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Innovative China: R&D Subsidies, Patent Measures, and Productivity

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Executive Summary

The forthcoming fourteenth Five-Year Plan (2021-2025) emphasizes innovation as the driving force to double China's GDP and income per capita until the year 2035, implying five percent annual output growth. China's innovative and economic performance, however, is less outstanding than often perceived, and there is still a long way before it reaches the status of a high-income country. Government intervention, either through subsidies or state ownership of firms, has often resulted in poor outcomes, when compared with market-based alternatives. In other words, market-oriented reforms have been more important to economic performance than subsequent government intervention in these markets. Notwithstanding China's substantial increase in innovation activity, productivity growth in the overall economy and manufacturing industries fell by half or more than half after the global financial crisis. Moreover, efficiency gains appeared largely within incumbent firms, whereas typical productivity gains from entry, exit or reallocation diminished or turned negative because of policy distortions.

While China's increasing innovation efforts may have prevented an even more severe productivity decline, returns to catching-up oriented R&D are diminishing, as China is closing in on its distance on the global knowledge frontier. At the same time, China faces more political restrictions abroad in accessing foreign cutting-edge technology. The increasingly inward-looking and mission-driven nature of Chinese innovation policy suggests that research productivity might continue to decline faster in China than elsewhere. Innovation policy, in general, may contribute to diminishing research productivity if additional R&D has lower economic returns than privately funded projects. Explicitly mission-driven policy may be even more harmful if government-supported technologies that contribute to strategic government purposes, such as national security, turn out to be economically inferior compared to the choice of the market. While China's innovation policy often addresses cutting-edge innovation and prestige projects, the desire to leap frog and move into radically new products and technologies may come at huge opportunity costs. In other words, results may be occasional Sputnik moments in galaxies of mediocracy.

Industrialized countries that find themselves exposed to greater competition from China should avoid premature conclusions that link China's apparent technological prowess to its industrial policy and (state-owned) national champions. If anything, the evidence suggests that economic achievements were realized not because of excessive government involvement, but despite such interventions. China's mission-driven, top-down innovation policy not only limits curiosity- and market-driven research, but also increases the likelihood of government failure. Instead of addressing funding deficiencies in the innovation system, R&D subsidies instead crowd-out private investments in R&D and fail to generate long-term productivity gains. Likewise, patent subsidies not only support financially constrained firms in the protection of intellectual property, but rather lead to disproportionate and excessive filings of low-quality patents. In a nutshell, China's innovation policy is sometimes effective but seldom efficient.

Greater market-oriented reforms would not only benefit the Chinese economy, but would also help to address concerns of foreign businesses and governments regarding unfair competition and strategic acquisition of technology through enterprises ultimately controlled by the party. Tariffs on Chinese imports, restricted technology transfer, screening of Chinese overseas investments and acquisitions, as well as the relocation of production sites from China to other countries signal the beginning of such disengagement. China is now at a crossroads between further opening-up and greater self-sufficiency. Eventually, greater market-oriented reforms may not only enhance China's access to the global research and technology frontier but also provide the opportunity for innovation that powers China's productivity growth.

1. Introduction

Since China initiated economic reforms in 1978, its economic performance has been remarkable. Between 1978 and 2007, the economy reached outstanding output growth of more than 8% annually (Zhu, 2012). However, the pace of output and productivity growth in the overall economy, as well as manufacturing industries in particular, has been slowing more recently (Bai and Zhang, 2017). While growth in gross domestic product (GDP) reached a peak of 14.2% in 2007, it has since declined to 6.1% in 2019 – the lowest rate in thirty years. Investigations into the accuracy of Chinese GDP accounting have shown that actual growth may even be between 1.8 and 2.6 percentage points lower than officially reported (Chen et al., 2019; Hu and Yao, 2019). Either way, further growth is needed for China to avoid the so-called 'middle income trap'. Despite four decades of ongoing development, Chinese GDP per capita level (purchasing power parity) has yet to reach the average income level of an upper-middle income country.

