ธนาคารแห่งประเทศไทย
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ก้าวข้าม Middle Income Trap: บทบาทของการลงทุนในโครงสร้างพื้นฐาน

Growth Management for Thailand: the Role of Infrastructure

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ธนาคารแห่งประเทศไทย

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ข้อคิดเห็นที่ปรากฏในบทความนี้เป็นความเห็นของผู้เขียน
ซึ่งไม่จำเป็นต้องสอดคล้องกับความเห็นของธนาคารแห่งประเทศไทย

บทคัดย่อ

บทวิจัยนี้มุ่งศึกษาบทบาทการลงทุนในโครงสร้างพื้นฐานเชิงกายภาพของไทยเพื่อช่วยยกระดับรายได้ประเทศไทยให้หลุดพ้นจาก Middle Income Trap เพื่อตอบคำถามว่าภาครัฐควรลงทุนในโครงสร้างพื้นฐานทางกายภาพอย่างไรให้เกิดประสิทธิผลสูงสุดต่อการผลิตภาคอุตสาหกรรมภายใต้ข้อจำกัดด้านงบประมาณ ผลการศึกษาเสนอแนะยุทธศาสตร์การลงทุนอย่าง “กระจุกตัว” ในพื้นที่ที่มีศักยภาพ โดยเฉพาะโครงสร้างพื้นฐานที่มีลักษณะเป็นโครงข่าย (network) เพื่อสนับสนุนการสร้าง hub ของภาคอุตสาหกรรม โดยเฉพาะอย่างยิ่งอุตสาหกรรมที่ใช้เทคโนโลยีสูงที่มีลักษณะเป็น increasing returns to scale ซึ่งจะได้ประโยชน์จากการมี hub ของภาคอุตสาหกรรมมากกว่า โดยเฉพาะผลผ่านช่องทางหลักคือการถ่ายทอดและแลกเปลี่ยนองค์ความรู้ระหว่างกัน (knowledge spillover) ที่สูง ซึ่งจะช่วยสนับสนุนการยกระดับภาคอุตสาหกรรมไทยและช่วยผลักดันให้ไทยก้าวพ้นจาก Middle Income trap ได้ในที่สุด ทั้งนี้ การพัฒนาโครงสร้างพื้นฐานทางกายภาพดังกล่าวต้องทำควบคู่ไปกับการพัฒนาโครงสร้างพื้นฐานทางสังคมด้วยเพื่อให้การยกระดับประเทศเป็นไปอย่างยั่งยืนและรอบด้านในระยะยาว

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บทสรุปผู้บริหาร

ไทยเป็นประเทศ Middle Income มาตั้งแต่ธนาคารโลกเริ่มจัดกลุ่มประเทศตามระดับรายได้ครั้งแรกเมื่อปี 1987 และขณะนี้แสดงอาการหลายอย่างของประเทศที่ติดอยู่ใน Middle Income Trap เช่น (1) มี GDP growth และการลงทุนที่ชะลอตัว โดยเฉพาะการลงทุนอยู่ในระดับที่ไม่เพียงพอต่อการ “take-off” ของระบบเศรษฐกิจ และ (2) การพัฒนาและสั่งสมองค์ความรู้อยู่ในระดับต่ำ ซึ่งทำให้ไม่สามารถพัฒนาสินค้าและบริการให้มีมูลค่าเพิ่มสูงขึ้นเพื่อ “move up the value chain” ได้เท่าที่ควร

แล้วไทยจะก้าวขึ้นเป็นประเทศ High Income ได้อย่างไร ไทยต้องปฏิรูปภาคอุตสาหกรรมโดยให้ความสำคัญกับภาคการผลิตที่เน้นนวัตกรรมและเทคโนโลยีระดับสูง โดยบทเรียนจากเกาหลีใต้และไต้หวันสะท้อนว่าไทยต้องเร่งลงทุนพัฒนาโครงสร้างพื้นฐานทั้งทางกายภาพ (เช่น สาธารณูปโภค และระบบขนส่ง) และทางสังคม (เช่น การปฏิรูปการศึกษา และการบังคับใช้กฎหมาย) ให้มีความพร้อม

บทวิจัยนี้มุ่งศึกษาบทบาทของการลงทุนในโครงสร้างพื้นฐานทางกายภาพของภาครัฐในการยกระดับรายได้ของประเทศ ซึ่งเป็นเรื่องที่ภาครัฐทำได้เร็วและเป็นรูปธรรมกว่าการพัฒนาโครงสร้างพื้นฐานทางสังคม เพื่อนำไปสู่ข้อเสนอแนะต่อภาครัฐว่าควรลงทุนในโครงสร้างพื้นฐานทางกายภาพอย่างไรให้เกิดประสิทธิผลสูงสุดภายใต้ข้อจำกัดด้านงบประมาณ ทั้งนี้ หากการผลิตภาคอุตสาหกรรมมีลักษณะ constant returns to scale (CRS) จะมีนัยเชิงนโยบายว่าการลงทุนในสาธารณูปโภคสามารถทำแบบกระจายตัวทั่วประเทศได้ แต่ในทางตรงกันข้าม หากการผลิตภาคอุตสาหกรรมมีลักษณะ increasing returns to scale (IRS) จะสนับสนุนกลยุทธ์การลงทุนแบบกระจุกตัวเพื่อสร้าง hub โดยในทางทฤษฎี IRS เกิดขึ้นได้จาก externalities ผ่านทางสามช่องทางหลัก ได้แก่ knowledge spillover (การถ่ายทอดและแลกเปลี่ยนองค์ความรู้ระหว่างกัน เช่น บริเวณ Silicon Valley) labor market pooling (ตลาดแรงงานในพื้นที่ที่ใหญ่ขึ้นจะทำให้มีทักษะของแรงงานตรงกับงานมากขึ้น) และ specialized intermediate inputs (ผู้ประกอบการแลกเปลี่ยน intermediate inputs ที่จำเป็นในกระบวนการผลิตได้สะดวก)

การศึกษาใช้ข้อมูลจากสำมะโนอุตสาหกรรมปี 2540 และ 2550 และข้อมูลการลงทุนภาครัฐในสาธารณูปโภคหลัก ได้แก่ ถนน ไฟฟ้า และน้ำประปา โดยถนนเป็นตัวแทนของโครงสร้างพื้นฐานที่มีลักษณะเป็นโครงข่ายและภาคเอกชนต้องพึ่งพาภาครัฐในการสร้างหรือจัดหามาก ขณะที่ไฟฟ้าและน้ำประปามีลักษณะดังกล่าวลดหลั่นลงไปตามลำดับ

ผลการศึกษาและนัยเชิงนโยบายที่สำคัญสรุปได้ ดังนี้

1. <u>ความเชื่อมโยงกับ growth</u> การลงทุนในโครงสร้างพื้นฐานของภาครัฐช่วยกระตุ้นการลงทุนของภาคเอกชน (K) และเพิ่มผลิตภาพแรงงาน (labor productivity) แต่ไม่มีผลต่อ capital deepening กล่าวคือไม่เปลี่ยน capital intensity (K/L) ของแต่ละภาคอุตสาหกรรม

2. <u>การผลิตภาคอุตสาหกรรมมี increasing returns to scale (IRS)</u> การลงทุนฯ ของภาครัฐในพื้นที่ที่มีภาคอุตสาหกรรมขนาดใหญ่ให้ผลคุ้มค่ามากกว่า สอดคล้องกับแนวคิดที่ว่า knowledge spillover, labor market pooling และ specialized intermediate inputs จะมีผลมากในพื้นที่ที่มีกิจกรรมทาง

เศรษฐกิจมาก แต่เมื่อเปรียบเทียบระหว่างการลงทุนในถนน ไฟฟ้า และน้ำประปา พบว่าการลงทุนในถนนมี IRS สูงกว่าการลงทุนในโครงสร้างพื้นฐานอีกสองประเภท เนื่องจากถนนมีลักษณะเป็นโครงข่ายเชื่อมโยงซึ่งเอื้อต่อการแลกเปลี่ยนและเคลื่อนย้ายปัจจัยการผลิต

