Nonlinear System Simulation and Forecasting of Regional Technology Innovation Using System Dynamics Method

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This work was supported by China Postdoctoral Science Foundation under grant 2021M693775, and supported by the Administrative Committee of Hengqin New Area through a Key Research Program.

ABSTRACT This study analyzed complex causal feedback loops in Regional Technology Innovation (RTI) system and established a system dynamics (SD) model of RTI. Taking China Guangdong Pilot Free Trade Zone as a sample, and running the model in VENSIM, it shows high fitting precision and good extrapolating performance. The simulation gives out the future trends of RTI, FCD, ATD and IPR royalties international trade of the region. This study proposed an effective model of RTI, and more importantly, it points out the type, direction and magnitude of the effects caused by IPR policy in RTI system. This SD model can also be used in policy effect simulation in the future.

INDEX TERMS System analysis and design, nonlinear dynamical systems, regional technology innovation, system dynamics, computer simulation.

I. INTRODUCTION

Current research on regional technology innovation (RTI) can involve many aspects [1]–[8]. Literatures indicate that RTI is a system which contains complex causal connections and effects. There are two quite controversial issues about RTI: One major issue is the relationship between economic globalization and RTI, mainly the discussion on the impact of Foreign Direct Investment (FDI) and Outward Foreign Direct Investment (OFDI) on RTI. There are a large number of literatures on international technology spillovers, and the perspectives and indicators are quite different. Some studies found that the effect of FDI technology spillover was not always significant, and the impacts are contingent on regional conditions, yet some found that FDI did not improve the local innovation ability, but had an inhibiting effect [9]–[16]. The other important issue is the relationship between IPR protection and RTI, which is how IPR protection influence RTI. Is IPR protection really improving the RTI, especially in regions that lag in technology? The answers given by current literatures are quite different [17]–[24].

In previous studies, we can see that the traditional qualitative analysis and quantitative analysis methods are widely used in the field of RTI. However, previous studies tent to oversimplify the real RTI system and ignore the complex nonlinear interactions in the system, therefore can’t explain or solve complexity and uncertainty problems in real RTI system. The purpose of this study is to conduct a systematic research in the relationship between FDI, OFDI, IPR and RTI, so as to have a better understanding in RTI system.

II. METHODS

The method of System Dynamics (SD) is adopted in this study, which can restore the operating status of the system from both qualitative and quantitative aspects [25], [26]. The purpose of this study is to establish a SD simulation model to describe the dynamic behaviours of RTI system under the influence of FDI, OFDI and IPR protection, so as to help researchers and policy-makers understand the complexity in RTI system more deeply and comprehensively.

As shown in Figure 1, the construction of SD method in this study includes conceptualization, modellization and simulation. Firstly, we analyse the mechanism of RTI system under the influence of FDI, OFDI and IPR protection, and define the boundary of the system. Secondly, multiple effects...
and causal feedback loops of the system are analysed, and the stock-flow model is established. Thirdly, the validity of the model is tested, the future development trend is carried out by simulation, and the conclusion is summarized.

III. CONCEPTUALIZATION

Regarding the RTI system as an information feedback system, we divide it into subsystems and treats the research object as a whole. In this study, the RTI system is divided into four subsystems: RTI environment, RTI effect, RTI impetus and RTI performance. The system conceptual model for RTI is built, as shown in Figure 2.

IV. MODELLIZATION

A. CAUSAL LOOP MODEL

A causal loop diagram is a qualitative analysis method to understand the causal circulation relationship between the model’s overall flow and variables. If the result of the effect is positive, it is indicated by a plus (+) sign, and if it is negative, it is indicated by a minus (−) sign. In this study, Causal loop diagram is used to describe the complex RTI system clearly from the qualitative point of view. There are learning effect, competition effect and incentive effect in the RTI system. The interactive relationship among various factors is connected to form feedback loops, and a causal model of RTI is built, as shown in Figure 3.

As shown in Figure 4, the causal feedback loop of learning effect in RTI system is mainly composed of two parts: the generation of learning effect and the accumulation of learning effect.