Against this backdrop, the Chinese State Council strives for greater innovation-driven[1] growth and world leadership in science and technology by 2050 (State Council, 2006). This ambitious target is supported by government policies that not only provide incentives for more research activities, but also lay out a mission-driven direction for innovation. Both China's research and development (R&D) expenditures, important inputs for innovation, and patent applications, a widely used measure for innovation output, have increased substantially since the turn of the century. Nonetheless, it remains unclear how far previous market reforms and the government's attempts to correct market failures and guide technological advances, e.g. through subsidies, have led to such increases. Instead of addressing funding deficiencies in the Chinese innovation system, R&D subsidies may instead crowd-out private investments in R&D, or allocate resources towards less productive activities. Likewise, patent subsidies may not support financially constrained firms in the protection of intellectual property, but rather lead to disproportionate and excessive filings of low-quality patents. If China fails to generate innovation that matters for output and productivity growth, both global leadership in science and technology and higher levels of income might move beyond reach.

Productivity Slowdown

As an international comparison, China's productivity level is equal to approximately one-third of that of the U.S.[2] Annual total factor productivity (TFP) growth in the overall economy fell sharply from a relatively high 2.8% in the early 2000s to 0.7% between 2009 and 2018 (Brandt et al., 2020). Since the beginning of the Reform and Opening-Up Policy in 1978, the contribution of TFP to Chinese GDP growth has steadily declined, and has been compensated instead by increasing investments in physical capital. In China's important manufacturing industries, average annual TFP growth was 2.0% between 1998 and 2007, determined by the entry and exit of firms, resource allocation towards *less* productive firms, and efficiency gains within incumbents (Brandt et al., 2020). Strikingly, TFP growth fell by half between 2007 and 2013 to 1.1% and efficiency gains appeared largely within incumbents, whereas contributions from entry, exit or reallocation diminished or turned negative.[3] Notably, more than a quarter of China's manufacturing sectors has experienced overall negative TFP growth in recent years (Brandt et al., 2020).

[1] "Innovation" is defined according to the Oslo Manual (2018): "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."
[2] Industrial labor productivity has surged from around 13% of the U.S. level in 1997 to 33% in 2015. Similarly, productivity in services has also risen from around 10% to 29% (Zhu et al., 2019).
[3] In value-added terms, the corresponding decline is from 8.0% to 4.4%. The key source of this decline occurs because entry of new firms no longer contributes positively.

Although a slowdown in productivity growth is a global phenomenon, the recent decline in China is all the more surprising given the economy's substantial room for catch-up. While China is already the largest economy globally, as measured by GDP (purchasing power parity), its productive efficiency has been stagnating. However, if China aims to catch-up with high-income countries a necessary condition is to accelerate productivity growth, as summarized by Brandt and Rawski (2019): "Looking ahead, China's shrinking labor force, diminishing returns to investment, and the declining growth rate for capital formation arising from economic rebalancing toward consumption all ensure the continued dominance of productivity increase as the key determinant of future growth."