3. <u>การลงทุนในโครงสร้างพื้นฐานที่มีลักษณะเป็นโครงข่าย</u> เช่น ถนน มีความสำคัญมากต่ออุตสาหกรรมที่มี capital intensity (K/L) สูง ซึ่งเป็นกลุ่มอุตสาหกรรมที่ใช้เทคโนโลยีในการผลิตและได้ประโยชน์จาก externalities เป็นอย่างมาก ขณะที่การลงทุนในไฟฟ้าและน้ำประปาเอื้อประโยชน์ให้กับอุตสาหกรรมที่มี K/L ต่ำ เนื่องจากผู้ประกอบการในอุตสาหกรรมเหล่านี้มักมีขนาดเล็ก ไม่สามารถจัดหาไฟฟ้าและน้ำประปาได้เอง

4. <u>ภาครัฐต้องลงทุนในโครงสร้างพื้นฐานอย่างมียุทธศาสตร์เพื่อยกระดับรายได้ของประเทศ</u> โดยหากต้องการผลักดันให้ภาคอุตสาหกรรมไทย “move up the value chain” ก็ควรเน้นลงทุนแบบกระจุกตัวเพื่อสร้างโครงข่ายของโครงสร้างพื้นฐานชนิดที่เอื้อต่ออุตสาหกรรมที่มี K/L สูงและภาคเอกชนทำเองไม่ได้ อาทิ สร้าง hub สำหรับอุตสาหกรรมที่ใช้เทคโนโลยีสูง ลงทุนแบบเชื่อมต่อกับโครงข่ายที่มีอยู่เดิมเพื่อเพิ่มผลด้านขนาด และทุ่มการลงทุนในพื้นที่ใหม่ที่มีศักยภาพเพื่อให้ประเทศไทยมีจำนวน hub มากขึ้น

5. <u>กำหนดพื้นที่ (zoning) สำหรับอุตสาหกรรมที่มี K/L ค่อนข้างต่ำซึ่งมักจะมีขนาดเล็ก โดยจัดหาโครงสร้างพื้นฐานเท่าที่จำเป็นให้</u> เพื่อให้การลงทุนในโครงสร้างพื้นฐานมีประสิทธิภาพมากขึ้นเพื่อช่วยลดต้นทุนให้ผู้ประกอบการ โดยสามารถทำร่วมไปกับนโยบายอื่นได้ เช่น การให้สิทธิประโยชน์ BOI ควรให้ในพื้นที่ที่จำกัดแทนที่จะให้สิทธิประโยชน์กระจายเป็นพื้นที่กว้าง เป็นต้น

ทั้งนี้ นโยบายด้านโครงสร้างพื้นฐานทางกายภาพต้องทำควบคู่กับการพัฒนาโครงสร้างพื้นฐานทางสังคม เพื่อให้การยกระดับประเทศเป็นไปอย่างยั่งยืนและรอบด้านในระยะยาว

Mere increases in inputs, without an increase in the efficiency with which those inputs are used–investing in more machinery and infrastructure–must run into diminishing returns; input-driven growth is inevitably limited.

- Paul Krugman (1994)

1 Introduction

Thailand has all the reason to celebrate when the World Bank, for the first time, upgraded the country to the rank of upper-middle income economy in July 2011. In addition to her GNI per capita that has almost doubled over the past decade alone, Thailand is also living in the dawn of the Asian Century, with Asia setting out to share more than half of the global GDP by 2050, provided that the region sustains its current growth path (ADB, 2011).

But one disturbing fact is that Thailand has been one of the "founding" members of the lower-middle income club since World Bank's debut income classification in 1987. Looking back in retrospect, Figure 1 should bring Thailand's failure in *keeping pace* with her friends into spotlight, let alone *catching up* with developed countries. Initially close to Thailand during 1950s, Taiwan and Korea have clearly embarked on the road to prosperity that leads them to high income status, while Thailand lost momentum early and stagnated at a relatively "comfortable" level of per capita income, soon to be outpaced by China. Despite the promise of the Asian Century, Thailand seems to risk being marginalized and caught in the so-called "Middle Income Trap".

Commentators often agree that Thailand - once an Asian superstar but now a tiring "fifth tiger" - failed to make the needed transition from resource-based to productivity-driven growth when the time was ripe. This same diagnosis has been given to Thailand time and again but coated under different terms - ranging from Jacobs (1971)'s description of Thailand as "modernization without development" to Doner (2009)'s more recent analysis that Thailand's growth success owed largely to her success in "sectoral diversification" rather than any transformative "upgrading" as experienced in the NICs.

So, what should Thailand do to reignite and sustain her growth momentum? With the global economic landscape continuously evolving, the Thai government must invest to improve Thailand's long-term competitiveness, graduating somehow beyond its recent short-sighted focus on stimulus and subsidy measures that cannot offer any permanent cure for the economy. Reflecting from experiences of successfully "upgraded" countries, we identify well-developed and adequate infrastructure to be a key *necessary* condition for success: while investing in infrastructure cannot guarantee these countries the high income status, they certainly cannot become high income economies with infrastructure of substandard or mediocre quality. By crowding in private sector's investment and enhancing labor productivity, public infrastructure investment can lead to sustained, productivity-driven growth that will pave Thailand's way out of the Middle Income Trap.

This paper explores the role of public infrastructure investment in moving Thailand up the global income ladder, and investigates in particular the presence of *increasing returns* in Thailand's manufacturing sector. The study is based on the premise that the government has a vital role in creating *external economies*, or the type of increasing returns owing to factors external to firms (e.g. conducive environment, well-connected network of infrastructure, etc.). We propose that by aiming strategically at creating such external economies, when and where possible, the government's money on infrastructure is effective both in the sense that its benefits on the manufacturing sector are multiplied, and in the sense that such investment can actually give rise to high-quality growth that will serve Thailand well over the long term.

While the notion of Middle Income Trap has been around for some time among Asian industrialists and policymakers, we believe that this study contributes in two meaningful ways. First, this paper adds more quantitative dimension to the Middle Income Trap dialogue, which often attempts to derive high-level policy recommendations that are motivated only by chosen pieces of stylized facts. The other contribution is the use of micro-level infrastructure and firm data in tackling these issues at hand. These datasets will also allow us to explore the spatial dimension of recent developments in Thailand's manufacturing sector and public infrastructure provision.

The rest of the paper is organized as follows. Section 2 discusses briefly on the so-called Middle Income Trap that Thailand is arguably facing, puts our study in a proper historical and international context, and highlights the significance of infrastructure development for high income economies. Section 3 empirically investigates whether public infrastructure investment has positive impacts on private investment and labor productivity in Thailand's case, and also explores the presence of increasing returns in Thailand's manufacturing sector. Section 4 outlines policy recommendations to address the Thai government's challenges on effective infrastructure investment. Section 5 then concludes the paper.

2 Avoiding the middle income trap: the role of infrastructure

We first provide an international, comparative context for our discussion and make the notion of Middle Income Trap, which is conceptual in nature, more concrete and quantifiable. We then aim to derive lessons from other countries - both from those who share the same destiny of being caught in the Trap and from those who already "made it" to the rank of high income. We then highlight the essential role of infrastructure development in countries that have successfully "upgraded" themselves to the high income status, and discuss on how public investment on infrastructure can help pave Thailand's way out of the middle income forest.

2.1 The "double-hump" in world income distribution

While Figure 1 may count as a quick evidence for cross-country income divergence, we proceed to examine the world income distribution and Thailand's relative position more closely. Based on Quah (1993)'s celebrated notion of "twin peaks", we estimate the density of cross-country per-capita income distribution over the past four decades. In doing so, we follow Quah by employing standard smoothed kernel estimation using real GDP per capita of 112 countries in 1979, 1989, 1999, and 2009. Our smooth kernel technique is justified by Robinson (2011), who established consistency and asymptotic normality of the smoothed kernel estimate even in the presence of spatial dependence. We employ the standard Gaussian kernel with bandwiths of 1000, 1500, 2000, and 2500 for the 1979, 1989, 1999, and 2009 data, respectively. For our illustrative purpose, choosing bandwidths is not a serious issue: they are chosen to smooth out noises and make it easier for our readers to notice developments of patterns in the global scale together with Thailand's relative performance.