Causal chain 1 is the generation of learning effect in RTI system, manifest as “regional open-up policy – regional opening degree – FDI/OFDI – knowledge inflow – learning effect – RTI efficiency – RTI capability”. With FDI inflow in the region, enterprises are usually established, factories are set up, talents are brought in, and local employees
are employed for production and R&D activity. By means of product exchange, talent flow, “doing by learning” and other methods, the region will gradually learn and imitate the advanced technology and experience brought in by FDI inflow, so as to improve the level of RTI capability. OFDI will also bring new technology, talent, data, sales network and other resources to local enterprises. The causal chain 1 is a positive chain, which reflects the improvement process of RTI capability under the technology spillover effect of FDI and OFDI.

Causal loop 2 is the accumulation of learning effect in RTI system, manifest as “learning effect – RTI efficiency – regional R&D investment – KAC – learning effect”. The degree of learning effect is affected by the KAC of this region. A better absorption capacity can make imitation translate into innovation more quickly in the learning process [3], [5], [27], and [28]. Causal loop 2 is a positive feedback loop, which reflects the continuous increase of regional R&D investment and accumulation of knowledge.

As shown in Figure 5, the causal feedback loop of the competition effect in RTI system is mainly composed of three parts: the generation of the competition effect, the reduction of the competition effect, and the intensification of the competition effect by IPR protection.

Causal chain 3 is the generation of competition effect, manifest as “regional opening degree – FDI – FCD – competition effect – RTI efficiency – RTI capability”. FDI will bring many local talents into the foreign company and occupy local market share, so that it worsens the living and innovation conditions of local enterprises and industries. Causal chain 3 is a negative chain, which reflects the process that the RTI efficiency in developing country is inhibited under the competition effect after the inflow of foreign capital and technology.

Causal loop 4 is the reduction of competition effect, manifest as “competition effect – RTI efficiency – RTI capability – regional R&D investment – ETD – competition effect”. The competition effect will increase the difficulty of local innovation. However, the region may continue to improve their independent innovation ability through a large number of learning and R&D activities, initiate catch-up and narrow the gap. Causal loop 4 is a negative feedback loop, which reflects the process of the region reducing its dependency on foreign technologies through independent innovation activities.

Causal loop 5 is the intensifying effect of IPR protection on competition effect, manifest as, “IPR protection – competitive effect – RTI efficiency – RTI capability – IPR protection”. An open-up region means that there will be a large number of foreign patents in the region, and IPR protection means that the interests of domestic and foreign patentees will be equally protected without discrimination. Therefore, the intellectual property system will play a positive role in preserving technology advantage of foreign patentees in the region. Causal loop 5 is a negative feedback loop, which reflects the consolidation of technological advantage under IPR protection.

As shown in Figure 6, the feedback loop of the incentive effect in RTI system is mainly composed of two parts: the improvement effect of IPR protection on RTI capability and the stimulation effect of IPR protection on regional R&D investment.

Causal chain 6 is the stimulating effect of IPR protection on regional R&D investment, manifest as “IPR protection – regional R&D investment – incentive effect”. On the one hand, the crackdown on infringement by IPR protection forces enterprises to stop imitating behavior, increase R&D investment, and turn to the road of independent innovation.
On the other hand, technological innovation can enhance the competitiveness of products, reduce production costs and bring market benefits, so as to enhance the enthusiasm for R&D activities and stimulate the R&D investment. Causal chain 6 is a positive chain, which reflects the process of gradually increasing R&D activities in the region under IPR protection.

Causal loop 7 is the mutual promotion between IPR protection and RTI efficiency, manifest as “IPR protection – RTI efficiency – RTI capability – IPR protection”. Causal loop 7 is a positive feedback loop that reflects IPR protection in a particular region can promote knowledge dissemination, promote innovation policy goals. Along with the increase of RTI capability, IPR protection strength is promoted.

B. STOCK-FLOW MODEL

Based on the causal loop model, a stock-flow model of RTI system is built, as shown in figure 7.