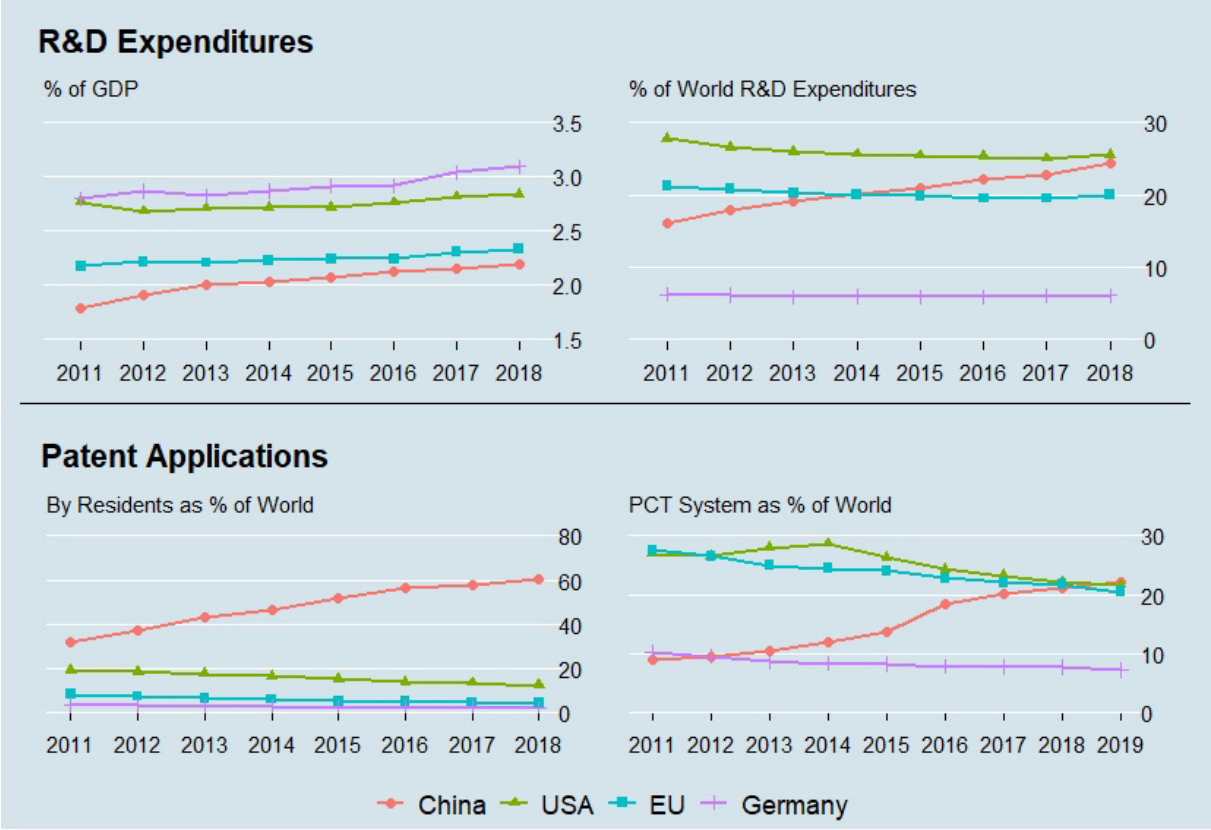
Innovation Speedup

In more developed economies, the decreasing growth contribution of capital accumulation is typically reconciled by technological progress – hence innovation becomes increasingly important to a country's development path (Aghion and Howitt, 2009). Indeed, China has had a persistent policy target to increase R&D among domestic firms since the late 1990s. The gross R&D expenditure target of the Chinese government in 2020 is approximately one-quarter of total global R&D spending. As for patents, though China is the leading global power in domestic patent applications, it also seeks leadership in international applications made under the Patent Cooperation Treaty (PCT). Such targets have been accompanied by numerous support instruments, and there has been a shift toward more mission-oriented policies, under which firms receive preferential funding for R&D projects that comply with the government's more explicit innovation agenda (Cao et al., 2013).

A comparison among international indicators suggests that China has already made remarkable progress in innovation inputs and outputs, i.e. R&D and patents (Wei et al., 2017). Figure 1 shows Chinese R&D expenditure as a proportion of GDP, which was 2.19% in 2018, higher than expected given Chinese per capita income (World Bank, 2020). In absolute terms, Chinese R&D expenditure is positioned slightly behind the U.S., and accounted for 24.37% of global R&D outlays in 2018 – while the U.S. accounted for 25.56%. Chinese firms supply three-quarters of total domestic R&D spending, above the OECD average of two-thirds, and approximately one-third of such spending comes from state-owned enterprises (Molnar, 2017). In line with growing R&D expenditure, China has decreased the average deficit in intellectual property receipts and payments, a rough proxy for dependence on foreign technology, from 15.9% to 10.2% of R&D expenditures between the 2000s and 2010s respectively. In parallel, Chinese innovation output has substantially increased. China accounted for a remarkable 60.74% of worldwide patent applications in 2018 and for the first time ranked first in PCT applications in 2019 (WIPO, 2020).