Has the world income distribution really changed over the past four decades? Not much at all. Figure 2 testifies that although we see improvements in absolute income per capita across the board, the world income distribution exhibits a "double-hump" feature, where countries cluster into two humps corresponding to low and high levels of income. This pattern, interestingly, persists throughout the four decades that we study. We also see that Thailand has been struggling along the global income ladder for ages, but failed to make any noticeable improvement in terms of her relative income position. In contrast, Taiwan and Korea started climbing the "rich" hump in 1990s, then continued to keep their relative distance with Malaysia and Thailand - and also China, which has almost closed its gap with Thailand. Moreover, the thinly distributed areas between the two humps also suggest the presence of some barriers in moving from the poor hump to the rich one. These results teach us an important lesson that catching up is by no means easy or given - only those who have put enough efforts can "make it" at the end.

2.2 Checklist: four common symptoms

We now proceed to identify countries that are caught in the Trap, aiming to extract key common features of these countries to better understand Thailand's case and also the Trap itself. For this purpose, we have to construct our own income criteria alternative to World Bank's for two main reasons. First, World Bank's income categorization can be dated back only as far as 1987, and we do not want to miss out lessons learned during the earlier part of the 20th century. Second, World Bank's classification is based on GNI per capita, which, for certain countries, was not available until recent decades.

Given the limitations above, we construct our income classification criteria based on GDP per capita. We identify a country to be *upper-middle income* for a particular year if its real GDP per capita falls between 20 and 49 percent of that of the US. We then define a country to be *caught* in the *Middle Income Trap* if it remains in the upper-middle income group for 10 years or longer. While these cut-offs are subjective to some degree and far from being perfect measures of a country's level of economic development, they are calibrated so that the resulting classification of major countries reasonably resembles World Bank's classification during the overlapped years (i.e. 1987-2010).

Table 1 and Figure 3 show the countries that our income criteria identify as arguably being caught in the Trap. To investigate what these patients have in common, we pick five sample countries ("UM5") for a closer examination. The UM5 group consists of two countries from East Asia (Malaysia and Thailand), two from Latin America (Brazil and Mexico), and another from a different socioeconomic background (Turkey). For the purpose of benchmarking, we compare UM5 countries with Korea, a high income nation that our criteria identify as being trapped for 20 years from 1973 to 1992; and also with China, a competent low-wage rival that has been classified as "upper-middle" for the first time in 2007, thus not yet trapped according to our criteria.

We find that UM5 countries share four common symptoms below. Since this part is intended to provide only a brief overview of the symptoms, we refrain from discussing these issues in-depth here.

Growth slowdown and insufficient investment

Figure 4a shows that output growth in UM5 countries often subsided after a period of strong growth that propelled them from low-income economies to middle-income ones. And as Figure 4b shows, the slowdown was often accompanied by a decline or stagnation of investment share in GDP. Among the UM5 countries, this characteristic is most evident in the case of Brazil and Mexico.

For a middle-income economy to "take off", its gross investment should sustain at a relatively high rate over an extended period of time, since investment is accumulative in nature and private and public capital stock existing in the economy needs to be large enough to accommodate growth. As shown in Figure 4c, UM5 countries fail to sustain their investment at a level high enough to reach a *criticial mass* necessary for their economies to take off, as benchmarked by Korea's average from 1979[1] to 2009. After the 1997 Asian Crisis, in particular, UM5 countries' gross investment remains substantially below the Korea benchmark, while China's investment seems to follow a distinctively higher path.

Low knowledge accumulation and innovation

Without enough domestic capabilities to develop new, innovative products that can generate higher value added for their economies, UM5 countries have had a difficult time moving "up the value chain". Generally speaking, high income countries give much higher priority on R&D activities compared to lower income countries. As Figure 5a shows, Korea's R&D expenditure amounted to 2.42 percent of GDP in 2006, almost 7 times of UM5's average of 0.36 percent of GDP. Despite some impacts of the 1997 Crisis on Korea's R&D spending[2], Korea staged not only a comeback but a glorious rise to secure its throne as one of the world's top innovation leaders, with its R&D spending totaling around 3.21 percent of GDP in 2007. In contrast, UM5's R&D spending continued to remain pitifully low, still densely located in the lower-left corner of the diagram. Of all the UM5 countries, Thailand's R&D spending seemed to stagnated the most, peaking around 0.26 percent of GDP in 2001 without any noticeable improvement since. Again, China's steep rise should be brought into spotlight. Developments in the number of researchers in Figure 5b also tell essentially the same comparative story, but with the gap between Korea and other countries widening at an even more startling pace.

Weak economic stability

History proves time and again that high economic stability is prerequisite to high and sustained growth. Persistent inflation pressures impede domestic growth, while high level of short-term external debt can render UM5 economies susceptible to external shocks. Figure 6a and 6b suggest that Thailand has done relatively well in these two indicators, especially when compared to countries in Latin America. Brazil, for instance, faced both inflation and debt crises following the second oil shock in 1973 and the surge of dollar interest rates in 1979 (Commission on Growth and Development, 2008).

[1] 1979 was the year that the Korean economy started taking-off noticeably according to many national income and growth variables.

[2] See also Figure 1, which shows clearly that Korea's income suffered gravely during the post-crisis year.

Political and social instability

Domestic instability deteriorates private sentiment terribly and often leads to policy discontinuation. History shows that even though some of the UM5 countries had their well-crafted national development plans ready in paper, they failed miserably when it came to implementation due to internal political and social tensions. Figure 7 suggests that the overall level of "fragility" - be it political, social, security-wise, or economic in nature - seems to be substantial in these countries. Throughout decades, Thailand, Brazil, and Turkey have witnessed relatively frequent incidents of military coups, protests, and various forms of civil violence compared to other middle- and high-income countries. And in contrast with Korea and Malaysia's laudable improvements over time, Thailand and Mexico's levels of fragility seem to be characterized by occasional swings between "good" and "bad" times.

Of all the four common symptoms discussed above, this paper focuses on addressing investment and innovation concerns through effective public infrastructure investment. The third symptom is not very serious since Thailand's economic stability has been relatively sound, while the fourth symptom is more institutional in nature and beyond our scope of study.

2.3 Three routes to prosperity, "upgrading", and the importance of "physical" infrastructure

Having learned from the losers, we also need to learn from the winners who have made it to high income status. From the pool of high income countries according to our income criteria, we identify three routes to prosperity that successful countries seem to follow, namely: *upgrading*, *economic integration*, and high income from *natural resource*. Table 2 summarizes these routes and sample countries that have been identified to follow each route. Of all these three routes, *upgrading* domestic industrial capabilities prove to be the most demanding and time-consuming, yet a permanently transformative one rather than a quick win. Given that the other two routes are somewhat beyond government's control, this seems to be the most promising solution for Thailand.

Experiences from successfully "upgraded" countries seem to suggest the significance of adequate and well-developed infrastructure. This includes both *social* infrastructure (e.g. education system, law enforcement, and government efficiency) and the more traditional *physical* infrastructure (e.g. highways, electricity, water, and ICT infrastructure). While we acknowledge the central role of social infrastructure in creating sustained and inclusive growth over the long term, this paper chooses to focus exclusively on physical infrastructure for two major reasons. First, this focus leads to policy implications that are more concrete, specific, and readily implementable. For example, while building clusters of high-tech industries definitely requires a large sum of money, such initiative is much more concrete and implementable than eradicating corruption. Second, physical infrastructure is an economy's *binding* constraint to economic development; without adequate infrastructure development, later stages of development can never take place. Physical infrastructure, in many cases, also serves as a starting point for social infrastructure upgrading - consider, for example, building more schools as a step towards making education accessible to all. And third, data on physical infrastructure are more detailed and clearly defined, as well as available further back in time. This third advantage should lend more credibility to our study results and implications.

