessions and rebounds when the source market falls into recession is driven by the intensive margin (size of FDI project) rather than the extensive margin (number of FDI projects). The key result remains robust when we replace FDI with the number of jobs created by FDI. However, the relation between R&D intensive FDI and recessions cannot be generalized to all aspects of technology. Turning to the intensity of applying existing technology, we find no evidence that FDI in industries that utilize more robots, information communication and technology (ICT), or intellectual property products responds to recessions in either destination or source markets. Similarly, no evidence is found when using alternative measures of technology related to total factor productivity (TFP), such as capital depreciation rate, intermediate intensity and labor intensity. However, we do find FDI in industries with higher investment-specific technological obsolescence, capital depreciation rate, asset fixity, and skilled labor, drops more aggressively during destination market recessions. The relation between technology FDI and recessions varies with technological characteristics, suggesting the necessasity to distinguish different aspects of technology when exploring its roles.

This paper contributes to the literature in three ways. First, we contribute to the literature on global allocation of R&D activities by documenting the role of business cycles. There is increasing research interest in how MNCs allocates R&D activities globally. Despite home-country bias (Belderbos, Leten, and Suzuki 2013), R&D activities have become increasingly globalized since 1990s (Branstetter, Glennon, and Jensen 2019). Berry (2019) argues that competition with industrial rivals motivate internationalization of R&D activities. Kumar (2001) documents that MNCs are attracted to larger markets with higher human capital and innovation capacity, which is confirmed by Shimizutani and Todo (2008) and Siedschlag et al. (2013). We contribute to this strand of literature by documenting the dynamic patterns of cross-border R&D investments during different stages of the business cycle, which also vary with different market characteristics.

Second, our work provides new evidence of creative destruction by showing that recessions can boost R&D intensive FDI under certain conditions. Recessions provide a good opportunity to invest in technology and upgrade productivity (Schumpeter 1942; Caballero and Hammour 1994; Aghion and Saint-Paul 1998; Canton and Uhlig 1999; Francois and Lloyd-Ellis 2003). Firms gain comparative advantage investing in technology in recession (Steenkamp and Fang 2011; Gulati, Nohria, and Wohlgezogen 2010; Amore 2015). Despite the benefits of technology investments in recessions, there is a lack of causal evidence that firms invest more in technology during recessions. We show that, conditional on destination market being in recession, R&D intensive FDI increases when the source market switches from a normal state to a recession. Moreover, when the destination market is in a deep recession, we find that R&D intensive FDI increases in response to the source market recession, which raises the FDI above pre-recession levels. Our result implies that deep and wide-spread recessions could be conditions for creative destruction.

Third, it adds international evidence on the cyclicality of R&D investments. Existing works on the cyclicality of technology investments typically focus on a single market. Geroski and Walters (1995), Aghion et al. (2012) and Fabrizio and Tsolmon (2014) document evidence of procyclical R&D investment in UK, France and US respectively. We generalize their findings to an international context. Controlling for a comprehensive list of fixed effects that include different combinations of destination market, source market, industry and time, we rule out the possibility that the result is driven by confounding variables, such as push factors, the external forces that drive FDI to the destination markets, i.e. global business cycles, and pull factors, the internal force that attracts FDI to the destination markets, i.e. domestic economic growth. We show that the procyclicality of technology FDI is limited to R&D intensive FDI from AM to AM only. This is consistent with the stylized fact that FDI activities among AM concentrates on R&D intensive goods (Antràs and Yeaple 2014). We find no evidence that R&D intensive FDI respond to recessions in EM. If there is reverse causality such that the drop in technology FDI leads to a recession in destination market, we should expect it to be more pronounced in EM, where FDI accounts for a larger proportion of investment and plays a more important role in economic growth. The lack of response by technology FDI to EM recessions suggests that the reverse causality is unlikely to drive our results.

The rest of the paper is organized as follows. Section 2 develops the hypothesis on the cyclicality of technology investment and discusses its relation with different types of recessions and country characteristics. Section 3 describes the data and methodology. Section 4 presents the empirical results. Section 5 concludes.

2 Theory and Hypothesis

2.1 Cyclicality of Technology Investment

During recessions when aggregate demand is weak, the opportunity costs of shifting resources from production to R&D is relatively low, which encourages investments in technology. A recession shakes up the economy, challenging the incumbents and rewards the innovators (Schumpeter 1942). Every time after a recession, some big names disappear while some innovative upstarts rise to reshape the industry. Creative destruction stimulates investment in technology that fosters long-term productivity growth (Caballero and Hammour 1994; Aghion and Saint-Paul 1998; Canton and Uhlig 1999). Investing in technology during recession also generates higher impact and value (Steenkamp and Fang 2011; Amore 2015), and increases the likelihood of surviving a recession stronger (Gulati, Nohria, and Wohlgezogen 2010).

While countercyclical investments in technology could be both socially optimal and strategically profitable, they may not be attainable for several reasons. First, firms are more likely to face credit constraints during recessions, which reduces their capacity to finance investment in technology. Aghion et al. (2012) show that R&D investments are procyclical for firms with credit constraints. A project, no matter how promising it is, may fail if it is short of funding in any stage of R&D. R&D takes a long time while the probability of success is low (Hart and Moore 1994). Firms are unlikely to push through R&D if they become credit-constraint during the recession. Given the long process and high risk of R&D, despite the reward of investing in a recession, firms that seek to balance risks and returns may invest in technology during booms when the likelihood of credit constraints is low.

Second, due to the externality of innovation, firms that invest in R&D have only a limited period to accrue benefits, before rival innovators improve and imitators copy the technology to drive down its value. Given the limited time available for the innovators to gain from their innovation, firms invest and commercialize their innovation during the economic booms when the demand is higher (Barlevy 2007). During the recession, the benefits accrued principally to the innovators are relatively limited, which discourages innovation. Geroski and Walters (1995) and Fabrizio and Tsolmon (2014) provide empirical evidence of procyclical R&D investment in UK and US, respectively. Although innovations generate long-term benefits, i.e. enhancing the probability of success and quality of products (Ilyina and Samaniego 2011), short-sighted firms tend to heavily weigh on their immediate benefits after the release of their innovation and before others seek to imitate or catch-up. Rapid obsolescence in technology and weaker intellectual property protection further increases the weights of short-term gain, which reduces R&D investment during recession (Fabrizio and Tsolmon 2014).

Third, commercializing technology in the recession may worsen unemployment, which is not desirable from policy makers' perspective. Technology substitutes for routine tasks, such as repetitive assembly, which can be done by following explicit rules (Autor, Levy, and Murnane 2003). The idea is supported by empirical evidence from the US (Autor, Levy, and Murnane 2003), UK (Goos and Manning 2007), and international markets (Michaels, Natraj, and Van Reenen 2014). Low-skilled workers, who are especially vulnerable during recessions, are hit hardest by technology adoption (Acemoglu and Restrepo 2019). Rising unemployment in a recession is a key policy challenge. Governments are not only concerned about economic growth but also social well-being, which may motivate them to downsize investments in technology or delay their commercialization to cope with recessions.

Existing studies on cyclicality of technology investment generally focus on a single market. It is unclear whether the countercyclical or procyclical forces dominate cross-border technology investments. MNCs that engage in cross-border investments are among the most competent (Helpman 2006). They are the dominant players in technology investment all over the world (UNCTAD 2005), which makes exploring how MNCs respond to recessions particularly interesting. On one hand, MNCs have relatively strong balance sheets and great vision that enables them to invest more countercyclically than their local peers. On the other hand, MNCs' investment is not limited to a single market. They have the flexibility and capacity to direct investments from markets that are in recession to those that are booming to better profit from business cycles. They can also perform R&D in one market and commercialize it in another to optimize technology gains in a similar spirit of Francois and Lloyd-Ellis (2003). We formalize Hypothesis 1 that MNCs invest less in technology during recessions and let the data tell us whether cross-border technology investments are countercyclical or procyclical. Technology FDI may not only respond to destinations market recessions but also source market recessions, which affect MNCs' funding capacity and comparative advantage. We take recessions in both markets into account in this study.

Hypothesis 1: Technology FDI falls during recessions.

2.2 Different Types of Recessions

The depth and duration of recession matter for investment decisions. Firms are particularly cautious of investing in technology when recession is long and deep, as they prioritize survivals over profitability. Many firms would not have survived should the recession dips deeper or lasts longer.

Deeper recessions are associated with tighter credit constraints that hit a larger proportion of firms. With more firms being credit-constraint and investing procyclically as predicted by Aghion et al. (2012), investment in technology is expected to decline further in deeper recessions;aggregate demand gets lower as the recession dips deeper. Given limited time interval of reaping innovation profit solely by the innovators, the theory of Barlevy (2007) implies that, the deeper the recession is, the greater the decline of technology investment. Deeper recessions may also enable firms without credit constraints to gain more market share and move up their rank in the industry faster.

Long recessions consume firms' internal surplus, erode their balance sheets and weaken their capacity to finance technology. In recent years, firms mostly finance their technology investment with internal cash flows and external equity issuance, which co-moves with business cycles (Brown, Fazzari, and Petersen 2009). The longer the recession is, the greater the supply and the weaker the demand for such equities, which drags down the equity valuation and reduces the funding available for technology investment. We therefore expect technology FDI to decline more when recessions last longer.