The crucial question is, however, whether China's innovation policy has been conducive to such achievements and whether Chinese innovation efforts are sufficiently rewarded by economic returns.

Figure 1: China's R&D expenditures and patent applications in international comparison



Notes: We consider 28 EU-member countries between 2011 and 2019. The EU's Gross Expenditures on R&D (GERD) as percentage of GDP represents a weighted average, according to each member country's contribution to the EU's GERD in purchasing power parities (PPPs). The EU's unweighted average is lower than the weighted average. Patent applications measure applications by residents with the national patent office or with the receiving office of the World Intellectual Property Organization (WIPO). Data is from World Bank, OECD and WIPO.

2. R&D Subsidies, Patent Measures & Productivity Returns

Effectiveness of R&D Subsidies

The key rationale for public R&D subsidies is a suboptimally low level of R&D investment, as a result of market failure caused by a public goods issue of 'non excludability' and financial constraints (Hall, 2008). An equally valid concern, however, cautions that public funds are ineffective as they may crowd-out privately financed R&D spending (Zúñiga-Vicente et al., 2014). Despite the considerable importance of Chinese R&D policy, few studies have evaluated the causal effects of R&D subsidies on private R&D expenditures by Chinese firms. Such empirical evidence suggests that the effectiveness of grants has increased with the introduction of the seminal 'Medium- to Long-term Plan for Science and Technology Development (2006-2020)' (MLP) after 2006, from partial crowding-out pre-2006 (Boeing, 2016) to additionality, observed since 2006 (Liu et al., 2016; Hu and Deng, 2018). However, the finding that R&D policy has become more effective over time was only established for the subpopulations of high-tech and privatized firms, respectively, which may have resulted in stronger and more positive effects of grants compared to the wider population of firms. Indeed, by analyzing the first decade of the 21st century, Boeing and Eberle (2019) confirm a partial crowding-out effect for the population of large- and medium-sized enterprises in China. They also show that R&D subsidies tend to increase non-research related investments in residential buildings, suggesting some misallocation of public funds.

Boeing and Peters (2019) observe the misappropriation of R&D subsidies by Chinese firms between 2001 and 2011 to show the effectiveness of such a policy in the presence of misappropriation, compared with the efficacy in a counterfactual scenario without misappropriation. Their study addresses the consequence of such noncompliant behaviors on the effectiveness of R&D policy in stimulating firms' R&D expenditures and contributes several important findings: First, in accordance with previous studies on China, R&D policy is found to have a partial crowding-out effect. In other words, R&D subsidies have increased total R&D expenditure, but by less than the total value of the subsidies. Second and most strikingly, policy efficacy is, in fact, more than twice as great as the effectiveness in the scenario with compliance. Simply put, misappropriation reduces the policy effect by half. Taken together, this shows that the design of Chinese R&D policy works towards additionality in principle, but better monitoring is advisable in order to fully exploit such a policy's potential. Third, they find full crowding-out for state-owned recipients of R&D subsidies, suggesting that these firms, in contrast to private firms, are not financially constrained. Noticeably, both effectiveness and counterfactual efficacy of R&D subsidies have significantly improved after policy changes introduced by the MLP. While both misappropriation and policy design rendered R&D subsidies ineffective before 2006, misappropriation has continued to undermine the efficacy of Chinese R&D programs thereafter. In essence, the full potential of China's R&D policy has not been realized yet.