Linkages between infrastructure and growth

Given the significance of infrastructure for Thailand's "upgrading", we now briefly discuss the impacts of infrastructure investment on growth and the linkage between infrastructure and growth. It is important to note that many studies treat infrastructure as *public* due to its heavy reliance on government provision. Also, a large number of studies treat *public investment* as a proxy of infrastructure investment, since it is often difficult to empirically disentangle infrastructure from public capital stock. Our discussion here, therefore, draws from all these related studies.

Although with some caveats, many empirical studies find the impacts of infrastructure investment on growth to be positive (e.g. Aschauer (1989), Easterly and Robelo (1993), etc.) At the same time, developments on the theoretical front suggest different implications on how these positive impacts might last: these benefits may be short-lived in the eyes of neoclassical economists, while more profound and long-lasting for those following the tradition of endogenous growth theory in the spirit of Romer (1987) and Romer (1990).

Conceptually, infrastructure development works its way to growth through three primary channels: (1) through its direct impact on public capital stock accumulation; (2) through its "crowding in" effects on private investment; and (3) through its benefits on productivity. Figure 8 provides a simple graphical summary of these channels. Note that in reality, all these three intermediate steps to growth - private investment, public capital stock, and productivity - are interlinked in nature. Consider, for example, higher labor productivity that leads to higher returns on private investment. Moreover, domestic growth also feeds back to infrastructure investment, since higher output may lead to higher saving and better means for financing available for the government. It is precisely the presence of this *reverse causality* that runs from growth back to infrastructure, or more generally public capital, that plagues many empirical studies that do not take care of the issue well enough. Past attempts include using instrumental variables (e.g. Aschauer (1989), who uses lagged investment), employing Granger causailty, and using data on stocks instead of flows (e.g. Arnold et al (2007)).

While infrastructure investment is often found to benefit growth, the positive impacts are not preordained. Past studies have pointed to possible variation in results across countries. Lars-Hendrik and Waverman (2001), for example, suggest that telecommunications infrastructure benefits OECD countries, but possibly not so for some others. In addition, the standard Keynesian framework also suggests the possibility of "crowding out" effects on private investment. The government's large investment projects on infrastructure increase demand for domestic inputs and funding, thus leading to higher price levels and interest rates and, eventually, higher costs for businesses. The impact of infrastructure investment, therefore, depends on how "crowding in" and "crowding out" effects offset each other. Fortunately, our focus on infrastructure for Thailand's "upgrading" is warranted by empirical evidence. For example, Aromdee, Rattnanubal, and Chai-anant (2005) suggest that "crowding in" effects dominate in Thailand's case. Employing the Bank of Thailand's Macroeconometric Model (BOTMM), they found that pass-through from interest rates to investment, which reflects "crowding out", is relatively small compared to the effect of growth on private investment, which reflects "crowding in".

Increasing returns through "external economies"

Still, one key question remains on how the Thai government should invest in infrastructure so that the investment effectively promotes sustainable, productivity-driven growth. Our empirical study in the next section is based on the premise that the government has a prime role in the creation of *external economies*, or the type of increasing returns owing to factors external to firms - including conducive business environment, well-developed infrastructure, among others[3]. By creating external economies, the government's money on infrastructure can support Thailand's manufacturing firms to benefit more fully from increasing returns.

Conceptually, external economies can manifest in three main forms, all of which benefit greatly from concentration of economic activities and well-developed network of infrastructure within the area. First, firms can benefit from *knowledge spillovers* that arise from firms'mutual exchange of knowledge. Populated by semiconductor manufacturers and high-tech firms, corporations and startups alike, Silicon Valley serves as a perfect breeding ground for cutting-edge innovations to emerge. It is the area where firms compete, collaborate, and co-innovate with one another. Second, firms and workers should benefit from *labor-market pooling*: deeper, larger labor markets should result in lower skill mismatches. And third, with firms in related industries concentrated in the area, input supplies can broaden their market, making it possible for them to provide highly *specialized intermediate inputs* that are sometimes needed in certain manufacturing activities, usually the more sophisticated ones.

[3] Distinction should be made between this and *internal economies*, which arises from within-firm factors such as firm's larger size that helps lower fixed costs on average.

3 Empirical investigation

We study the impacts of public infrastructure investment on private sector's investment, capital intensity, and labor productivity during the 1997-2007 period. In doing so, we employ micro-level data on firms from the 1997 and 2007 edition of Thailand's Industrial Census, and data on total infrastructure investment from 1997 to 2006 obtained directly from relevant authorities. We explore how the impacts on firms vary across industries and types of infrastructure - namely, highways, electricity, and water - down to district (*amper*) level. We carefully construct our data and develop our methodology to address the issues of reverse causality, measurement errors, and spatial dependence, which are often not satisfactorily taken care of in many empirical studies on infrastructure-growth linkages.

3.1 Data description and choice of variables

Firm data

For firm-level data, we choose to employ the latest two editions of the Industrial Census conducted by the National Statistic Office (i.e. the 1997 and 2007 editions), mainly due to their comprehensive coverage and large sample size. Alternatively, we could have used the Industrial Survey, which is conducted much more frequently. But in the survey, the number of firms included for *each industry* in *each district* is often too small due to the survey's relatively limited coverage. This issue could pose a serious problem to our study, since we also want to explore variation across industries and districts.

Of all the 23 manufacturing industries (at two-digit level of ISIC categories) covered in the censuses, our analysis focuses on seven industries (Table 3) that are chosen based on three criteria, namely: the industry's total number of firms in the censuses, the industry's total value added, and the industry's total number of workers. These criteria aim to concentrate our efforts on industries with all-around significance to Thailand's manufacturing sector. For each edition of the census, we consider only private, profit-seeking firms with more than ten workers. This cap at ten workers aims to avoid sampling errors since data for firms of this size or smaller in the census are obtained by sampling, whereas each and every firm with more than ten workers is included as an observation in the census. Another reason is to avoid measurement errors that should occur more frequently for small firms.

We employ four key variables for our regression analysis, all of which are aggregated at district level. For each district, (1) we define *private investment* as the district's total increase in book value of fixed assets, excluding land, over the 1997-2007 period. We are particularly interested in investment that contributes to productivity, so we exclude land because a significant portion of it does not contribute directly to firms' production. This is partly due to the fact that land is often hold merely as an asset in firm's portfolio or for speculative purpose. (2) We define *capital intensity* as the district's total book value of fixed assets divided by the district's total number of workers (i.e. including both paid and non-paid workers). (3) We define *labor productivity* as the district's total value added divided by the district's total number of workers. (4) And lastly, to represent the district's aggregare size of economic activity, we define *size* as the district's total value added. This variable is important in exploring the presence of "increasing returns", which benefits from concentration of economic activity within the district.

Two caveats deserve attention. First, even though we use the "1997" census, we manage to avoid distortion on our variables due to the 1997 Crisis since the census was in fact conducted in 1996. Second, our aggregation at district level benefits us in two ways. On one hand, this aggregation helps average out *measurement errors* that may occur at firm level. We also argue, on the other hand, that the district level is small enough to prevent *reverse causality* that runs back from growth to infrastructure. In other words, our working assumption is that each district, with all firms located in the district combined, is too small to have enough power to affect decision on public infrastructure provision. This is plausible in Thailand's case, since public infrastructure relies very heavily on the role of central government.