C. VARIABLES

Variable selection criteria are representativeness, data comprehension, comparative objectivity, repeatability and simplicity. The connotation of variables and the reasons of their selection are explained in this subsection.

RTI capability – This study uses the number of PCT patent applications of the region to measure RTI capability. The data limits the patent inventor to Chinese nationals from the region, which conforms to the meaning of RTI in terms of source. The data also requires that each patent has been approved by the PCT, so the quality of the application is relatively valid. Therefore, it is the most suitable index to measure the RTI capability at present, and also available. The index comes from China’s Intellectual Property Development Research Report and Yearbook of Patent Treaty [29], [30].

RTI efficiency – In this study, RTI efficiency is measured by the number of PCT patent applications in the region per hundred-million-yuan R&D investment, and the data is calculated.

Regional live patent quantity – Regional live patent quantity refers to the number of patents currently in force in the region. The index represents the overall innovation level of the region. However, the index does not distinguish the nationality of patent applicants and right holders, cannot accurately measure the innovation capability of the local region. In this paper, this index is used as the auxiliary variable of the model, and the data are selected from the Statistical Annual Report of the National Intellectual Property Administration.

Knowledge quantity – This index is measured by the total trade in intellectual property services in the region.

KAC – Regional knowledge absorption refers to the learning process in which innovative organizations acquire knowledge through knowledge search, selection and digestion, so as to enhance productivity and competitiveness by absorbing and using new knowledge [27]. Universities, research and development institutions, enterprises and other innovative organizations can act as the main body of regional knowledge absorption [2]. In this paper, the number of R&D personnel and the number of R&D institutions are used to measure the regional knowledge absorption capacity, the data are selected from Statistical Yearbook of Guangdong.

FCD – This paper refers to the calculation method from China Science and Technology Indicators and uses the ratio of regional FDI to regional GDP to measure FCD.

ETD – From the perspective of technology demand, external technology dependency should be the proportion of foreign technology demand in the total technology demand. Refers to China Science and Technology Indicators, the calculation formula is as follow:

\[
ETD = \frac{\text{IPR royalties trade deficit}}{(\text{Regional R&D investment}) + \text{IPR royalties trade deficit}}
\]

Regional IPR protection index – The index is selected from China’s Intellectual Property Development Research Report,
TABLE 1. Variable name, attribute, initial value and unit.

| Variable name                  | Attribute | Initial value (Unit) |
|--------------------------------|-----------|----------------------|
| Regional open-up policy        | Constant  | 1(Dmln)              |
| IPR policy strength           | Auxiliary | 1(Dmln)              |
| RTI capability                | State     | 14711(PCT patents)   |
| RTI increment                 | Rate      | 4911(PCT patents)    |
| Regional population           | State     | 10430(Ten-thousand people) |
| Immigrate population          | Rate      | 10.2(%)              |
| Emigrate population           | Rate      | 0.01(%)              |
| Birth population              | Rate      | 1.255(%)             |
| Death population              | Rate      | 0.446(%)             |
| FDI                           | Auxiliary | 2026089(Ten-thousand USD) |
| OFDI                          | Auxiliary | 227800(Ten-thousand USD) |
| Knowledge quantity            | Auxiliary | 1149(Hundred-million USD) |
| Live patent quantity per 10,000 people | Auxiliary | 4.02(Piece/people) |
| Regional GDP                  | Auxiliary | 46013.06(Hundred-million RMB) |
| IPR royalties trade deficit   | Auxiliary | 1220906(Ten-thousand USD) |
| Regional R&D investment       | Auxiliary | 808.75(Hundred-million RMB) |
| RTI efficiency                | Auxiliary | 6.07(Piece/Hundred-million RMB) |
| Regional IPR protection index | Auxiliary | 62.5(Dmln)           |
| Ratio of R&D personnel        | Auxiliary | 4.28(%)              |
| Number of R&D personnel       | Auxiliary | 44.66(Ten-thousand people) |
| Number of scientific research institutions | Auxiliary | 4452(Institutions) |
| ETD                           | Auxiliary | 0.13(Dmln)           |
| FCD                           | Auxiliary | 48.54(Dmln)          |
| R&D investment intensity      | Auxiliary | 2.79(%)              |