At the beginning of the recession, investors are typically uncertain whether the economy would rebound shortly or fall further. Few may be aware of the recession and act on it when it first starts. The initial shock can be propagated as the recession evolves. It is not until the recession manifests itself that most investors realize it and act accordingly. Economic growth is typically lower during the propagation stage of the recession (Samaniego and Sun 2015). Moreover, installation of new productive capital usually takes time, which leads to a lagged response of actual investment to business cycle (Kydland and Prescott 1982). We therefore expect a greater drop in technology FDI during the propagation stage, when the perception of the recession is relatively clear.

The response of technology FDI to different characteristics of recessions can be summarized in Hypothesis 2.

Hypothesis 2: Technology FDI falls more aggressively when recessions are deeper, longer, and clearer.

2.3 Institution, Regulation and Finance

In markets where intellectual property protection (IPP) is weaker in preventing infringement, innovators have less time to gain from their R&D before the imitation and obsolescence of its technology, technology investments are further discouraged during recessions (Fabrizio and Tsolmon 2014). According to Acemoglu, Johnson, and Robinson (2005), property rights institutions have a first-order effect on long-run economic growth and investment. We therefore expect technology FDI to decline more aggressively during recessions in markets with weaker IPP. Similarly, when the rules of law (ROL) are weaker in enforcing contract or punishment on infringement, technology investments are expected to be lower.

In markets with tighter market entry regulation, it would be relatively difficult to respond to business cycles by moving capital in and out. Facing high entry barrier, MNCs are likely to seize the opportunity to invest in the ideal location rather than wait until after the recession. In other words, technology FDI is expected to be more responsive to recessions when the destination market is more open.

Financial development promotes economic growth (King and Levine 1993). For a market that is more financially developed, it is relatively easy to raise funds for technology investments and therefore R&D industries grow disproportionately faster (Rajan and Zingales 1998; Ilyina and Samaniego 2011). The greater the degree of financial development, the higher the reliance of technology investment on external finance (Brown, Fazzari, and Petersen 2009). However, financial markets usually bear the brunt of recessions, which significantly undermines the funding availability of technology investments. We expect greater contractions of funding capacity in markets with higher financial development during a recession, which leads to a larger decline in technology investments. In contrast, with a shallower financial market, technology investments do not heavily rely on external finance anyway and are therefore expected to suffer less during recessions.

The response of technology FDI to different market characteristics can be formalized to Hypothesis 3.

Hypothesis 3: Technology FDI falls more during recessions in markets with weaker institution, looser regulation and higher financial development.

3 Data and Methodology

3.1 Data

3.1.1 Foreign Direct Investment

The data on cross-border greenfield investment projects are from fDi Markets of Financial times. fDi Markets collects data primarily from publicly available sources such as newswires, and supplemented with private market reports. Each observation is cross-referenced against multiple sources, with primary focus on direct company sources. The dataset reports the name and location of the investor, the destination, sector, size of the investment project, as well as the number of jobs created for a wide range of countries over the world. We map the variable "Subsector" in this dataset with 3-digit ISIC codes revision 2 so as to merge with the industry-level technology measures.

To understand the response of FDI to business cycles across different industries characterized with heterogeneous technology intensity, we aggregate investments by the destination and source markets in each year for each industry. We restrict the sample to the manufacturing sector with ISIC code ranging from 311 to 390 due to the data availability of industry-level technology measures. As core technology are innovated and applied most intensively in the manufacturing sector, FDI in the manufacturing sector meet our purpose of understanding technology related FDI. The final sample covers FDI flows from 72 source markets to 122 destination markets over 28 distinct manufacturing industries from 2003 to 2018. The quality of this greenfield FDI dataset is endorsed by various issues of UNCTAD's World Investment Report (see for example UNCTAD (2019)) and academic research such as Duanmu (2014) and Aizenman, Jinjarak, and Zheng (2018).

3.1.2 Technology

The core industry-level measure of technology is *R&D intensity*, the ratio of R&D expenditures to total capital expenditures. As R&D intensity is stable over time within the same sector and the rank of sectors in terms of R&D intensity is consistent across countries (Ilyina and Samaniego 2011), we follow Samaniego and Sun (2015) by using R&D intensity for each of the 28 manufacturing industries based on US firm-level information averaged over 1970-1999. In particular, R&D intensity is computed for each publicly traded US firm from the Compustat dataset in each year, and then average by industry over 1970-1999 to get the industry-level R&D intensity.

Technological progress is mainly driven by R&D activities. However, broader definition of technology can also be in the form of applying existing technology or improving total factor productivity (TFP). We use alternative measures that reflect other aspects of technology in the robustness checks. The first measure is the industry-level share of robots, calculated as the number of robots used in an industry as a share of the total robots used in the whole manufacturing sector. The data is from the International Federation of Robotics (IFR) 2019 reports, which covers the stock of industrial robots in operation from 2004 to 2018. The industry classification reported by IFR is different from ISIC revision 2, some industries are disaggregated, while others are not. We first sum the disaggregated industries to the ISIC level, and then for each sector, compute the median level of robot shares, calculated as the number of robots used in an industry as a share of the total robots used in the manufacturing sector. For the more aggregated industries in IFR, we sum the FDI according to match its classifications. We use the industry-level robots share in the US averaged over the period from 2004 to 2018 as the indicator for the depth of automation, again assuming it represents the standard industry characteristics and are constant across countries.

The second measure of technology application is information and communication technology (ICT). ICT intensity in each sector is calculated as the ratio of capital expenditure on ICT equipment to total assets. The third measure of technology is the intensity of intellectual property products, calculated as the ratio of capital expenditure on equipment related to intellectual property to total assets. Data on both ICT and intellectual property products are from EU KLEMS and are averaged over the period of 2008-2015. Because the capital input table EU KLEMS uses more aggregate classification with only 13 manufacturing industries, we map our FDI data to these broader industries when exploring these two aspects of technology.

We also follow Ilyina and Samaniego (2011), Samaniego and Sun (2015), and Samaniego and Sun (2020) to define technology as measures related to the total factor productivity growth. Technological characteristics are then captured by the features of capital, inputs and labor, which can be summarized as the follows:

1. *Investment-specific technical change* measures the rate of decline in the price of capital goods relative to the price of consumption and services. It is obtained from the BEA industry-level capital flow tables. This indicator reflects the extent to which technology embodied in capital goods becomes obsolete (Greenwood, Hercowitz, and Huffman 1997).

2. *Investment lumpiness* is defined as the average number of investment spikes per firm during a decade in a given industry, obtained from Compustat. A spike is defined as an annual capital expenditure exceeding 30% of the firm's stock of fixed assets (Doms and Dunne 1998). Samaniego (2010) suggests that investment lumpiness may indicate that a significant portion of a firm's capital cannot be transferred (alienated) without destroying its value, and hence, capital that tends to be adjusted in "lumps" is less suitable as collateral.

3. *Depreciation* is the industry rate of capital depreciation, computed with the BEA industry-level capital flow tables. Industries that use capital with high rates of depreciation might have more difficulty raising external funds during recessions since rapidly depreciating capital is less adequate as collateral.

4. *Asset fixity* is the ratio of fixed assets to total assets, obtained from Compustat. According to Hart and Moore (1994), non-fixed assets are intangible and thus may be less contractible or transferable, leading to a sensitivity to credit constraints.

5. *Intermediate intensity* is measured by the difference between gross output and value added, divided by gross output using UNIDO INDSTAT3. Industries that use intermediate inputs more intensively may be particularly sensitive to international trade conditions since most intermediate goods are traded internationally.

6. *Input specificity* is the relationship-specificity indicator, measured by the proportion of inputs that are not sold on an organized exchange or reference-priced in a trade publication, and therefore reflects the extent to which this good is dependent on specific relationship. The data is from Nunn (2007).

7. *Labor intensity* is total wages and salaries divided by the total value added, using UNIDO INDSTAT3. It measures the overall importance of labor in production.

8. *Skilled labor* measures the intensity of human capital using the average wage bill, i.e., the ratio of wages over total number of employees from UNIDO INDSTAT3.

9. *TFP growth* is the growth of the technology component from the Cobb-Douglas production function. It measures the efficiency of utilizing capital and labor. Manufacturing industry TFP growth data are computed with the NBER-CES Manufacturing Industry Database and use

Domar weights to aggregate these TFP growth from the SIC classification to the ISIC revision 2.

3.1.3 Recession

We follow Braun and Larrain (2005) in defining recessions as the periods from peak to trough. Using the Hodrick-Prescott filter, we identify trough as the year when the logarithmic annual real GDP falls below the trend by at least one standard deviation of the cyclical component of GDP.[2] The peak is identified as the nearest year that precedes the trough and features a detrended GDP that is higher than that of its previous and posterior years. The dummy variable R_d (R_s) equals to 1 if the destination (source) market is in a recession and 0 otherwise.[3] Annual real GDP is obtained from World Development Indicators (WDI).

We follow Samaniego and Sun (2015) to decompose the recession into (i) shock (the first year of a recession); and (ii) propagation (the years following a shock in a given recession). In addition, the magnitude and duration of recessions could also shape cross-border technology investment. We further define *deep* recessions as episodes of recessions in which the magnitude of trough, measured by the absolute value of the lowest detrended GDP during a recession, is at the deepest 50th percentile of all recessions. All the others are classified as moderate recessions. Further more, we classify recessions that last for more than 3 years, the longest 50th percentile of the recession duration, as *long* recessions and the rest as short recessions. To differentiate recessions from banking crises, we also classify the recession episodes according to whether they are accompanied with any banking crises as indicated by the Systemic Banking Crises Database of Laeven and Valencia (2012).