Infrastructure data

We choose to focus exclusively on three types of infrastructure, namely: highways, electricity, and water. Our choice of infrastructure is based on two reasons. First, these three infrastructures differ in terms of their dependence on government provision; or to put it differently, they differ in terms of private sector's *affordability*. Highways are interconnected across country and their construction costs are high, thus the high dependence on government provision. Electricity is more affordable to private firms, as we can see that some industrial parks and large businesses have built their own electricity substations for their own use. Among the three types of infrastructure, water is the most affordable one - consider, for example, the widespread ground-water welling by households. By considering these three infrastructures with various degrees of affordability, we can assess the role of government provision conveniently just by comparing their estimation results. Second, these three infrastructures are fundamental to all types of manufacturing activity, which should make them reasonable candidates since we also explore on how the impacts of infrastructure investment vary across industries.

What variables should we use to represent infrastructure investment? Ideally, we wish to obtain data on total infrastructure stock in 1997 and 2007, then treat the difference between the two data points as investment. But the task of obtaining or estimating stock of infrastructure in every district is daunting. Instead, we employ reasonable proxies for investment in each of the three infrastructure, as follows. (1) For electricity, we use each district's total capacities of transformers of every single substation in Thailand that has started its operation during the 1997-2006 period. We obtain these data directly from the Provincial Electricity Authority (PEA). (2) For highways, we use the Department of Highways (DOH)'s "proposed" annual budget for construction expenditure for each province. Using this variable at province level should not pose any problem to our analysis, since highways are interconnected across many districts. That is, the benefits of building highways in one district are unlikely to be limited only within that district. Moreover, if we use physical units to measure investment in highways, our data and results might be difficult to interpret meaningfully. For example, highways that are four-lane wide are qualitatively different from highways of other size. Using certain variables while omitting others, therefore, can lead to potentially misleading results. (3) Lastly, for water, we employ the Provincial Waterworks Authority (PWA)'s annual investment budget on service area expansion for each province. Although driven mainly by data availability, this choice of variable works fine since it captures an accumulative expansion in water-related infrastructure.

One small caveat for investment in highways and water is that we omit the 1998 observations. This is due to some cuts in budgetary spending that seemed to follow IMF's rescue package soon after Thai baht devaluation in July 1997. But for electricity, there is no need to remove the 1998 observation since we are already working in terms of physical units.

Geographical data

Besides firm and infrastructure data, we also obtain the most up-to-date[4] datasets of Thailand's political boundaries from the Ministry of Interior in the format of ESRI Shapefile, which contains coordinates of each sub-district (*tambon*)'s outer boundary. Based on this file, we compute each district's centroid, which is later used in our spatial econometric analysis.

Lastly, it is important to note three more exclusions that we have implemented. (1) We exclude Bangkok, Nonthaburi, and Samutprakarn from our analysis. For electricity and water, these provinces are serviced by the Metropolitan Electricity Authority (MEA) and the Metropolitan Waterworks Authority (MWA), not the PEA and the PWA, so these provinces' data on electricity and water might be incompatible with those of other provinces. (2) We consider only districts with total positive value added in both 1997 and 2007, since we want to explore how private "investment" is impacted. (3) We also exclude outliers with unlikely values that we interpret as measurement errors (e.g. firms with less than 10 baht of capital).

[4] As of July 2011.

3.2 Spatial overview

Before proceeding to our econometric analysis, we now examine our firm and infrastructure datasets more closely. We provide a historical context for the observed spatial patterns[5] (Figure 10a-13c), noting significant developments in Thailand's manufacturing and infrastructure provision during the 1997-2007 period that may be reflected in the data. This brief overview should motivate us to the presence and the significance of spatial dependence in reality.

Firm data

Figure 10a-12c show developments in Thailand's manufacturing sector in terms of spatial distribution of our key variables over the 1997-2007 period. Most noticeably, Thailand is no longer Bangkok and "the rest". Clustered almost exclusively around Bangkok's immediate neighbors and the Eastern Region in 1997, Thailand's value added creation seemed to spread more widely to other regions in 2007 - with Chiang Mai-Lam Pun, Khon Kaen, and Songkhla gaining more prominence over the decade (Figure 10a). To explore the emergence of these areas further, we perform Anselin (1995)'s Local Moran test, which detects spatial autocorrelation and is used as a standard means in the literature to identify local clusters and outliers. Evidence from Local Moran's I statistic (Figure 10b) reveals that, still, only Bangkok's neighbors and the Eastern Region survive as "statistically significant" clusters of high value added (at 0.05 level) in both 1997 and 2007. The test identifies Lam Pun (in 1997) and Khon Kaen (in 2007) as high value-added areas that are surrounded by low-value areas, indicating that these two spots are more isolated in nature.

A quick examination on three other variables of interest - private investment (Figure 12a), capital intensity (Figure 12b), and labor productivity (Figure

[5] These dot density plots (Figure 11a-15b) involve some subjective steps in the making, so readers should interpret these plots with cautions: (1) The decision on how much value one dot represents is subjective to some degree. We choose an appropriate value such that the resulting graphics show spatial patterns clearly without being cluttered. Whenever we compare the same variable in 1997 and 2007, one dot in each of the plots represents the same value. (2) These dots might not correspond to exact geographical locations. They are placed *psuedo-randomly* within the boundary of the smallest geographical unit applicable. For example, Figure 11a shows *district-level* total value added. If district A's total value added warrants two dots in the plot, the two dots might be placed *anywhere* within district A's outer contour according to the pseudo-random algorithm used. Dot density plots are totally valid when the geographical unit of interest is sufficiently small, such as a district. However, dot density plots at province level, such as in Figure 14c (since the variable is available only at province level), require readers to ignore spatial patterns within a particular province and focus for the country-wide patterns. (3) For dense areas, these dots might overlay one another. For example, in Figure 11a (bottom), there can be many overlapping dots around Bangkok and in the Eastern Region.

These are trade-offs we need to make when using dot density plots. However, they are superior to other standard approaches, such as chloropleth maps, in showing spatial patterns. After all, one potential solution for concern (3) is to use three-dimensional plots, but such plots are impossible to display on a two-dimensional surface without some areas being hidden from view.

12c) - also seemed to reflect the emergence of these same areas. Preechametta (2011) points out that original equipment manufacturers (OEM), as well as factories in high-tech assembly industries such as electronics and automobile, are concentrated heavily in Bangkok and its nearby provinces such as Ayudhaya, Saraburi, Nakhon Ratchasima, Ratchaburi, Petchaburi, Samutsakorn, Chonburi, and Rayong. A number of large industrial parks are located in these provinces, which are much more well-equipped in terms of basic infrastructure and transportation compared to other provinces.

Infrastructure data

For highways (Figure 13a): Investment during the period was clustered heavily around Bangkok, Ayudhaya, Saraburi, and Chiang Mai. Part of this owed to inter-city motorway projects, which aimed to build high-quality highways that can accommodate high vehicle speed. Routes that are now in operation include the Eastern Part of Kanchanapisek Road (Bang Pa-In - Bang Plee, completed in 1998), the Southern Part of Kanchanapisek Road (Bang Plee - Bang Khun Tian, completed in 2007), and the new Bangkok-Chonburi Motorway (completed in 1999). In addition, traffic lane expansion projects also contributed significantly to the total investment sum including, for instance, the expansion of the Lampang-Chiang Mai Portion of Highway No.11 to four lanes (completed in 2001).

For electricity (Figure 13b): A large portion of investment was spent on building transformer stations, as part of the Transmission Line and Transformer Station Development Project Phase 6, which focused on Bangkok's immediate vicinity and the Eastern Region. The project attempted to accommodate rising demand for electricity in these areas, aiming to support businesses and industries.

For water (Figure 13c): Budget for service area expansion projects during 1997-2007 was allocated based on urgent needs. Total investment was high in Service Area 7 in the Northeastern Region, in line with NESDB (2009)'s finding that these are the areas that need water most urgently. Another area with high investment is Ayudhaya thanks to rising demand from the province's industrial areas.