D. EQUATIONS

Using SPSS to analysis the data of Guangdong Free Trade Zone from year 2010 to year 2019, the equations of the model are built and shown as follows:

(01) $\text{FDI} = \text{ACTIVE INITIAL (IF THEN ELSE) Regional open-up policy} > 0, \text{RANDOM UNIFORM (0.9, 1.1, 1)} * (42100.5 \times \text{regional IPR Protection Index} - 6.33 * \text{RTI capability} - 388100), 0, +06$

(02) $\text{OFDI} = \text{ACTIVE INITIAL (IF THEN ELSE) Regional open-up policy} > 0, \text{RANDOM UNIFORM (0.8, 1.4, 2)} * (8 * \text{RTI capability} + 130000), 0, 227800$

(03) $\text{RTI capability increment} = 6200 * \text{RTI efficiency} - 31500$

(04) $\text{RTI capability} = \text{INTEG (RTI capability increment, 14711)}$

(05) $\text{Regional R&D investment} = 113.8 * \text{Regional intellectual property protection index} - 6657$

(06) $\text{Regional population} = \text{INTEG (birth population + immigrate population - death population - emigrate population, 10440)}$

(07) $\text{Regional live patents quantity} = \text{regional population} * \text{live patents per 10000 people}$

(08) $\text{FCD} = \text{FDI / regional GDP}$

(09) $\text{ETD} = \text{IPR royalties trade deficit} / (\text{regional R&D investment} + \text{IPR royalties trade deficit})$

(10) $\text{Regional GDP} = \text{Active Initial (0.242 * live patents quantity + 38717.1, 46013.1)}$

(11) $\text{Regional IPR protection index} = (72 + 0.000147 * \text{RTI capability}) * \text{IPR policy strength}$

(12) $\text{KAC} = \text{number of R&D personnel + number of research institutions}$

(13) $\text{RTI efficiency} = 2E-05 * \text{regional GDP} + 0.5 * \text{incentive effect degree} - 0.0018 * \text{competitive effect degree} + 6.8$

(14) $\text{Live invention patents per 10,000 people} = 0.0792 * \text{knowledge quantity} - 5.72$

(15) $\text{Incentive effect degree} = \text{ETD} * \text{regional IPR protection index}$

(16) $\text{IPR royalties trade deficit} = 0.5 * \text{regional population} + 4.1 * \text{FCD} - 0.002 * \text{RTI capability} - 5.280$

(17) $\text{Knowledge quantity} = \text{SMOOTH (0.0068 * KAC + 2.8e-05 * (FDI + OFDI) + 50, 0.1)}$

(18) $\text{Ratio of R&D personnel} = (0.00265 * \text{regional R&D investment} + 1.686) / 1000$

(19) $\text{Competitive effect degree} = \text{FCD} * \text{regional IPR protection index}$

(20) $\text{R&D investment intensity} = \text{Regional R&D investment / Regional GDP}$

(21) $\text{Number of R&D personnel} = \text{regional population} * \text{ratio of R&D personnel}$

(22) $\text{Number of scientific research institution} = 13.544 * \text{Regional R&D investment} - 11767.4$

V. SIMULATION

A. MODEL VALIDATION

SD model testing methods usually include structure evaluation test, extreme case test, behavior reproduction test and so calculated by weighting the judicial, administrative and effectiveness of IPR protection with data from China Supreme Court, China Supreme Procuratorate, State Intellectual Property Office, State Market Supervision and Administration, Publicity Department of the Communist Party of China and the General Administration of Customs [29].

Model variable name, attribute, initial value and unit are set—e.g., Table 1.
on. According to the structural behavior test method proposed by Barlas [31], whether the model structure is composed of factors related to the real system is tested through structural verification and extreme case analysis. The behavior of each
structural factor is tracked over time, and the amplitude and trend under the extreme condition are analyzed, and the abnormal behavior is rescheduled.