3.1.4 Macroeconomic Data

Macroeconomic characteristics could affect the MNCs' decisions regarding technology FDI. Proprietary technology transfers associated with FDI highly depends on IPP. We measure IPP with the property rights enforcement index developed by the Property Rights Alliance (2008). In a society where rules of law (ROL) is strong, the rules of society, the quality of contract enforcement, property

[2]The value of λ is 6.25, as recommended for annual data by Ravn and Uhlig (2002).

[3]The NBER definition of the contraction is similar to ours, except that it is defined using monthly data and that it excludes the peak, presumably under the assumption that the conditions that lead to the contraction do not coincide with the peak. We are using annual data out of necessity, so that in general the shock that leads to the contraction will coincide with the *year* in which the peak occurs. The alternative of dropping the year in which the peak occurs in general does not change our results concerning the interaction of contractions with technology, as discussed later.

rights and laws enhance the protection of the proprietary technology. We obtain ROL from Worldwide Governance Indicators (WGI). To understand how FDI regulation affects MNCs' investment decisions, we utilize the FDI restrictiveness index from OECD, which measures foreign equity limitations, screening or approval mechanism, restrictions on the employment of foreigners and operational restrictions. An alternative regulation measure is the minimum capital as percentage of income per capita to start a business from the World Bank's Doing Business data. It is an indicator of entry cost and reflects the restrictiveness of entry regulation in the destination market. Moreover, technology investments are sensitive to financial development (Rajan and Zingales 1998; Ilyina and Samaniego 2011), which determines funding availability. We follow King and Levine (1993) in measuring the financial development by the credit-to-GDP ratio as well as the stock-market-capitalization-to-GDP ratio from WDI.

It takes a long time to change these measures of market-level characteristics substantially. Given the relative stability of country rank along these variables, we average IPP over the available period over 2007–2013 and the other measures over 2003 – 2018. Based on the average measures, we classify the markets into two groups according to whether their measures are higher than the whole sample's median value.

3.2 Methodology

We study the differential effects of recessions across industries with varying levels of technology. The key measure of industry-level technology is R&D intensity ($R\&D_i$), the ratio of R&D expenditures to total capital expenditures. To capture a broad aspect of technology, we also employ industrial technology measure such as ICT, robots, and productivity related characteristics in the robustness checks. Focusing on R&D aspect of technology, we estimate the following model to evaluate the response of technology FDI to recessions:

$$\begin{aligned} log(1+FDI_{ds,i,t}) = {} & \beta_d \times R_{d,t} \times R\&D_i + \beta_s \times R_{s,t} \times R\&D_i \\ & + \beta_{ds} \times R_{d,t} \times R_{s,t} \times R\&D_i + \delta_{ds,t} + \delta_{ds,i} + \delta_{i,t} + \varepsilon_{ds,i,t} \end{aligned} \tag{1}$$

The variable $FDI_{ds,i,t}$ is the bilateral FDI to destination market d from source market s in industry i at period t. Following the convention in literature, we take the log of 1 plus $FDI_{ds,t}$ as the dependent variable to deal with zeros in the sample (see for example Aghion et al. 2012). The dummy variable $R_{d,t}$ ($R_{s,t}$) equals 1 during a destination (source) market recession and 0 otherwise. We refer to all non-recession periods as normal states to facilitate discussion. The comprehensive list of fixed effects absorbs most compounding factors. The destination-source-time fixed effects, $\delta_{ds,t}$, absorb the time-varying interaction between destination and source markets that affect bilateral FDI such as international relation, trade linkages, and change in comparative advantage in growth potential. Moreover, $\delta_{ds,t}$ captures the effects of push and pull factors that drive and attract FDI to destination d,[4] the dynamic motivations of cross-border investment by source market s, and the roles of global factors such as risk appetite and liquidity on FDI. The destination-source-industry fixed effects, $\delta_{ds,i}$, digests the industry-level variations in bilateral FDI. Industrial structure differs across markets, while a destination market may attract investment in some industries more than the others, i.e. due to easy access to inputs or economics of scale, a source market may concentrate in an industry to best utilize its comparative advantage. These variations which may affect FDI are controlled by $\delta_{ds,i}$. The industry-time fixed effects, $\delta_{i,t}$, takes care of the time variations or industrial cycles in each industry. Finally $\varepsilon_{ds,i,t}$ is the error term.

If $R\&D_i$ is a dummy variable that equals to 1 for R&D intensive industries, it is clear that Eq.(1) compares the FDI difference between R&D intensive and R&D light industries in recessions with that in normal times. The coefficient β_d represents the effect of the destination market's recession on R&D intensive FDI, conditional on the source market being in normal times. Similarly, the coefficient β_s reflects the effect of the source market recession on R&D intensive FDI, conditional on the destination market being in a normal state. The coefficient of the triple interaction term β_{ds} records the additional impact of destination (source) market recession on R&D intensive FDI when both markets fall into recessions, relative to the scenario when only the destination (source) market is in a recession. In other words, the impact of destination recession on R&D intensive FDI conditional on the source market being in recession is recorded by the sum of β_d and β_{ds}. Similarly, the effect of source market recession on R&D intensive FDI conditional on the destination market being in a recession is captured by the sum of β_s and β_{ds}. The sum of β_d, β_s and β_{ds} captures the response of R&D intensive FDI to the simultaneous recessions in destination and source markets.

When $R\&D_i$ is a continuous variable with a higher value corresponding to higher R&D intensity,

[4] Push factors refer to external forces that drive FDI to destination market such as global liquidity, source market monetary policy, etc. Pull factors are destination market-specific factors such as economic growth, market size, liberalization that attract FDI to the destination.

the interpretation of coefficients in Eq.(1) are similar. A negative and statistically significant estimated coefficient of β_d (β_s) suggests less FDI to more R&D intensive industry, that is, R&D intensive FDI falls during destination (source) market recessions. The difference is that the magnitude of the coefficients now measures the elasticity of FDI to the degree of technology intensity rather than the growth rate of FDI. To avoid the controversy on which sectors are $R\&D_i$ intensive and which are not, we focus on the continuous measures of technology. Similar specifications are adopted by Rajan and Zingales (1998), Ilyina and Samaniego (2011), and Samaniego and Sun (2015) to evaluate the roles of recessions and financial development on economic growth.

FDI to AM and EM differs significantly in their motivation and distribution across sectors. For example, FDI tends to target for technology, knowledge and market size in AM; but, they are attracted to cheap labor and high growth potential in EM. Similarly, FDI from AM and EM are driven by different forces. To enhance the comparability between the R&D intensive and R&D light FDI, we group the destination and source markets by AM and EM and evaluate them separately. From here onward, technology FDI refers to R&D intensive FDI unless otherwise specified. We turn to explore other aspects of technology in Section 4.3.2.

4 Empirical Analysis

We first present the baseline results in Section 4.1, where we see that technology FDI falls during destination recessions and re-bounces when source markets also enter recessions. After documenting the basic pattern, we perform heterogeneity analysis in Section 4.2 to understand how recession types, institution, regulation and financial development shape the relation between technology FDI and recessions. Section 4.3 checks the robustness of baseline results.

4.1 Baseline results

We explore the impacts of recessions on technology FDI by estimating Eq.(1), which compares the difference between R&D intensive and R&D light FDI in and out of recessions. The results are presented in Table 1. Column 1 shows that the coefficient of $R_d \times R\&D$ is negative and statistically significant, which means that R&D intensive FDI from AM to AM drops when the destination market is in recession and the source market is normal. Appendix Table A3 shows that the most and least

R&D intensive industries in our sample are Other Chemicals (ISIC code 352, R&D = 1.95) and Apparel (ISIC code 322, R&D = 0.02), respectively. The coefficient of $R_d \times R\&D$ in column 1 implies that, during a recession in the destination market and normalcy in the source market, FDI to Other Chemicals declines by 32% $(= -.165 \times (1.95 - 0.02))$ more than that to Apparel. The result is consistent with Barlevy (2007) and Fabrizio and Tsolmon (2014) that R&D investments fall during recessions. This is because recessions are accompanied with weaker demand, which reduces the reward of R&D and discourages investments in R&D intensive industries.

FDI from AM to AM does not seem to respond to source market recessions when the destination market is in normal times as the coefficient of $R_s \times R\&D$ is not statistically significant. Interestingly, the coefficient of the triple interaction term $R_d \times R_s \times R\&D$ is positive and statistically significant. It suggests that, compared to the scenario when either destination or source market is in recession, R&D intensive FDI increases when both destination and source markets are in recession. To better understand the result, we consider two scenarios. In the first scenario, only the source market is in recession such that $R_s = 1$ and $R_d = 0$. The coefficient of $R_s \times R\&D$ indicates that the impact of a source market recession on technology FDI in this scenario is -0.067, which is not statistically significant. In the second scenario, both destination and source markets are in recession such that $R_s = 1$ and $R_d = 1$. The impact of the source market recession on technology FDI in such a scenario is 0.141, which is calculated as the sum of the coefficients of $R_s \times R\&D$ (-0.067×0.154) and $R_d \times R_s \times R\&D$ (0.208×0.154). The impact difference of the source market recession on R&D intensive FDI between the second and first scenario is 0.208, which is statistically significant at the 5% level. It means that, FDI increases by additional 20.8% in response to a source market recession for every unit increase in R&D intensity, when the destination market switches from a normal state to a recession. More specifically, when a destination market turns into recession, in response to the source market recession, FDI to the most R&D intensive industry (Other Chemical) increases by an additional 40.1% $(= 20.8\% * (1.95 - 0.02))$ more than that to the least R&D intensive industry (Apparel). With a similar argument, we can show that, when the source market transitions from a normal state to a recession, FDI increases by an additional 20.8% to the destination market recession for every unit increment in R&D intensity.