3.3 Models and Spatial Dependence

To investigate effects of infrastructure on various variables of interest, we consider a standard panel regression:

$$y_{it} = \alpha_i + \alpha_t + \beta' x_{it} + u_{it}, \quad i = 1, ..., \ n, \quad t = 1, \ ..., \ T, \tag{1}$$

where y_{it} are scalar random variables, x_{it} are p-dimensional column vector random variables, the p-dimensional column vector β is unknown, the prime denotes transposition, a scalar α_i represents unobserved individual characteristics of the i-th observation (district), scalars α_t capture the time effect, and u_{it} are unobserved scalar disturbances. In our empirical analysis, the vectors x_{it} contain estimates of stock of publicly owned water supply, electricity and highways. Therefore it is likely that x_{it} and α_i will be correlated, i.e. certain districts close to Bangkok tend to attract public investment in physical infrastructure more than others. Hence the least square estimate (LSE) of β from (1) will generally be inconsistent. The standard approach to deal with this problem is to employ fixed-effect estimation

$$\widehat{\beta}_{FE} = \left\{ \sum_{t=1}^{T} \sum_{i=1}^{N} (x_{it} - \overline{x}_i)(x_{it} - \overline{x}_i)' \right\}^{-1} \left\{ \sum_{t=1}^{T} \sum_{i=1}^{N} (x_{it} - \overline{x}_i)(y_{it} - \overline{y}_i) \right\},$$

where $\overline{y}_i = T^{-1} \sum_{t=1}^{T} y_{it}$ and $\overline{x}_i = T^{-1} \sum_{t=1}^{T} x_{it}$. This estimate can be regarded as the LSE of β from equation (1) after within group averages are removed, i.e. for $i = 1, \ ..., \ n, \quad t = 1, \ ..., \ T$,

$$y_{it} - \overline{y}_i = (\alpha_t - \overline{\alpha}) + \beta' (x_{it} - \overline{x}_i) + (u_{it} - \overline{u}_i),$$

where $\overline{\alpha} = T^{-1} \sum_{t=1}^{T} \alpha_t$.

However, we will not employ this estimation technique in this paper since it requires data on stocks of physical infrastructure. Instead, we apply the difference operator to equation (1) to obtain the differenced model: for $i = 1, \ ..., \ n, \quad t = 2, \ ..., \ T$,

$$y_{it} - y_{i,t-1} = (\alpha_t - \alpha_{t-1}) + \beta' (x_{it} - x_{i,t-1}) + (u_{it} - u_{i,t-1}). \qquad (2)$$

With our data, $T = 2$ so (2) becomes

$$y_i = \alpha + \beta' x_i + u_i, \qquad (3)$$

where $y_i = y_{i2} - y_{i1}, \ x_i = x_{i2} - x_{i1}, \ \alpha = \alpha_2 - \alpha_1$ and $u_i = u_{i2} - u_{i1}$. The unknown α is the difference of the time effect and the unknown β is the extent to which y_{it} change in response to changes in x_{it}. With (3) new flows of physical infrastructure will suffice for regression analysis. It is important to note that by considering the differenced model, we essentially turn a panel regression to a rather standard univariate regression.

If the observations are independent, then, under suitably weak conditions, the LSE of β from (3), $\widehat{\beta}$, is root-n-consistent and has a standard asymptotic normal distribution of the form

$$\sqrt{n} \left(\widehat{\beta} - \beta \right) \to_d N(0, \ \Sigma), \qquad (4)$$

where Σ is the asymptotic covariance matrix. A standard heteroskedasticity-robust estimate in the style of Eicker (1967), popularized in econometrics by White (1980), can be employed to obtain a consistent estimate of the asymptotic covariance matrix. However the independence assumption may be too strong for our data. Spatial dependence is likely to arise from local shocks hitting some districts and interaction among economic agents due to spillovers, competition and externalities.

3.3.1 Tests for Spatial Dependence

To check for spatial dependence of the disturbances in our regression, we employ a test proposed by Robinson (2008). There are a few advantages of the tests in Robinson (2008) over other tests proposed in the literature. First, the author focused on detecting departure from zero correlation of the disturbances of a linear model. This allows him to establish the standard chi-square limit distribution and a few finite sample properties of the test statistics under fairly weak assumptions. Second, the test statistics, which are essentially the Lagrange Multiplier statistics, are easy to compute and can be applied to both time series and spatial data. Third, they allow uses of multivariate weights.

Even though the author proposed some test statistics with improved finite-sample properties, we do not employ them in this paper. Instead, we employ the test statistic

$$\xi = \widehat{a}_n' \widehat{B}_n^{-1} \widehat{a}_n, \tag{5}$$

where

$$\widehat{a}_n = \sum_{i=1}^{n} \sum_{j=1}^{n} \psi_{ij} \widehat{u}_i \widehat{u}_j, \quad \widehat{B}_n = 2 \sum_{i=1}^{n} \sum_{j=1}^{n} \psi_{ij} \psi_{ij}' \widehat{u}_i^2 \widehat{u}_j^2$$

$\psi_{ij},\ 1 \leq i,\ j \leq n,\ n \geq 1$ are d-dimensional column vectors of weights chosen by practitioners and $\widehat{u}_{in}$ are the residuals from the regression. The only reason for choosing this test statistic is that it is robust to heteroskedasticity. It is worth noting that a natural choice of the weights ψ_{ij} should reflect alternative probabilistic models that can capture temperal or spatio dependence of the disturbances. One requirement on the weights is that $\psi_{ii} = 0$ and $\psi_{ij} = \psi_{ji}$ for all $1 \leq i,\ j \leq n,\ n \geq 1$. If the intended weights $\psi_{ij}^*,\ \psi_{ji}^*$ are such that $\psi_{ij}^* \neq \psi_{ji}^*$, we can set $\psi_{ij} = \psi_{ji} = (\psi_{ij}^* + \psi_{ji}^*)/2$. Under suitably weak conditions on triangular arrays of random variables, Robinson (2008) showed that under the null of no spatial dependence, as $n \to \infty,\ \xi \to_d \chi_d^2$.

3.3.2 Asymptotic Distribution

The presence of spatial dependence usually leads to a complicated problem. The simplest case is when researchers have to deal with data which can be regarded as a random field on a d-dimensional lattice $\mathbb{Z}^d,\ d \geq 2$, where $\mathbb{Z}^d$ is the cartesian d-product of the space of integers $\mathbb{Z}$. With time series data, $d = 1$, the idea of the past affecting the current and future values is natural since its index space is a subset of an ordered field. However for $d \geq 2$, it is unclear how the natural order of influence should be. Whittle (1954) proposed a parametric model where each random variable depends on its leads and lags, a generalization of a linear time series. In addition to, the mathematical complexity of this generalization, Guyon (1982) demonstrated that a further difficulty arises from the so-called "edge effect", which can be regarded as the curse of dimensionality, even with a simple statistical problem such as estimation of autocovariances.

The problems get much worse when researchers have to analyse irregularly-spaced data. There are two main types of modelling that have been proposed to addres this difficulty. The first line of research is based on generalizing a linear process in time series analysis. Instead of regarding observations as a sequence of random variables, we have to consider them as a triangular array of random variables. The most popular model along this line is known as the Spatial Autoregressive (SAR) model. In our context, it can be assumed that

$$u_n = \rho W_n u_n + \varepsilon_n, \tag{6}$$

where $u_n = (u_{1n},\ ...,\ u_{nn})'$ is a vector of disturbances, W_n is an $n \times n$ matrix of weights, and $\varepsilon_n = (\varepsilon_{1n},\ ...,\ \varepsilon_{nn})'$ is a vector of innovations. Equation (6) can be re-written as

$$u_n = (I_n - \rho W_n)^{-1} \varepsilon_n,$$

where I_n is the identity matrix of order n, assuming that $I_n - \rho W_n$ is invertible. This implies that

$$u_{in} = \sum_{j=1}^{n} b_{ijn}(\rho)\, \varepsilon_{jn},$$

where $b_{ijn}(\rho)$ is the (i,j)-th element of the matrix $(I_n - \rho W_n)^{-1}$. That is u_{in} is just a weighted average of a finite number of shocks in the economy. The weight matrix will determine how much each disturbance u_{in} (to a particular district) is affected by a particular shock ε_{jn}. One serious drawback with this strategy is that one can hardly get a solution of u_n in (6) which is stationary.