The objectivity of the model is verified by comparing the model simulation results with actual data. The simulation time was set as 10 years, starting from 2010 to 2019, and the step length was 1 year. China Guangdong Pilot Free Trade Zone was selected as the sample. VENSIM software was used to run the model, and the simulated result fit well with the real data. The fitting of the true value and the simulated value is shown in Figure 8:

B. SENSITIVITY ANALYSIS

Sensitivity analysis of the RTI system is conducted in this study. Adjust the value of IPR policy strength and see how the key parameters of the system behave. The result of sensitivity analysis is shown in following figures.

As shown in figure 9(a), IPR policy can cause different effects in different stage on innovation efficiency. In early stage of the RTI system which is the time from year 2010 to year 2018, IPR policy does not have a significant influence on innovation efficiency, no matter what value the policy strength change into. After year 2018, the positive effect starts to show and gradually increases along time, which means the stronger IPR policy gets, the higher innovation efficiency is at this stage. This simulation result suggests that carrying out a strong IPR policy too early usually does not have a remarkable effect on technology innovation. In the early stage when the region is technological backwards, the excessively high level of IPR protection will enhance the incentive effect, decrease the competition effect and finally lead to the decline of regional innovation efficiency.

As shown in figure 9(b), IPR policy strength has positive effect on R&D investment intensity, stronger IPR policy lead to more R&D investment. The influence of IPR policy on R&D investment intensity is quite strong in early stage, and will get lower and lower along with time. This simulation result suggests that carrying out a strong IPR policy too early will cause a heavier financial burden to domestic R&D institutions in the region.

As shown in figure 9(c), The influence of IPR policy on IPR royalties trade deficit changes over time, and also differs from the policy strength itself. When raising IPR policy strength up to 130% and 160%, it shows positive effect on IPR royalties trade deficit, which means the stronger IPR policy is, the higher IPR royalties trade deficit is. At the same time, IPR policy can also shorten the time of IPR royalties trade deficit, and accelerate the transition from deficit to surplus. When raising IPR policy strength up to 190%, IPR royalties trade deficit shows both lower number and faster turning into surplus.

This sensitivity analysis also indicates that the conclusion coming from this SD model is consistent to the truth. To sum up, the effect of IPR policy is wide and diversified according to different stages of development in the RTI system.

FIGURE 9. Sensitivity analysis diagrams of RTI system model.

Policy-makers should consider not only the overall positive effect of IPR policy on technology innovation, but also the different effects in different stage, so as to keep the suitable level of IPR protection in the region.
**C. FORECASTING**

A valid SD simulation model is built according to the complex situation existing in the real world, and it has the function of simulating system behavior and can predict the future trend [26]. Run it through VENSIM software, the results are shown in Figure 10.

According to the forecasting results, ETD of the region will keep decreasing, which means the positive feedback effectiveness in RTI system is growing stronger and stronger. Therefore, by the year 2024, IPR royalties trade deficit of this region will stop increasing and start decreasing. By the year 2038, the number became negative, which means IPR royalties trade of the region will no longer be deficit, but be surplus. If the policy-maker regulate and control the IPR policy strength properly, this turning point may come sooner.

**VI. CONCLUSION**

The novelty of this research can be described as follows:

1. An effective RTI system simulation model is proposed, presenting the dynamic behaviors of a region under influence of FDI, OFDI and IPR protection. This model contains 30 variables, and can explain positive and negative feedback loops in the RTI system, including the learning effect, competition effect and incentive effect. Taking Guangdong Free Trade Zone as a sample, the value of FDI, OFDI, FCD, ETD, population, R&D investment, GDP, PCT patent applications, IPR royalties trade volume in this region is successfully simulated in VENSIM.

2. It points out the type, direction and magnitude of the effects caused by IPR policy in a RTI system. There are three effects of IPR protection in RTI system, which are the attraction of FDI, the intensification of domestic and foreign technological competition and the incentive of domestic independent innovation. There are two directions of how IPR protection impact on RTI efficiency and capability, which means positive and negative effects are taking places at the same time. The magnitudes of all the effects are in models and equations.