We now turn to analyze the aggregate impact of destination and source market recessions on R&D intensive FDI respectively, conditional on simultaneous recessions and, in an extreme case, global recessions. The impact of the destination market recession on R&D intensive FDI, conditional on the source market being in recession, is 0.043,[5] which is not statistically significant. It indicates that, although R&D intensive FDI falls during a destination market recession, it recovers to pre-recession levels when the source market also falls into a recession. The impact of a source market recession on R&D intensive FDI conditional on the destination market being in recession is 0.141,[6] which is not statistically significant either. Recall that the coefficient of $R_s \times R\&D$ is also not statistically significant, our results suggest that R&D intensive FDI does not respond to the source market recession, regardless of the stage of business cycle in the destination market. The total response of R&D intensive FDI to simultaneous recessions in destination and source markets is 0.024,[7] which is economically small and statistically insignificant. It implies that R&D intensive FDI remains resilient during global recessions. To summarize, R&D intensive FDI from AM to AM drops during a destination market recession only when the source market is in a normal state, and recovers to pre-recession levels when the source market is also in a recession.

Columns 2 to 4 of Table 1 report estimation results for FDI from AM to EM, EM to AM, and EM to EM, respectively. For investments that involve EM, there is no evidence that R&D intensive FDI responds to the destination or (and) source market recessions. The impacts of recessions on technology FDI concentrate on AM, which is consistent with the stylized fact that FDI among AM are primarily on R&D intensive activities (Antràs and Yeaple 2014). However, the finding that R&D intensive FDI to EM is acyclical contradicts with Barlevy (2007) and Fabrizio and Tsolmon (2014), which focus on the US market. Such a deviation from literature can be driven by the dominance of vertical FDI in EM (Roy and Viaene 1998), which produces in EM, i.e. to utilize cheap labor or materials, and sells to international markets. There are greater uncertainties in EM than AM (Gavin and Hausmann 1998), which motivates MNCs to diversify production in several EM to mitigate risk (Aizenman 2003). Such arrangements may mute technology FDI's response to EM recessions. R&D intensive FDI from EM do not respond to recessions for at least two reasons. First, instead of seeking for profits, EM may invest for strategic purposes, i.e. acquiring some specific-technology, which is inelastic. Second, EM are relatively inexperienced in cross-border investments and may not be able to respond quickly to rising uncertainties in recessions.

[5] It is calculated as the sum of the coefficients of $R_d \times R\&D$ (-0.165) and $R_d \times R_s \times R\&D$ (0.208) as in column 1 of Table 1.

[6] It is calculated as the sum of the coefficients of $R_s \times R\&D$ (-0.067) and $R_d \times R_s \times R\&D$ (0.208) as in column 1 of Table 1.

[7] It is calculated as the sum of the coefficients of the three interaction terms.

Table 1: Technology FDI in recessions.
The dependent variable is $log(1+FDI_{ds,i,t})$, where $FDI_{ds,i,t}$ is the foreign direct investment (FDI) to destination market d from source market s in industry i at period t. The recession dummy variable R_d (R_s) equals to 1 during the destination (source) market recession and 0 otherwise. *R&D* is the industry-level R&D intensity, calculated as the ratio of R&D expenditure to the total capital expenditure. Columns 1 to 4 report the estimation results based on FDI from advanced markets (AM) to AM, AM to emerging markets (EM), EM to AM, and EM to EM, respectively. Source-destination-industry, source-destination-year, and industry-year fixed effects are included in all regressions. Heterogeneity robust standard error clustered by source-destination-industry is reported in the parenthesis. ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)
	AM to AM	AM to EM	EM to AM	EM to EM
$R_d \times$R&D	-0.165**	-0.034	-0.037	-0.141
	(0.072)	(0.093)	(0.222)	(0.235)
$R_s \times$R&D	-0.067	0.007	-0.042	0.102
	(0.060)	(0.061)	(0.202)	(0.338)
$R_d \times R_s \times$R&D	0.208**	0.043	-0.217	-0.019
	(0.103)	(0.125)	(0.433)	(0.540)
Constant	3.054***	3.538***	2.653***	3.474***
	(0.008)	(0.008)	(0.022)	(0.017)
Observations	18,970	13,745	1,911	1,684
R-squared	0.452	0.473	0.573	0.543

The heterogeneous response of R&D intensive FDI to recessions in AM and EM mitigate the concerns of reverse causality. FDI is more important for the economic growth in EM than AM. If our result is driven by FDI reducing the likelihood of recessions in destination markets, the coefficient of $R_d \times R\&D$ should be more negative for EM than for AM; however, we find the opposite. The insignificant response of R&D intensive FDI to EM recessions mitigates the concerns of such reverse causality. If more FDI leads to a higher likelihood of recessions in destination markets, our results can only be strengthened after addressing reverse causality. From here onward, we focus on R&D intensive FDI from AM to AM, which is more general and representative, to explore its response to recessions.

4.2 Heterogeneity Analysis

So far, we have documented that R&D intensive FDI from AM to AM falls during destination market recessions, but recovers to pre-recession levels when source markets also fall into recessions. In this section, we further explore the heterogeneous response of R&D intensive FDI to different types of recessions and market characteristics in destination markets.

4.2.1 Different Types of Recessions

Depth of Recessions Deep recessions hit the economy harder than moderate ones. The deeper the recession, the larger the number of firms that will suffer from credit constraints, the smaller the rents of R&D, and the lower the technology investments will be (Barlevy 2007; Aghion et al. 2012). To test whether the response of R&D intensive FDI varies with the depth of recessions, we evaluate the impacts of deep and moderate recessions on technology FDI separately. We classify episodes of recession with magnitudes of trough above the 50th percentile of all recessions in AM as deep recessions and the rest as moderate recessions.

We re-estimate Eq.(1) by replacing R_d with R_{d_a}, alternative definitions of recession specified in the first row (deep and moderate), while keeping the control group (observations during normal times) unchanged. The results are presented in Table 2. The dummy variable R_{d_a} in column 1 (2) equals to 1 during deep (moderate) recessions in destination markets and 0 during normal times.[8] Column 1 and 2 summarize the impacts of deep and moderate recessions on R&D intensive FDI separately. The coefficient of $R_{d_a} \times R\&D$ is negative in both columns, but only statistically significant at 10% during moderate recessions. The coefficient of the triple interaction term is positive and statistically significant at the 5% level in deep recessions (column 1) but not in moderate recessions (column 2). The baseline result that R&D intensive FDI rebounds when the source market falls into a recession is mainly driven by deep recessions.

Furthermore, the total impact of the source market recession on R&D intensive FDI, conditional on the destination market being in a deep recession, is positive and statistically significant at the 5% level. In particular, the source market recession increases the R&D intensive FDI by 26.3%, which is calculated as the sum of the coefficients of $R_s \times R\&D$ and $R_{d_a} \times R_s \times R\&D$. It suggests that a source market recession enhances R&D intensive FDI only when the destination market is in a deep recession. The result is consistent with the philosophical argument of Schumpeter (1942) and the theoretical prediction of Caballero and Hammour (1994), Aghion and Saint-Paul (1998), and Canton and Uhlig (1999) that recessions provide a good opportunity to invest in technology. Our result complements existing literature by showing that creative destruction exists under certain restricted conditions such as deep recessions.

[8] R_{d_a} has no value during episodes of moderate recessions in destination markets.

Duration of Recessions Some recessions last longer than the others and exert more profound influences on the economy. It is more difficult for firms to finance investments when facing a long-term instead of temporary recession. Long recessions exhaust existing resources accumulated during economic expansions, making it hard to raise funds both internally and externally. To test whether the duration of recessions shapes technology FDI, we decompose recessions into long and short recessions. We classify recession episodes that last longer than 3 years (the 50th percentile value in the duration of all recession episodes in AM) as long recessions, and the rest as short recessions.

We re-define the dummy variable R_{d_a} as 1 during a long recession in the destination market and 0 during a normal state, and then estimate Eq.(1) by replacing R_d with R_{d_a}. The results for the response of R&D intensive FDI to long and short recessions are presented in column 3 and 4 of Table 2, respectively. The coefficient of $R_{d_a} \times R\&D$ is negative and statistically significant in long recessions but not in short recessions. It suggests that the baseline result that R&D intensive FDI falls during destination market recessions is mainly driven by the long recession episodes. Comparing the coefficients of $R_{d_a} \times R_s \times R\&D$ in columns 3 and 4, we find little difference between long and short recessions in terms of their additional impacts on R&D intensive FDI when the source markets switches to recessions. To summarize, long recessions in destination markets reduce R&D intensive FDI but it is not the key as to why R&D intensive FDI re-bounces during simultaneous recessions in both destination and source markets.