Robinson (2011) proposed a generalization of this linear process to

$$u_{in} = \sum_{k=1}^{\infty} b_{ik,n} \varepsilon_k,$$

where the scalar weights $b_{ik,n}$ depends both on i and n, $\{\varepsilon_k\}$ is an independent process, and the infinite sum is the mean-square limit of the sequence $\left\{\sum_{k=1}^{K} b_{ik,n}\varepsilon_k\right\}_{K=1}^{\infty}$. This generalization nests a wide class of linear time series, such as the $ARMA$ models, as special cases. Hence it admits stationary solutions. See justification and motivation for this process in Robinson (2011). Robinson and Thawornkaiwong (2010) showed that under weak dependence the LSE of β in (3), $\widehat{\beta}$, has a standard asymptotic distribution of the form (4). Moreover, they extended the results in Robinson and Hidalgo (1997) by showing that these standard asymptotic properties may hold under strong dependence given that the collective memory of the regressors and the disturbances are sufficiently weak.

The other modelling strategy is to assume that the data is, to some degree, second-order stationary. Conley (1999) considered a particular type of a compound stochastic process and showed that irregularly spaced spatial data on $\mathbb{R}^d$ is essentially a random field on the lattice $\mathbb{Z}^d$. His idea is similar to the one proposed by Parzen (1963) to deal with irregularly spaced time series. Under strong mixing assumptions, Conley showed that $\widehat{\beta}$ has the standard asymptotic distribution as in (4). Even though Conley (1999) was able to show analitical tractability of his model, his assumptions on the compound process are restrictive and result in computationally intensive calculation. Given the nature of our data, particularly its agglomerative pattern, we will follow the interpretation in Robinson (2011) that our data is a realization of a generalized linear process with weak dependence. Hence $\widehat{\beta}$ has the asymptotic distribution as in (4).

3.3.3 Covariance Estimation

Given the asymptotic distribution of the form (4), another complication arising from spatial correlation is estimation of the asymptotic covariance matrix Σ. Under (6), a parametric approach can be employed to obtain a consistent estimate of Σ by estimating ρ. See, for example, Lee (2004). Consistency of this type of covariance estimate depends entirely on the assumption that the specification in (6) is correct. For robust estimation, Kelejian and Prucha (2007) proposed a consistent nonparametric estimate of Σ under the assumptions similar to those in Parzen (1957) but stressed cases where the disturbances have the representation of the SAR-type in (6). They also pointed out the insight stated in Conley (1999) that measurement errors in the distances do not affect consistency of the covariance estimate as long as the errors are bounded.

In this paper, we employ a quadratic-form estimate proposed in Robinson and Thawornkaiwong (2010) that is consistent under more general form of spatial dependece and under weak assumptions analogous to the ones in Parzen (1957). The estimate is

$$\widehat{\Sigma} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} x_{in} x_{jn}' \widehat{u}_{in} \widehat{u}_{jn} w_{ijn}, \tag{7}$$

where

$$w_{ijn} = \prod_{k=1}^{d} h\left\{ \left(s_{ik} - s_{jk} \right) / m_k \right\},$$

h is a real-valued function and $m_1, \ ..., \ m_d$, depending on the sample size n, are non-negative integers forming a truncation vector $m = (m_1, \ ..., \ m_d)'$, and s_{ik} are the k-th element of locations s_i. Note that s_i are the discretized locations of the observed locations on a rectangular grid. That is if $s_i^* = (s_{i1}^*, \ ..., \ s_{id}^*)'$ is the observed location of the i-th observation, then we set $s_i = (s_{i1}, \ ..., \ s_{id})'$ where s_{ik} is the smallest integer such that $s_{ik} \geq s_{ik}^*$. See Robinson and Thawornkaiwong (2010) for details and discussion. Unlike Kelejian and Prucha, they employ locations rather than distances in calculating the weights in the quadratic form. To obtain a nonnegative definite estimate of Σ, with distances rather locations, Kelejian and Prucha (2007) relied on the results on positive definite functions in Schoenberg (1938) and Golubov (1981) and stressed the importance of the modified Bartlett window. On the other hand, Robinson and Thawornkaiwong

(2010) showed that with the discretized locations, one essentially transform an estimation problem of the covariance matrix into the one of estimating the spectral density of a random field on a lattice $\mathbb{Z}^d$ at zero frequency. Then the insight from Robinson (2007) can be employed including nonnegative definiteness of an estimate with the Parzen window. Even though an issue related to measurement errors of the locations is not stated explicitly, Assumption C3 in Robinson and Thawornkaiwong (2010) implicitly allows this type of errors. As expected, this estimation technique requires that $\Pi_{i=1}^d m_i/n \to 0$ as $n \to \infty$.

3.4 Empirical Results

To investigate effects of public investment in infrastructure we employ a linear model in (2) where the i-th observation is a vector of aggregate variables of interest within the i-th district. As stated in the previous section, we only employ new flows of public investment in water supply, electricity and highways. Beside their own importance, these three types of infrastructure can be good representatives of other infrastructure. Highways exhibit a higher degree of being a network-type infrastructure compared with electricity and water supply, respectively. Second, water supply is more affordable from the private sector's point of view compared with electricity and highways, respectively. The dependent variables are capital stock, capital intensity measured by the ratio of capital to worker, and labor productivity measured by added value per worker. In this paper we think it is more natural to regard infrastructure as a part of an economic environment rather than an input in firms' production functions as in Aschauer (1989) and many subsequent papers. For example, an opening of a new electrical substation may not have a significant direct improvement in the production but is likely to encourage firms to invest in new machines that could be easily damaged by a blackout. For the regression specification, we follow Hall and Jones (1999) and Banerjee and Iyer (2005) by focusing the reduced form. That is

$$\Delta y_i = \alpha + \beta_1 \Delta Water_i + \beta_2 \Delta Electricity_i + \beta_3 \Delta Highways_i + u_i, \qquad (8)$$

where the changes are the differences of variables of interest between 1996 and 2006 and u_i are the disturbances. As indicated in the previous section, α can be interpreted as the difference of the time effects. Our specification differs from that in Hall and Jones (1999) but is similar to the one in Banerjee and Iyer (2005) since our regression only allows a linear function of changes in infrastructure. The reason is based purely on a statistical ground. We found that the values of the R-squared statistics from the regression in (8) are much higher than those with specfications in Hall and Jones (1999).

In order to give an indirect test for the presence of increasing returns to scale, we consider the following augmented regression

$$\begin{aligned} \Delta y_i \;=\; & \alpha + \beta_1 \Delta Water_i + \beta_2 \Delta Electricity_i + \beta_3 \Delta Highways_i + \beta_4 Size_i \qquad (9) \\ & + \beta_5 Size_i \Delta Water_i + \beta_6 Size_i \Delta Electricity_i + \beta_7 Size_i \Delta Highways_i + u_i, \end{aligned}$$

where $Size_i$ is the aggragate added-value of the i-th district in 1996 as discussed in the data section. It should be noted that (9) cannot be interpreted as being implied by the panel regession in (1) as u_i is the difference between disturbances to the three dependent variables in 1996 and 2006. It is likely that $Size_i$ and the disturbances in 1996 should be correlated and hence the LSE of the unknwon slope parameters is inconsistent despite our belief that the bias should be quite small. However, we can interpret the regression in (9) as a linear model indicating how the private sector responds to changes in infrastructure also taking the scale effect into account. As we employ the lagged variable representing size of a particular industry in each district, we can safely assume that this should be orthogonal to the disturbances which reflect shocks after 1996. With this interpretation, the least square estimation will be a valid estimation technique given weak spatial dependence. It should be noted that we also compare the R-squared statistics under the specification in (9) and the analogous one to Hall and Jones (1999). It turned out that we are in favor of this specification over the ones with log transformations.