3. This model can be useful to help the policy-makers decide when to carry out stronger IPR policy in a specific region, and see what the outcome will be. Simulation of this model can show the impact of IPR policy on regional technology innovation performance, including innovation efficiency and patent ownership. Simulation of this model can also show what the impact of IPR policy on regional economics will be, including R&D investment intensity and IPR royalties trade deficit.

In future research, this model can be used to carry out IPR policy simulation experiments, to demonstrate different behaviors of the RTI system, so as to evaluate the influence of policies and avoid rash decisions in policy-making. This model can also be used in international trade policy effect simulation, to demonstrate how RTI is influenced by FDI flow and OFDI flow in a specific region.

**ACKNOWLEDGMENT**

The authors appreciate the support of The Administrative Committee of Hengqin New Area, The Development and Reform Commission of Hengqin New Area. They truly thank the peer reviewers for their insightful and positive feedback and comments.

**REFERENCES**

[1] J. Stuck, T. Broekel, and J. R. Diez, “Network structures in regional innovation systems,” *Eur. Planning Stud.*, vol. 24, no. 3, pp. 423–442, Mar. 2016.

[2] A. D. Monte, S. Moccia, and L. Pennacchio, “Regional entrepreneurship and innovation: Historical roots and the impact on the growth of regions,” *Small Bus. Econ.*, pp. 1–23, Nov. 2020, doi: 10.1007/s11187-020-00425-w.

[3] T. Schlegel, C. Pister, D. Harhoff, and U. Backes-Gellner, “Innovation effects of universities of applied sciences: An assessment of regional heterogeneity,” *J. Technol. Transf.*, pp. 1–56, Feb. 2021, doi: 10.1007/s10967-020-09839-w.

[4] A. Malik, P. Sharma, V. Pereira, and Y. Temouri, “From regional innovation systems to global innovation hubs: Evidence of a quadruple helix from an emerging economy,” *J. Bus. Res.*, vol. 128, pp. 587–598, May 2021.

[5] T. Agasisti, C. Barra, and R. Zotti, “Research, knowledge transfer, and innovation: The effect of Italian universities’ efficiency on local economic development 2006–2012,” *J. Regional Sci.*, vol. 59, no. 5, pp. 819–849, Nov. 2019.

[6] E. Migueluez and R. Moreno, “Relatedness, external linkages and regional innovation in Europe,” *Regional Stud.*, vol. 52, no. 5, pp. 688–701, 2018.

[7] Y. Fu, A. Supriyadi, T. Wang, L. Wang, and G. T. Cirella, “Effects of regional innovation capability on the green technology efficiency of China’s manufacturing industry: Evidence from listed companies,” *Energies*, vol. 13, no. 20, p. 5467, Oct. 2020.

[8] J. Hong, C. Zhou, Y. Wu, R. Wang, and D. Marinova, “Technology gap, reverse technology spillover and domestic innovation performance in outward foreign direct investment: Evidence from China,” *China World Economy*, vol. 27, no. 2, pp. 1–23, Mar. 2019.
[9] P. L. Ghazalian and F. Amponsem, “The effects of economic freedom on FDI inflows: An empirical analysis,” Appl. Econ., vol. 51, no. 11, pp. 1111–1132, Mar. 2019.

[10] H. B. Guo, “Research on the influence of OFDI on Jiangsu’s regional innovation capability,” J. Asian Stud., vol. 23, no. 3, pp. 427–448, Aug. 2020.

[11] B. Han, “Does China’s OFDI successfully promote environmental technology innovation?” Complexity, vol. 2021, pp. 1–13, Mar. 2021.

[12] Z. Li, J. Li, and B. He, “Does foreign direct investment enhance or inhibit regional innovation efficiency?” Chin. Manage. Stud., vol. 12, no. 1, pp. 35–55, Mar. 2018.