Stages of Recessions While some investments bear the brunt of recession, others feel the pain only in the later stages once the recession manifests itself. Economic growth slows down further as the initial shock is propagated. Typically, only at the propagation stage of the recession does it become clear that the economy is in fact in recession. We follow Samaniego and Sun (2015) in decomposing a recession into two stages: (i) shock, the first period of the recession; and (ii) propagation, the recession periods after the shock. We then estimate Eq.(1) for the shock and propagation stages of recessions separately and report the results in columns 5 and 6 of Table 2. The coefficient of $R_{d_a} \times R\&D$ is negative and statistically significant at the 10% level in both the shock and propagation stages of recessions. The coefficient of the triple interaction term is positive and statistically significant only in the propagation stage. It suggests that, when the source market falls into a recession, the additional increment of R&D intensive FDI in response to the destination recession concentrates on the propagation stage. The sum of $R_{d_a} \times R\&D$ and $R_{d_a} \times R_s \times R\&D$ is 0.324, which is positive and statistically significant at the 5% level. It indicates that source market recession promotes R&D intensive FDI during the propagation stage of destination market recessions. Our finding supports creative destruction during the propagation stage of recessions.

Concurrence with Banking Crises Some recessions are accompanied by a banking crisis, which further tightens the credit constraints, especially when banks hoard liquidity to protect themselves from unexpected shocks. Hardy and Sever (2020) document evidence that financial crisis, in particular banking crisis, reduces the number of patents in industries with more credit constraints. To see whether the baseline results are driven by banking crises, we group the destination recessions into two categories, one with and one without banking crises and report the estimation results in columns 7 and 8 of Table 2. The coefficient of $R_{d_a} \times R\&D$ in column 8 is negative and statistically significant, which suggests that, even in the absence of banking crises, R&D intensive FDI falls in response to destination recessions. Although the coefficient of the triple interaction term is positive in both sub-samples, neither is statistically significant. It suggests that, unlike the depth of recessions, banking crises are not the fundamental reason that R&D intensive FDI bounces during simultaneous recessions in destination and source markets. Since our sample in this subsection is limited to AM whose banking crisis periods concentrate in 2008 and 2009, it is not surprising that most coefficients are not statistically significant in column 7 when recessions concur with banking crises in destination markets.

4.2.2 Institution, Regulation and Finance

Institution In this section, we explore whether the response of R&D intensive FDI to recessions varies with destination market characteristics . Strong intellectual property protection (IPP) increases rents for innovators, which is expected to encourage technology investment. We classify destination markets into two subgroups, strong and weak IPP, depending on whether their IPP is above or below the median value among all AM. Estimating Eq.(1) for each sub sample, we present the result in columns 1-2 of Table 3. We find that R&D intensive FDI drops during destination market recessions only for the sub-sample with weak IPP. It is consistent with Fabrizio and Tsolmon (2014) that weak IPP discourages technology investment. Replacing IPP with the alternative measure of institution, we find similar results. Strong rules of law (ROL) enforces contract or punishes infringement, which mitigates imitation and increases the interval during which innovators can reap profits from their innovation . We repeat the same exercise for ROL and show in columns 3-4 that R&D intensive

Table 2: Heterogeneity across different types of recessions.
The dependent variable is $log(1+FDI_{ds,i,t})$, where $FDI_{ds,i,t}$ is the foreign direct investment (FDI) to destination d from source s in industry i at period t. The dummy variable R_{d_a} takes the value of 1 during the particular type of recession specified in the top rows. The dummy variable R_s equals to 1 during the source market recession and 0 otherwise. *R&D* is the industry-level R&D intensity, calculated as the ratio of R&D expenditure to the total capital expenditure. The sample includes FDI between advance markets only. Source-destination-industry, source-destination-year, and industry-year fixed effects are included in all regressions. Heterogeneity robust standard error clustered by source-destination-industry is reported in the parenthesis. ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Depth of Recession		Duration of Recession		Stages of Recession		Concurrence with Banking Crisis	
R_{d_a}	Deep	Moderate	Long	Short	Shock	Propagation	Yes	No
R_{d_a}×R&D	-0.138	-0.232*	-0.187**	0.009	-0.215*	-0.154*	0.010	-0.192**
	(0.085)	(0.120)	(0.080)	(0.192)	(0.125)	(0.083)	(0.201)	(0.081)
R_s×R&D	-0.064	-0.069	-0.044	-0.094	-0.070	-0.036	-0.121	-0.036
	(0.076)	(0.114)	(0.072)	(0.128)	(0.087)	(0.082)	(0.180)	(0.068)
$R_{d_a} \times R_s$×R&D	0.327**	0.196	0.202*	0.216	0.050	0.360***	0.157	0.191
	(0.148)	(0.152)	(0.116)	(0.349)	(0.162)	(0.128)	(0.270)	(0.133)
Observations	16,345	15,882	17,640	13,914	14,876	16,957	2,207	14,586
R-squared	0.466	0.469	0.460	0.483	0.477	0.464	0.542	0.464

FDI drops more pronouncedly when ROL is weak. To summarize, weak institution depresses R&D intensive FDI during destination market recessions.

In terms of the coefficient of the triple interaction term, there is no evidence that it differs between strong and weak IPP (see columns 1 and 2), or strong and weak ROL (see columns 3 and 4). These results suggest that institution quality has little additional impact when both destination and source market are in recessions.

Regulation To understand the roles of FDI regulations, we classify destination markets into two sub-samples, tight and loose regulation, depending on whether their average FDI restrictiveness index is above or below the median value of all AM in the sample. The results in columns 5 and 6 of Table 3 suggest that only when the FDI regulations in the destination market is relatively loose would R&D intensive FDI drop during destination market recessions and bounce back when the source market enters into a recession. Tight regulation on FDI increases the costs of investment timing, which mutes the response of technology FDI to recession (see column 5). In column 6 for the sub-sample with loose regulation, the sum of the coefficients of $R_s \times R\&D$ and $R_d \times R_s \times R\&D$ is positive and statistically significant, suggesting that conditional on destination market in recession, source market recession boosts R&D intensive FDI in less regulated destination markets.

Measuring the strictness of regulation with market entry instead, we find similar evidence in columns 9-10. The results suggest that while loosely regulated markets are exposed to procyclical technology investment, they also attract R&D intensive FDI during simultaneous recessions in destination and source markets. It appears that the flexibility to invest in a market helps attract technology FDI during global recessions.

Financial Development To test whether financial development increases the sensitivity of R&D intensive FDI to recessions, we break destination markets into two sub-samples according to whether their financial development indicators are above or below the median value. We measure financial development with (i) credit-to-GDP ratio, and (ii) stock market capitalization as a ratio of GDP. The estimation results based on both indicators are fairly similar, as shown in columns 9-12 of Table 3. We find that the sub-sample with high financial development is driving the key result that R&D intensive FDI falls during destination market recessions and rebounds when source markets enter a recession. There is no evidence that R&D intensive FDI responds to recessions in the sub sample with low financial development.

Financial markets are volatile. Higher financial developments enjoy better access to capital in booming periods but also suffer a larger capital contraction when the market busts. All else held the same,, recession reduces the funding availability from markets with higher financial development more aggressively. Higher financial development thus exerts greater impact on R&D activities that depend highly on financial access for long-run growth (Ilyina and Samaniego 2011) .

4.3 Robustness Checks

4.3.1 Alternative Measures of FDI

To check the robustness of our main results to alternative measures of FDI, we replace FDI in Eq.(1) with (i) the average project size; (ii) the number of investment projects; (iii) the number of jobs created; and (iv) FDI normalized by destination market GDP. Similar to industry-level FDI used in the main context, all of these measures are aggregated by destination and source markets for each industry in each period. The estimation results are reported in columns 1 to 4 of Table 4, respectively. Columns 1 and 2 show that the average project size of R&D intensive FDI drops significantly during destination market recessions but not the number of R&D intensive FDI projects. It suggests that the baseline results that R&D intensive FDI drops during destination market recession is mainly driven by the intensive margin (size of project) rather than the extensive margin (number of projects).

Column 3 shows that the number of jobs created by R&D intensive FDI drops during destination market recessions and rebounds when source markets switch from normal times to recessions. The pattern is consistent with the value of R&D intensive FDI in the baseline results. In column 4, where the GDP-normalized FDI is the dependent variable, the coefficient of $R_d \times R\&D$ is negative but no longer statistically significant. It suggests that the drop of R&D intensive FDI documented in the baseline results is proportional to the decline in destination GDP. The coefficients of the triple interaction term remain positive and statistically significant in column 4, which suggests that R&D intensive FDI as a ratio of GDP increases when both destination and source markets are in recession. However, GDP is used to identify recession. Normalizing FDI by GDP is potentially endogenous, so we will be careful in its interpretation.

Table 3: Heterogeneity across institution, regulation and financial development.