Patent-based Innovation Measures

It is well documented that Chinese patent subsidies have contributed to an increase in patent quantity (Dang and Motohashi, 2015; Li, 2012). Given that a rational agent will apply for a patent if the expected value exceeds the cost of patenting, a cost reduction, e.g. through subsidies, disproportionately incentivizes the filings of inferior patents (Griliches, 1990). Hence, Chinese innovation policy may increase the quantity of patents, but incentivize applications of a lower quality. Boeing and Mueller (2019) address the challenges of empirically assessing Chinese patent quality. One such issue is that China's patent office does not publicly disclose citation data, which is widely used to measure patent quality. Moreover, even if citations were observable, further problems would arise. Citation inflation through an increase in subsidy-induced, low-quality patent applications may introduce an upward bias of such a measure over time, resulting in an over-optimistic assessment of Chinese innovation capacity. The authors instead analyze Chinese patent quality by comparing domestic citations to foreign ones, which are invariant to Chinese economic policy, as economic indicators. International comparability of citations is ensured by restricting the analysis to citations generated by international search reports in the PCT system.

The use of foreign citations shows that Chinese PCT patent applications represent merely a third of the non-Chinese quality benchmark, whereas upon including domestic- and self-citations, the quality level converges to, or even surpasses, the international benchmark. Thus, the authors conclude that, in China, only foreign citations, not domestic- and self-citations, are a valid indicator of patent quality. Comparing this with Germany, as a representative country without patent subsidies, the authors show that all three citation types may be used as economic indicators if policy distortion is not a concern. In conclusion, the results show that, in China, domestic- and self-citations suffer from an upward bias in quality, and should be employed with caution if they are to be interpreted as such. More generally, the findings support the concern that indicators fail as reliable measures if they become the target of policy.

Comparing the technological capacities of the top-five global innovative economies between 2001 and 2009, Boeing and Mueller (2016) show that the expansion of Chinese PCT applications has occurred to the detriment of quality. Although China has undergone an unforeseen increase in patent applications, its technological capacity has increased less than would be expected when only the number of patent

applications are taken into consideration. With a mean value of 32.1%, China's patent quality is significantly below that of the benchmark group (100%), which consists mainly of high-income countries. However, there is heterogeneity according to technologies and China ranges from 27.5% in electrical engineering to 42.2 % in consumer goods and construction, while the fields instruments, mechanical engineering, chemistry, and process engineering are in between (in ascending order). From a global perspective, the U.S. leads with an average value of 123.3%, followed by Korea (93.5%), Germany (71.9%), Japan (59.6%), and China (32.1%). From a regional perspective, this analysis also underlines that Western supremacy in innovation is not set in stone and has gradually shifted towards Asia.

Research Productivity & Returns to Innovation

Considering R&D input levels in the U.S., a recent study has shown that steady increases in inputs are coupled with constant output growth, at best, implying that research productivity is actually declining over time (Bloom et al., 2020). China has exhibited a very rapid expansion of research inputs since the turn of the century. However, the deflation of firms' R&D expenditures as measured by the nominal wage rate for Chinese researchers shows that the resulting output growth is less than proportional to such inputs. During the first and second decades of the 21st century, a 21.9% growth rate for effectively employed researchers is coupled with a 23.8% *decrease* in estimated research productivity (Boeing and Huenermund, 2020). In other words, ever more R&D inputs are needed to keep output growth constant. China has undergone a large decline in research productivity in the last two decades, which also reflects its rapid transformation towards innovation-led growth, from initially low levels of R&D. While further investigation is needed to distinguish between decreasing returns on R&D and suboptimal choices of R&D projects, the hitherto analysis also puts China's subsequent increase in R&D inputs into perspective. Ideas are not only getting harder to find in high-income economies like the U.S. and Germany, but the same holds true for the largest R&D spender in Asia. If China's future innovation policy will indeed support self-sufficiency to the detriment of access to global knowledge spillovers, productivity growth will be even harder to sustain. In addition to this, China's development will be affected detrimentally if indigenous innovation turns out to be less powerful than envisioned by Chinese policymakers.