[13] H. Mühlen and O. Escobar, “The role of FDI in structural change: Evidence from Mexico,” World Economy, vol. 43, no. 3, pp. 557–585, Mar. 2020.

[14] N. U. Rehman, “FDI and economic growth: Empirical evidence from Pakistan,” J. Econ. Administ. Sci., vol. 32, no. 1, pp. 63–76, May 2016.

[15] Z. Shen and F. Puig, “Spatial dependence of the FDI entry mode decision: Empirical evidence from emerging market enterprises,” Manage. Int. Rev., vol. 58, no. 1, pp. 171–193, Feb. 2018.

[16] N. Vujanović, N. Stošić, and I. Hashi, “FDI spillovers and firm productivity during crisis: Empirical evidence from transition economies,” Econ. Syst., vol. 45, no. 2, Jun. 2021, Art. no. 100865.

[17] L. G. Branstetter, R. Fisman, and C. F. Foley, “Do stronger intellectual property rights increase international technology transfer? Empirical evidence from U.S. firm-level data,” Quart. J. Econ., vol. 121, no. 1, pp. 321–349, 2006.

[18] D. Christopoulos, N. Papageorgiadis, C. Wang, and G. Magkonis, “IPR law protection and enforcement and the effect on horizontal productivity spillovers from inward FDI to domestic firms: A meta-analysis,” Manage. Int. Rev., vol. 61, pp. 235–266, Apr. 2021.

[19] R. Falvey, N. Foster, and D. Greenaway, “Intellectual property rights and economic growth,” Rev. Develop. Econ., vol. 10, no. 4, pp. 700–719, 2006.

[20] P. C. Neves, O. Afonso, D. Silva, and E. Sochirca, “The link between intellectual property rights, innovation, and growth: A meta-analysis,” Econ. Model., vol. 97, pp. 196–209, Apr. 2021.

[21] R. L. Ostergård, “The measurement of intellectual property rights protection,” J. Int. Bus. Stud., vol. 31, pp. 349–360, Jun. 2000.

[22] N. Papageorgiadis, F. McDonald, C. Wang, and P. Konara, “The characteristics of intellectual property rights regimes: How formal and informal institutions affect outward FDI location,” Int. Bus. Rev., vol. 29, no. 1, Feb. 2020, Art. no. 101620.

[23] S. Stern and F. Murray, “Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis,” J. Econ. Behav. Org., vol. 63, no. 4, pp. 648–687, 2007.

[24] M. Zhao, “Conducting R&D in countries with weak intellectual property rights protection,” Manage. Sci., vol. 52, no. 8, pp. 1185–1199, Aug. 2006.

[25] G. Schweiger, H. Nilsson, J. Schoeeggl, W. Birk, and A. Posch, “Modeling and simulation of large-scale systems: A systematic comparison of modeling paradigms,” Appl. Math. Comput., vol. 365, Jan. 2020, Art. no. 124713.

[26] K. Saeed, “Slicing a complex problem for system dynamics modeling,” Syst. Dyn. Rev., vol. 8, no. 3, pp. 251–261, 1992.

[27] W. M. Cohen and D. A. Levinthal, “Absorptive capacity: A new perspective on learning and innovation,” Administ. Sci. Quart., vol. 35, no. 1, pp. 128–152, Mar. 1990.

[28] M. Runiewicz-Wardyn, “The role of knowledge absorption and innovation capability in the technological change and economic growth of EU regions,” Int. J. Manage. Econ., vol. 39, no. 1, pp. 51–69, Oct. 2014.

[29] China Intellectual Property Development Report 2019. Accessed: Jun. 2, 2021. [Online]. Available: http://www.cnipa-ipdirc.org.cn/Upload/2020-09/202091892354.pdf

[30] Yearbook of Patent Cooperation Treaty 2020. Accessed: Mar. 18, 2021. [Online]. Available: http://www.wipo.int/ipstats

[31] Y. Barlas, “Formal aspects of model validity and validation in system dynamics,” Syst. Dyn. Rev., vol. 12, no. 3, pp. 183–210, 1996.

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