The dependent variable is $log(1+FDI_{ds,i,t})$, where $FDI_{ds,i,t}$ is the foreign direct investment (FDI) to destination d from source s in industry i at period t. The recession dummy variable R_d (R_s) equals to 1 during the destination (source) market recession and 0 otherwise. *R&D* is the industry-level R&D intensity, calculated as the ratio of R&D expenditure to the total capital expenditure. The sample is divided into two subgroups depending on whether the destination market's average insitution quality, regulation strictiveness and financial development is above the sample median. The sample includes FDI between advance markets only. Source-destination-industry, source-destination-year, and industry-year fixed effects are included in all regressions. Heterogeneity robust standard error clustered by source-destination-industry is reported in the parenthesis. ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Institution				Regulation				Financial Development			
	Intellectual Property Protection		Rule of Law		FDI Restrictiveness		Market Entry		Credit/GDP		Market Capitalization/GDP	
	Strong	Weak	Strong	Weak	Tight	Loose	Tight	Loose	High	Low	High	Low
$R_d \times$R&D	0.002	-0.236**	0.028	-0.223**	-0.139	-0.159*	0.015	-0.320***	-0.272***	0.016	-0.374***	0.062
	(0.090)	(0.095)	(0.092)	(0.094)	(0.108)	(0.084)	(0.088)	(0.107)	(0.090)	(0.092)	(0.104)	(0.087)
$R_s \times$R&D	-0.157**	0.127	-0.127*	0.079	-0.037	-0.061	-0.016	-0.138*	-0.108	-0.008	-0.186**	0.072
	(0.068)	(0.103)	(0.072)	(0.095)	(0.085)	(0.080)	(0.097)	(0.073)	(0.082)	(0.082)	(0.073)	(0.092)
$R_d \times R_s \times$R&D	0.204*	0.281*	0.189	0.268*	0.066	0.343**	0.001	0.433***	0.332**	0.050	0.473***	-0.074
	(0.121)	(0.168)	(0.127)	(0.153)	(0.136)	(0.135)	(0.165)	(0.123)	(0.130)	(0.144)	(0.129)	(0.145)

Table 4: Alternative measures of FDI.
The recession dummy variable R_d (R_s) equals to 1 during the destination (source) market recession and 0 otherwise. R&D is the industry-specific R&D intensity, measured by the average R&D expenditure as a ratio of the total capital spending. The dependent variables in columns 1 to 4 are respectively (1) project size, measured by the log of 1 plus the average project size; (2) project number, the log of 1 plus the total number of FDI project; (3) job number, the log of 1 plus the total number of jobs created by FDI; and (4) FDI/GDP, the log of 1 plus FDI normalized by destination market GDP. Only FDI between advanced markets are included. Source-destination-industry, source-destination-year, and industry-year fixed effects are included in all regressions. Heterogeneity robust standard error clustered by source-destination-industry is reported in the parenthesis. ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

	(1) Project Size	(2) Project Number	(3) Job Number	(4) FDI/GDP
$R_d \times$R&D	-0.119**	-0.032	-0.145**	-0.097
	(0.058)	(0.020)	(0.068)	(0.075)
$R_s \times$R&D	-0.040	-0.021	-0.046	-0.064
	(0.052)	(0.016)	(0.053)	(0.061)
$R_d \times R_s \times$R&D	0.142*	0.045	0.214**	0.216**
	(0.086)	(0.029)	(0.093)	(0.107)
Observations	18,970	18,970	18,970	18,970
R-squared	0.416	0.559	0.490	0.872

4.3.2 Alternative Measures of Technology

Thus far, technology has been measured by R&D intensity. Higher R&D intensity is associated with greater technology improvement in the future. But broad definitions of technology cover not only the research and development of new technology, but also applications of existing technology, as well as factors that can improve total factor productivity (TFP). We check whether the relations between technology FDI and recessions are unique to R&D or robust to other technological characteristics in this section.

We first look at the applications of existing technology. Robots have been increasingly used in the manufacturing sector to automate routine work. Following Acemoglu and Restrepo (2019) , we measure the degree of automation by the number of robots used in each industry as a share of the total robots used in the whole manufacturing sector. The intensity of applying ICT in each industry is calculated by the ratio of expenditure on ICT equipment to total assets. The intensity of applying intellectual property products in each industry is measured by the ratio of expenditure on software and other equipment related to intellectual property products to all assets. Greater value of robot share, ICT intensity and intellectual property products intensity correspond to more intensive technology applications. Replacing *R&D* in Eq.(1) with each of these three measures of technology applications, we re-run the estimation and present the results in columns 1to 3 of Table 5. There is no evidence that recessions in either destination or source markets affect FDI to industries with more intensive applications of existing technology, such as robots, ICT or intellectual property products.[9] These results reveal the difference in technology applications and development in shaping FDI during recessions.

We also broaden technology to measures that could improve the total factor productivity (TFP) following Ilyina and Samaniego (2011). The growth in TFP could be driven by an improvement in capital, inputs and labor. From the perspective of capital, we use (i) investment-specific technical change, which reflects the extent that technology embodied in capital goods becomes obsolete; (ii) investment lumpiness, the frequency of big investments; (iii) depreciation, the industry rate of physical and economic depreciation; and (iv) asset fixity, the ratio of fixed assets to total assets. In terms of inputs, we look at intermediate intensity, the ratio of intermediate inputs over gross output; and input specificity, which measures the proportion of inputs that are not sold on an organized exchange nor reference-priced in a trade publication (Nunn 2007). As for labor, we use labor intensity, the total wages and salaries divided by the total value added; and skilled labor, which measures the intensity of human capital. A more detailed description on these measures and their constructions can be found in Ilyina and Samaniego (2011). We also include the TFP growth indicator from Samaniego and Sun (2020).

The results in columns 4 to 12 of Table 5 show that FDI to industries with higher investment-specific technical change, input specificity and human capital intensity, falls significantly during destination recessions. However, there is no evidence that other technological characteristics matter for FDI in recessions. Throughout the various measures of technological characteristics, we find no evidence of additional impact of simultaneous recessions in destination and source markets on technology FDI. It suggests that recovery of technology FDI during simultaneous recessions are unique to R&D intensive FDI. Unlike other technology measures, R&D activities that take longer to harvest, face high risk and require large amounts of investment during the development process, are extremely sensitive to aggregate economic fluctuations.

[9] We also check an alternative indicator of R&D intensity which is measured as R&D expenditure over total sales ratio from Ngai and Samaniego (2011). The results are similar to our baseline and available upon request. However, because this measure is affected by markups in an environment with imperfect competition by construction, we need to use it with caution and do not treat it as a pure technological measure.

Table 5: Alternative measures of technology.
The dependent variable is $log(1+FDI_{ds,i,t})$, where $FDI_{ds,i,t}$ is the foreign direct investment (FDI) to destination d from source s in industry i at period t. The recession dummy variable R_d (R_s) equals to 1 during the destination (source) market recession and 0 otherwise. X_i is the industry-level measure of technology characteristics specified in the same row. Detailed description of each technological measure is given in Appendix Table A1. Only FDI among advanced markets are included. Source-destination-industry, source-destination-year, and industry-year fixed effects are included in all regressions. Heterogeneity robust standard error clustered by source-destination-industry is reported in the parenthesis. ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Existing Technology			Capital				Input		Labor		TFP
X_i	Robot	ICT	IPP	Investment-specific Technical Change	Investment Lumpiness	Depreciation	Asset Fixity	Intermediate Intensity	Input Specificity	Labor Intensity	Skill Labor	TFP Growth
$R_d \times X_i$	-0.285	-3.982	-0.878	-0.026**	-0.052*	-0.011*	-0.244	-0.161	-0.114**	-0.219	-0.045**	-0.093*
	(0.233)	(3.226)	(0.759)	(0.013)	(0.028)	(0.006)	(0.173)	(0.101)	(0.057)	(0.134)	(0.022)	(0.052)
$R_s \times X_i$	0.180	0.805	0.357	0.001	-0.004	0.002	0.101	0.058	0.011	0.047	0.006	0.016
	(0.233)	(2.932)	(0.691)	(0.011)	(0.023)	(0.005)	(0.149)	(0.087)	(0.050)	(0.114)	(0.020)	(0.045)
$R_d \times R_s \times X_i$	0.139	2.723	0.894	0.014	0.050	0.005	-0.074	0.011	0.046	0.027	0.024	0.033
	(0.384)	(5.040)	(1.182)	(0.042)	(0.042)	(0.009)	(0.257)	(0.153)	(0.087)	(0.204)	(0.034)	(0.079)

5 Conclusion

This paper studies how MNCs allocate technology investment during recessions. Comparing R&D intensive FDI with R&D light FDI in recessions relative to normal states, we document evidence that R&D intensive FDI falls during destination market recessions and recovers to pre-recession levels if source markets also fall in recessions. These findings are limited to FDI from AM to AM. There is no evidence that R&D intensive FDI respond to EM recessions. R&D intensive FDI is more responsive to deeper, longer recessions and during their propagation stages. In destination markets with relatively weaker institutions on intellectual property protection and ROL, looser FDI regulations and higher financial development, R&D intensive FDI drops more aggressively during recessions. In particular, when the destination market is in a deep recession, R&D intensive FDI rises significantly during a source market recession. Whether technology FDI is procyclical, acyclical or countercyclical depends on business cycles in both destination and source markets, and more broadly on the global business cycle. It appears that difficult environments such as global recessions exhaust options for MNCs and motivates R&D intensive FDI, which fosters creative destruction.

References

Acemoglu, Daron, Simon Johnson, and James A Robinson (2005). "Institutions as a fundamental cause of long-run growth". In: *Handbook of economic growth* 1, pp. 385–472.

Acemoglu, Daron and Pascual Restrepo (Aug. 2019). "Robots and Jobs: Evidence from US Labor Markets". In: *Journal of Political Economy*. ISSN: 0022-3808. DOI: 10.1086/705716.

Aghion, Philippe and Gilles Saint-Paul (Sept. 1998). "VIRTUES OF BAD TIMES Interaction Between Productivity Growth and Economic Fluctuations". In: *Macroeconomic Dynamics* 2.3, pp. 322–344. ISSN: 1365-1005. DOI: 10.1017/s1365100598008025.

Aghion, Philippe et al. (2012). "Credit constraints and the cyclicality of R&D investment: Evidence from France". In: *Journal of the European Economic Association* 10.5, pp. 1001–1024. DOI: 10.1111/j.1542-4774.2012.01093.x.