Within this context, the following question needs to be addressed: what are the productivity returns to R&D expenditures and patent applications by Chinese firms? Boeing et al. (2016) investigate this question for the decade between 2001 and 2011. They estimate an elasticity of TFP to patent applications that ranges from 0.013 to 0.051 (depending on firm ownership and the quality of patents). These results are similar to those found in Fang et al. (2016), where such an elasticity ranges from 0.014 to 0.050 (depending on the method by which TFP is computed), larger than that observed in the U.S. Furthermore, Boeing et al. (2016) show that, overall, strong increases in the size of patent stocks are related to diminishing positive, or even vanishing, productivity returns. While there were productivity gains from patenting between 2001 and 2006, such an effect did not persist for state-owned enterprises since 2007. Similarly, private firms not only gained higher returns from R&D than state owned firms, but they also performed more sophisticated innovation, related to higher productivity gains.

Boeing et al. (2016) detail several key findings. Overall, private firms are more exposed to competition which appears to increase R&D effectiveness. Second, a strong increase in patent applications does not directly translate into productivity gains, but on average exhibits decreasing marginal returns. For state-owned enterprises, which are more responsive to government targets, patents have become disconnected from productivity growth. This finding challenges the benefits of patent subsidies, as it seems that they not only fill gaps in financing the protection of intellectual property, but also lead to an expan-

sion of low value patents, to the detriment of China's average patent quality. Third, the study also documents very limited benefits from (international) R&D collaborations with enterprises, universities and research institutes, suggesting that between 2001 and 2011, the absorptive capacity of Chinese firms was largely insufficient to benefit from formal (international) knowledge spillovers.

3. Discussion and Policy Implications

Based on the prior review, two main findings stand out. First, China's innovative and economic performance, on average, is less outstanding than often perceived and there is still a long way to go before it reaches the status of a high-income country. Second, government intervention, either through subsidies or state ownership of firms, has often resulted in poor outcomes when compared with market-based alternatives. In other words, market-oriented reforms have been more important to Chinese economic performance than subsequent government intervention in these markets. Either way, China has clearly increased its innovation activity, but the question remains why this innovation acceleration has not boosted recent productivity growth.

Two worthwhile areas of further investigation stand out. First, China's share of basic research in total R&D has hovered consistently around the 5% mark during the last two decades, whereas high-income countries typically have shares between 15% and 20% (UNESCO Institute for Statistics, 2020). Though R&D also includes applied research and development, basic research is the main driver of breakthrough scientific discovery, cutting-edge technology and radical innovation. Conversely, much of China's R&D has supported the absorption and adaptation of existing knowledge and technologies, potentially resulting in more certain economic outcomes. Incremental, bottom-up innovation has offered significant returns, in particular to private firms. Given that China's per capita income barely reaches a quarter of that in the U.S., there is enormous room for applied R&D that will help to lower costs and improve products – and hereby maintain China's competitiveness without pushing the global technology frontier through basic research. Second, there is a substantial difference between *correcting* market failure vs. *directing* technological change. While the first allows for blue sky research, the latter at best allows for creativity within predetermined intellectual silos. China's mission-driven, top-down innovation policy not only limits curiosity- and market-driven research, but also increases the likelihood of government failure in policy design. The government might either unintentionally support technologies that are economically suboptimal, or intentionally prioritizes technologies that contribute to national security where economic gains are of second-order importance. While China's innovation policy often addresses cutting-edge innovation and prestige projects, the desire to leap frog and move into radically new products and technologies may come at huge opportunity costs. In contrast, the Chinese economy may realize substantial efficiency gains in the medium term by moving towards the global technology frontier as a whole instead of pushing a few research projects beyond that frontier.