Aizenman, Joshua (Dec. 2003). "Volatility, employment and the patterns of FDI in emerging markets". In: *Journal of Development Economics* 72.2, pp. 585–601. ISSN: 03043878. DOI: 10.1016/S0304-3878(03)00123-8.

Aizenman, Joshua, Yothin Jinjarak, and Huanhuan Zheng (Sept. 2018). "Chinese outwards mercantilism â The art and practice of bundling". In: *Journal of International Money and Finance* 86, pp. 31–49. ISSN: 02615606. DOI: 10.1016/j.jimonfin.2018.03.016. URL: https://linkinghub.elsevier.com/retrieve/pii/S0261560618301906.

Alfaro, Laura and Maggie Xiaoyang Chen (2012). "Surviving the global financial crisis: foreign ownership and establishment performance". In: *American Economic Journal: Economic Policy* 4.3, pp. 30–55.

Amore, Mario Daniele (Oct. 2015). "Companies learning to innovate in recessions". In: *Research Policy* 44.8, pp. 1574–1583. ISSN: 00487333. DOI: 10.1016/j.respol.2015.05.006.

Antràs, Pol and Stephen R Yeaple (2014). "Multinational firms and the structure of international trade". In: *Handbook of international economics*. Vol. 4. Elsevier, pp. 55–130.

Autor, D. H., F. Levy, and R. J. Murnane (Nov. 2003). "The Skill Content of Recent Technological Change: An Empirical Exploration". In: *The Quarterly Journal of Economics* 118.4, pp. 1279–1333. ISSN: 0033-5533. DOI: 10.1162/003355303322552801. URL: https://academic.oup.com/qje/article-lookup/doi/10.1162/003355303322552801.

Barlevy, Gadi (2007). “On the Cyclicality of Research and Development”. In: *American Economic Review* 97.4, pp. 1131–1164.

Belderbos, Rene, Bart Leten, and Shinya Suzuki (Oct. 2013). “How global is RandD? Firm-level determinants of home-country bias in RandD”. In: *Journal of International Business Studies* 44.8, pp. 765–786. ISSN: 00472506. DOI: 10.1057/jibs.2013.33.

Berry, Heather (Nov. 2019). “Internationalizing firm innovations: The influence of multimarket overlap in knowledge activities”. In: *Journal of International Business Studies*, pp. 1–23. ISSN: 14786990. DOI: 10.1057/s41267-019-00284-y.

Branstetter, Lee G., Britta Glennon, and J. Bradford Jensen (Oct. 2019). “The IT revolution and the globalization of R&D”. In: *Innovation Policy and the Economy* 19.1, pp. 1–37. ISSN: 15372618. DOI: 10.1086/699931.

Braun, MatÍas and Borja Larrain (June 2005). “Finance and the Business Cycle: International, Inter-Industry Evidence”. In: *The Journal of Finance* 60.3, pp. 1097–1128. ISSN: 00221082. DOI: 10.1111/j.1540-6261.2005.00757.x. URL: http://doi.wiley.com/10.1111/j.1540-6261.2005.00757.x.

Brown, James R, Steven M Fazzari, and Bruce C Petersen (2009). *Financing Innovation and Growth: Cash Flow, External Equity, and the 1990s R&D Boom*. Tech. rep. 1. DOI: 10.1111/j.1540-6261.2008.01431.x.

Caballero, Ricardo J and Mohamad L Hammour (1994). “The Cleansing Effect of Recessions”. In: *American Economic Review* 84.5, pp. 1350–1368.

Canton, Erik and Harald Uhlig (1999). “Growth and the Cycle: Creative Destruction versus Entrenchment”. In: *Journal of Economics* 69.3, pp. 239–266.

Doms, Mark and Timothy Dunne (1998). “Capital Adjustment Patterns in Manufacturing Plants*”. In: *REVIEW OF ECONOMIC DYNAMICS* 1.2, pp. 409–429.

Duanmu, Jing Lin (Oct. 2014). “State-owned MNCs and host country expropriation risk: The role of home state soft power and economic gunboat diplomacy”. In: *Journal of International Business Studies* 45.8, pp. 1044–1060. ISSN: 14786990. DOI: 10.1057/jibs.2014.16.

Fabrizio, Kira R and Ulya Tsolmon (2014). “An Empirical Examination of the Procyclicality of R&D Investment and Innovation”. In: *Review of Economics and Statistics* 96.4, pp. 662–675. DOI: 10.1162/REST_a_00412.

Francois, Patrick and Huw Lloyd-Ellis (2003). “Animal spirits through creative destruction”. In: *American Economic Review* 93.3, pp. 530–550. ISSN: 00028282. DOI: 10.1257/000282803322156972.

Gavin, Michael and Ricardo Hausmann (1998). “Macroeconomic Volatility and Economic Development”. In: *The Political Dimension of Economic Growth*. Palgrave Macmillan UK, pp. 97–116. DOI: 10.1007/978-1-349-26284-7_5.

Geroski, P. A. and C. F. Walters (1995). “Innovative Activity over the Business Cycle”. In: *The Economic Journal* 49.195, pp. 558–577.

Goos, Maarten and Alan Manning (Feb. 2007). “Lousy and lovely jobs: The rising polarization of work in britain”. In: *Review of Economics and Statistics* 89.1, pp. 118–133. ISSN: 00346535. DOI: 10.1162/rest.89.1.118.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W. Huffman (1997). “Investment, Capacity Utilization, and the Real Business Cycle”. In: *The American Economic Review* 78, pp. 402–417. DOI: 10.2307/1809141. URL: https://www.jstor.org/stable/1809141.

Gulati, Ranjay, Nitin Nohria, and Franz Wohlgezogen (2010). “Roaring Out of Recession”. In: *Harvard Business Review* 88.3, pp. 62–69.

Hardy, Bryan and Can Sever (2020). “Financial crises and innovation”. In: *BIS Working Paper*.

Hart, O. and J. Moore (Nov. 1994). “A Theory of Debt Based on the Inalienability of Human Capital”. In: *The Quarterly Journal of Economics* 109.4, pp. 841–879. ISSN: 0033-5533. DOI: 10.2307/2118350. URL: https://academic.oup.com/qje/article-lookup/doi/10.2307/2118350.

Helpman, Elhanan (2006). “Trade, FDI, and the Organization of Firms”. In: *Journal of Economic Literature* XLIV, pp. 589–630.

Ilyina, Anna and Roberto M. Samaniego (Aug. 2011). “Technology and Financial Development”. In: *Journal of Money, Credit and Banking* 43.5, pp. 899–921. ISSN: 00222879. DOI: 10.1111/j.1538-4616.2011.00401.x. URL: http://doi.wiley.com/10.1111/j.1538-4616.2011.00401.x.

King, R. G. and R. Levine (Aug. 1993). “Finance and Growth: Schumpeter Might Be Right”. In: *The Quarterly Journal of Economics* 108.3, pp. 717–737. ISSN: 0033-5533. DOI: 10.2307/2118406. URL: https://academic.oup.com/qje/article-lookup/doi/10.2307/2118406.

Kumar, Nagesh (Jan. 2001). "Determinants of location of overseas R&D activity of multinational enterprises: The case of US and Japanese corporations". In: *Research Policy* 30.1, pp. 159–174. ISSN: 00487333. DOI: 10.1016/S0048-7333(99)00102-X.

Kydland, Finn E and Edward C Prescott (1982). "Time to build and aggregate fluctuations". In: *Econometrica: Journal of the Econometric Society*, pp. 1345–1370.

Laeven, Luc and Fabián Valencia (2012). "Systemic Banking Crises Database: An Update". In: *IMF Working Paper*, pp. 12/163.

Michaels, Guy, Ashwini Natraj, and John V. Van Reenen (Mar. 2014). "Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years". In: *Review of Economics and Statistics* 96.1, pp. 60–77. ISSN: 15309142. DOI: 10.1162/REST_a_00366.

Nunn, N. (May 2007). "Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade". In: *The Quarterly Journal of Economics* 122.2, pp. 569–600. ISSN: 0033-5533. DOI: 10.1162/qjec.122.2.569. URL: https://academic.oup.com/qje/article-lookup/doi/10.1162/qjec.122.2.569.

Rajan, Raghuram G. and Luigi Zingales (June 1998). "Financial Dependence and Growth". In: *American Economic Review* 88.3, pp. 559–586. ISSN: 00028282. DOI: 10.2307/116849. URL: https://www.jstor.org/stable/116849.

Ravn, Morten O and Harald Uhlig (2002). "On adjusting the Hodrick-Prescott filter for the frequency of observations". In: *Review of economics and statistics* 84.2, pp. 371–376.

Roy, Santanu and Jean-Marie Viaene (1998). "On strategic vertical foreign investment". In: *Journal of International Economics* 46, pp. 253–279.

Samaniego, Roberto M. (Mar. 2010). "Entry, exit, and investment-specific technical change". In: *American Economic Review* 100.1, pp. 164–192. ISSN: 00028282. DOI: 10.1257/aer.100.1.164.

Samaniego, Roberto M. and Juliana Yu Sun (2015). "Technology and contractions: Evidence from manufacturing". In: *European Economic Review* 79, pp. 172–195.

— (2020). "The relative price of capital and economic structure". In: *Review of Economic Dynamics*.

Schumpeter, Joseph A. (1942). *Capitalism, Socialism and Democracy*. Harper and Brothers, NewYork. DOI: 10.4324/9780203202050.

Shimizutani, Satoshi and Yasuyuki Todo (Apr. 2008). "What determines overseas R&D activities? The case of Japanese multinational firms". In: *Research Policy* 37.3, pp. 530–544. ISSN: 00487333. DOI: 10.1016/j.respol.2007.11.010.

Siedschlag, Iulia et al. (Sept. 2013). "What determines the location choice of R&D activities by multinational firms?" In: *Research Policy* 42.8, pp. 1420–1430. ISSN: 00487333. DOI: 10.1016/j.respol.2013.06.003.

Steenkamp, Jan Benedict E.M. and Eric Er Fang (July 2011). "The impact of economic contractions on the effectiveness of R&D and advertising: Evidence from U.S. companies spanning three decades". In: *Marketing Science* 30.4, pp. 628–645. ISSN: 07322399. DOI: 10.1287/mksc.1110.0641.

UNCTAD (2005). *Transnational corporations and the internationalization of R & D*. United Nations, p. 332. ISBN: 9211126673.

— (2019). *World Investment Report 2019: Special Economic Zones*. Tech. rep. United Nations Conference on Trade and Development, p. 4. URL: https://unctad.org/en/PublicationsLibrary/wir2019%7B%5C_%7Den.pdf.

Appendix

Appendix Table A1: Variable Definitions

Name	Definition	Source
$FDI_{ds,i,t}$	FDI from source s to destination d in industry i at period t	fDi Markets
R&D intensity	The ratio of R&D expenditures to total capital expenditures.	Compustat
R_d	Dummy variable that equals to 1 during destination market recession	WDI, author calculation
R_s	Dummy variable that equals to 1 during source market recession	WDI, author calculation
IPP	Intellectual property protection rights enforcement index	Property Rights Alliance
ROL	Rules of society, the quality of contract enforcement, property rights and laws	WGI
FDI restrictiveness index	Foreign equity limitations, screening or approval mechanism, restrictions on the employment of foreigners and operational restrictions	OECD
Foreign entry	Entry costs paid as a share of income per capita	Doing Business
Financial Development	1. Credit-to-GDP ratio 2. Stock market capitalization as a ratio of GDP	WDI
Robot	The number of robots used in a sector divided by the total robots in the manufacturing industry	IFR
ICT	the ratio of capital expenditure on ICT equipment to total assets.	EU KLEMS
Intellectual property products	the ratio of expenditure on intellectual property equipments to total assest.	EU KLEMS
Investment-specific technical change	The rate of decline in the price of capital goods relative to the price of consumption and services	BEA
Investment lumpiness	Average number of investment spikes in a given industry	Compustat
Depreciation	The industry rate of capital depreciation	BEA
Asset fixity	The ratio of fixed assets to total assets,	Compustat
Intermediate intensity	The difference between gross output and value added divided by gross output	UNIDO
Input specificity	The proportion of inputs that are not sold on an organized exchange or reference-priced in a trade publication	Nunn (2007)
Labor intensity	Total wages and salaries divided by the total value added	UNIDO
Skilled labor	Average wage bill, i.e., the ratio of wages over total number of employees	UNIDO
TFP growth	Growth in the technology component of Cobb-Douglas production function.	NBER, author calculation

Appendix Table A2: List of Destination and Source Markets

Source Markets				Destination Markets			
Advance Markets		Emerging Markets		Advance Markets		Emerging Markets	
ISO	N	ISO	N	ISO	N	ISO	N
AUS	542	ARG	35	AUS	708	ARG	386
AUT	1,030	BGD	5	AUT	340	BGD	75
BEL	716	BGR	13	BEL	688	BGR	396
CAN	1,087	BRA	289	CAN	768	BRA	1,214
CHE	2,013	CHL	64	CHE	334	CHL	238
CHL	64	CHN	1,769	CHL	238	CHN	2,979
CZE	136	COL	26	CZE	621	COL	326
DEU	4,244	HUN	63	DEU	2,239	HUN	716
DNK	954	IDN	33	DNK	289	IDN	598
ESP	1,532	IND	1,064	ESP	1,137	IND	1,871
EST	46	MEX	217	EST	133	MEX	1,204
FIN	936	MYS	295	FIN	307	MYS	741
FRA	2,678	PAK	12	FRA	1,564	PAK	112
GBR	2,598	PER	6	GBR	1,897	PER	157
GRC	131	PHL	34	GRC	62	PHL	368
HUN	63	POL	185	HUN	716	POL	1,263
IRL	355	RUS	476	IRL	293	ROU	831
ISL	13	THA	220	ISL	5	RUS	1,565
ISR	242	TUR	412	ISR	89	THA	851
ITA	1,781	UKR	75	ITA	521	TUR	677
JPN	3,705	VEN	13	JPN	553	UKR	317
KOR	1,193	ZAF	168	KOR	528	VEN	35
LTU	45			LTU	231	ZAF	455
LUX	307			LUX	30		
LVA	9			LVA	106		
MEX	217			MEX	1,204		
NLD	1,593			NLD	659		
NOR	442			NOR	96		
NZL	124			NZL	135		
POL	185			POL	1,263		
PRT	154			PRT	202		
SVN	81			SVK	457		
SWE	1,430			SVN	68		
TUR	412			SWE	294		
USA	6,144			TUR	677		
				USA	3,400		

Appendix Table A3: Measures of technological characteristics

Industry	ISIC code	R&D	Robots (%)	ICT (%)	Investment-specific Technical Change	Investment lumpiness	Depreciation	Asset fixity	Intermediate intensity	Input specificity	Labor Intensity	Skilled labor	TFP Growth
Apparel	322	0.020	0.05	2.46	4.369	1.998	6.437	0.134	0.493	0.975	0.447	1.084	0.991
Wood products	331	0.032	0.05	1.53	3.926	1.720	9.525	0.305	0.596	0.670	0.467	1.624	0.996
Beverages	313	0.039	4.39	1.23	3.975	1.290	7.090	0.372	0.549	0.949	0.248	2.378	1.008
Petroleum refineries	353	0.057		0.91	3.923	0.763	6.776	0.591	0.833	0.759	0.173	3.450	0.984
Iron and steel	371	0.066	2.12	1.34	3.442	0.951	6.578	0.427	0.578	0.816	0.477	2.691	1.012
Food products	311	0.073	4.39	1.23	3.948	1.195	7.090	0.373	0.658	0.557	0.281	1.780	1.002
Paper and products	341	0.083	0.11	1.53	3.250	0.902	8.632	0.472	0.551	0.885	0.363	2.406	0.999
Other non-met. Min. prod.	369	0.095		1.25	4.754	0.990	8.234	0.480	0.478	0.963	0.385	2.072	0.992
Printing and publishing	342	0.100		1.53	4.410	1.670	9.745	0.261	0.350	0.995	0.407	1.969	0.978
Non-ferrous metals	372	0.101	2.12	1.34	3.431	1.245	5.393	0.364	0.681	0.460	0.424	2.373	1.008
Glass and products	362	0.115		1.25	4.379	1.755	7.554	0.400	0.409	0.967	0.399	2.189	1.011
Textiles	321	0.144	0.05	2.46	3.914	1.232	7.665	0.345	0.586	0.820	0.458	1.463	1.002
Fabricated metal products	381	0.147	6.04	1.34	3.421	1.365	7.043	0.274	0.488	0.945	0.455	2.025	1.004
Footwear	324	0.153		2.46	4.056	2.239	8.325	0.160	0.483	0.934	0.446	1.156	0.997
Furniture, except metal	332	0.155	0.05	1.53	4.045	1.381	8.312	0.280	0.484	0.910	0.488	1.555	1.005
Plastic products	356	0.171	8.30	1.25	3.204	1.557	10.072	0.374	0.494	0.985	0.402	1.808	1.005
Misc. pet. and coal products	354	0.186		0.91	3.996	1.042	6.776	0.372	0.648	0.895	0.300	2.395	0.982
Rubber products	355	0.187	6.05	1.25	3.144	1.098	10.072	0.322	0.482	0.923	0.423	2.139	1.015
Leather	323	0.198		2.46	4.008	1.927	9.266	0.135	0.550	0.848	0.444	1.439	1.006
Tobacco	314	0.222		1.23	3.975	0.815	5.248	0.189	0.357	0.483	0.117	2.648	0.980
Industrial chemicals	351	0.269		0.85	4.595	1.340	9.646	0.381	0.558	0.884	0.241	2.921	1.009
Other manufactured prod.	390	0.302	3.18	1.67	2.996	2.006	10.070	0.186	0.460	0.863	0.414	1.640	0.997
Transport equipment	384	0.316	49.67	1.04	3.847	1.614	10.559	0.264	0.598	0.985	0.440	2.815	1.003
Pottery, china, earthenware	361	0.503		1.25	4.603	1.292	8.234	0.400	0.311	0.946	0.475	1.733	0.999
Machinery, electric	383	0.814	18.70	2.42	4.313	2.704	9.381	0.208	0.443	0.960	0.407	2.268	1.044
Machinery, except electrical	382	0.933	1.15	1.96	5.149	2.694	8.832	0.195	0.479	0.975	0.433	2.389	1.031
Prof. & sci. equip.	385	1.194	0.13	1.68	4.456	2.790	9.210	0.181	0.344	0.981	0.382	2.550	0.997
Other chemicals	352	1.951	0.07	0.85	4.683	2.130	6.888	0.207	0.393	0.946	0.218	2.568	1.003