Without its innovation efforts, however, China's productivity decline might have been even more severe, as exemplified by additional economic problems. First, rapid economic growth is usually followed by a slowdown, due to diminishing returns to higher levels of physical and human capital. Second, adoption of technologies from high-income economies has been an important productivity source, but has gradually abated as China converges to the global technology frontier and has less access to existing, advanced technology abroad. Third, the Chinese economy has experienced a structural transformation from manufacturing to services, in which there are typically lower productivity rates among workers than those in former manufacturing industries. Finally, a deterioration in the efficiency of resource allocation may lead to resource misallocation toward less efficient firms and sectors, which is often associated with state ownership.

Incomplete reforms to the state-owned sector are a well-known concern to economists, both in China and abroad. During 1978-2007, the state sector "contributed essentially zero to aggregate growth in total factor productivity" (Zhu, 2012). Negative externalities extend beyond the state-owned firms themselves to the sectors and regions they inhabit: "in almost every dimension – the rate of start-up of new firms, size of firms, TFP, and wages - . . . new firms are weaker where the SOEs are more dominant" (Brandt et al., 2019). While the private sector provides the major share of domestic employment and output, state-owned enterprises dominate 'strategic' industries but suffer from low efficiency, despite wide-scale political support (Li, 2020). Competitive neutrality, market-based resource allocation, as well as unrestricted entry and exit across as many sectors as possible would increase productivity in the overall economy, while the presence of state-owned enterprises should be restricted to natural monopolies and sectors related to national security (Li, 2020). State-ownership may also benefit from corporate governance reforms to reduce conflict between ownership and control, as well as profit and policy orientation (Rong et al., 2017).[4]

Such reforms would not only benefit the Chinese economy, but would also help to address concerns of foreign businesses and governments regarding unfair competition and strategic acquisition of technology through state-owned enterprises. Tariffs on Chinese imports, restricted technology transfer, screening of Chinese overseas investments and acquisitions, as well as the relocation of production sites from China to other countries signal the beginning of such disengagement. China is now at a crossroads between further opening-up and greater self-sufficiency (State Council, 2020).[5] It remains to be seen if any such road will lead to world leadership in science and technology before 2050. Industrialized countries that find themselves exposed to greater competition from China should avoid premature conclusions that link China's apparent technological prowess to its mission-driven policy agenda and (state-owned) national champions. If anything, the evidence suggests that economic achievements were realized not because of excessive government involvement, but despite such intervention. Eventually, greater market-oriented reforms may not only enhance China's access to the global research and technology frontier but also provide the opportunity for innovation that powers China's productivity growth. From a policy perspective, the upcoming fourteenth Five-Year Plan (2021-2025) emphasizes more innovation to double China's GDP and income per capita until 2035, implying output growth rates of around five percent annually. Respectively, the required R&D inputs will be substantial. The design and implementation of China's upcoming "National Medium and Long-term Science and Technology Development Plan (2021-2035)" will detail further innovation goals and supporting policies along that road.

[4] Conversely, recent attempts to increase the United Front's influence in China's private economy may give rise to more policy-oriented investments (China Daily, September 17th 2020).

[5] For the time being, China's government pursues opening-up and self-sufficiency in parallel. While acknowledging China's current dependence on foreign core technologies in certain fields, the long-term policy goal is to end such dependency (President Xi's speech at a Scientist Forum, September 11th 2020) and to reverse it to allow "artificially cutting off supply to foreigners" while China's domestic supply system "operates normally in extreme situations" (President Xi's speech at the 7th Meeting of the Central Financial and Economic Affairs Commission, April 10th 2020). Concepts such as "domestic and international dual circulation" – China's economic size may be leveraged to enhance domestic self-reliance, global competitiveness, and foreign dependence on Chinese technology – as well as "military-civil integration" suggest that the policy relevance of innovation extends beyond economic development.

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