An alternative specification to (9) is

$$\begin{aligned}\Delta y_i &= \alpha_1 + \gamma_1 \Delta Water_i + \gamma_2 \Delta Electricity_i + \gamma_3 \Delta Highways_i + \\ &\quad \alpha_2 \mathbf{1}\left(Size_i > \tau\right) + \gamma_4 \Delta Water_i \mathbf{1}\left(Size_i > \tau\right) + \gamma_5 \Delta Electricity_i \mathbf{1}\left(Size_i > \tau\right) \\ &\quad + \gamma_6 \Delta Highways_i \mathbf{1}\left(Size_i > \tau\right) + u_i,\end{aligned} \tag{10}$$

where τ is an unknown threshold point. This specification may be more natural than ours since it is more consistent with economic theories assuming increasing returns and hence predicting multiple equilibria. Hansen (2000) showed that the nonlinear least square estimate of the slope parameters have standard asymptotic properties under the assumption that the observations are strictly stationary.

However, we decided to employ the specification in (9) rather than the one is (10) for a few reasons. First, given the agglomerative patterns in our data, a great degree of heterogeneity of the observations makes the assumption on strict sationarity seems too strong for our applications. Second, we had some experiments with this particular model but it turned out that the proposed estimation technique always chose threshold points that are so large that very few observations are classified in the second (high) regime. This makes inference with respect to the second regime impossible. It is likely that the objective function based on the independent and identically distributed (i.i.d.) assumption of the innovations could be the reason for this problem. Moreover, to our knowledge, this estimation technique is only applicable to regression with two regimes. Models with multiple regimes may fit the data better than the one with only two regimes.

3.4.1 Empirical Tests for Spatial Dependence

To demonstrate the importance of spatial dependence we employ the test in Robinson (2008), as described in the previous section, to detect any departure from zero correlation of the disturbances. After obtaining the LSE of the parameters in (9), we can compute the residuals which can be employed to construct the test statistic in (5). For simplicity, rather than employing multivarite weights, the univariate weights ψ_{ijn} are set to be

$$\psi_{ijn} = \left\|s_i^* - s_j^*\right\| / \left(1 + \left\|s_i^* - s_j^*\right\|^2\right),$$

where s_i^* is the two-dimensional centriod of the i-th district. The unit of s_i^* is 20 kilometres. This choice of normalization reflects our belief on how far the effects of spillovers and regional shocks could have a significant impact. Smaller normalizations, such as 1 kilometre, could lead to cases where spatial dependence will die out too quickly.

Recall that under the null hypothesis of no spatial dependence, as $n \to \infty$, $\xi \to_d \chi_1^2$. The results in Table 4 show that the residuals of some regression models, particularly those on labor productivity, exhibit spatial dependence. This confirms our intuition about the role of regional shocks and spillovers. Note that power of this test should depend on how well the weights ψ_{ijn} reflect the true spatial patterns. In our analysis, we keep the weights constant for all industry and all regression models. It is very likely that if ψ_{ijn} are chosen appropriately, then the power of the test could increase substantially.

3.4.2 Main Empirical Results

Given evidence of spatial depence shown above, obtaining a consistent estimate of an asymptotic covariance matrix becomes a serious issue. We employ a consistent estimate in (7), which is robust to a large class of disturbances exhibiting heteroskedasticity and spatial depedence. Given the agglomerative patterns, we believe that spatial dependence should die out quickly. Hence we employ the Parzen window in (7) to obtain a nonnegative definite estimate with a faster rate of convergence compared with the modified Bartlett window.

Figure 14 shows a plot of the 2-dimensional centroids of districts with textile industry in 1996 and 2006. This plot gives us an idea how we should choose the truncation vector. In the following tables containing estimates of the unknow parameters in (9) and various standard errors, let $m_1 = (6,\ 12)$ and $m_2 = (10,\ 20)$. There are two exceptions. For the chemical industry we set $m_1 = (10,\ 20)$ and $m_2 = (20,\ 40)$ since at low values of m the estimates are quite unstable. For the television and IC industry we set $m_1 = (3,\ 8)$ and $m_2 = (5,\ 16)$ since the districts with this industry only cluster around a relatively much smaller region. Our choices of the truncation vectors are quite arbitrary. Apart from taking into account distribution of locations of the centroids as in Figure 14, our choices are determined by our experiments over the truncation vectors which give stable estimates of the variances. The results are presented in Tables 5a-5c, for effects on capital stock, capital intensity and labor productivity, respectively. Point estimates are in bold-face and standard errors are in parentheses beneath them with non-robust ones above the robust ones.

One striking feature one can easily observe from the tables is the importance of the heteroskedasticity and spatial correlation. See the difference of the non-robust and the robust standard errors. It is rather obvious from the tables that the scale effect matters. This is suggested by statistical significance of coefficients of the interaction terms. Moreover, it can be seen that the effects of investment in infrastructure on labor productivity and private investment in capital are more prominent than on changes in capital intensity. For example, investment in infrastructure hardly has any effect on captial intensity of the chemical sector. The only statistically significant coefficient is the one on *size*. The coefficient on $\Delta water$ is also unclear due to a substantial change of the standard errors from one choice of the truncation vector to another. On the other hand, investment in infrastructure has clear effects on labor productivity and investment (change in capital). This observation with evidence of the scale effect is consistent with the assumption of increasing returns rather than constant returns to scale. Recall that the typical functional form of constant returns to scale is

$$Y_{it} = A_t K_{it}^{\alpha} L_{it}^{1-\alpha},$$

where A_t represents technological level, Y_{it}, K_{it} and L_{it} are output, capital and labor of the i-th district at time t. We have that

$$\Delta \log \left(Y_{it}/L_{it} \right) = \Delta \log A_t + \alpha \Delta \log \left(K_{it}/L_{it} \right).$$

Under the neoclassical model of growth with constant returns, $\Delta \log A_t$ captures the time effect. Hence a change in labor productivity of the i-th district is a result of a change in captial intensity only. On the other hand, our finding is more consistent with the new growth theories where increasing returns to scale play a crucial role.

It should be noted that since our objective is to make sectoral comparison, we do not employ the general-to-specific methodology to select suitable models and specifications for the regression. If one is to employ the general-to-specific approach, one has to keep dropping a variable which is not statistically significant from a regression. By doing so, one can reduce the variance that was previously inflated by extra uncertainty due to a large number of regressors in (9) and hence make some coefficients more statistically significant.

In order to investigate sectoral comparison, we consider Figures 15a-15c. These figures show plots of coefficients of the interaction terms from the regression on physical capital of the private sector and labor productivity against capital intensity of each industry measured by the ratio of a nationwide value of firms' capital to a nationwide aggregate number of workers within a particular industry. The plots from the regression on changes in capital intensity are not shown since the results are rather statistically trivial as mentioned above. The reason for plotting these coefficients against an industry's capital intensity is that capital intensity can be a good proxy for the level of spillovers. It is natural to assume that the role of knowledge spillovers should be high for an industry whose capital intensity is high. Therefore these plots can suggest roles of spillovers. A solid dot represents a coefficient of an interaction term which is statistically significant at a 10% level for one of the two standard errors. A fitted line is obtained from the least square technique employing both statistically significant and insignificant coefficients. The inclusion of the insignificant coefficients should not affect the fitted line much given the fact that they should be close to zero. For those that are not close to zero, they can potentially become statistically significant if the general-to-specific method is employed.

Given our initial hypothesis about the role of infrastructure, it is quite striking to see downward sloping fitted lines of the effects on of investment in water supply and electricity. However, this does not mean that electricity and water system are not good for hi-tech industries. It should be noted that, in our analysis, we only investigate effects of "public" investment in infrastructure. The downward sloping fitted lines indicate that the hi-tech industries gain less benefit from public investment in electricity and water system. This interpretation is consistent with our data provided by the PEA that firms with high capital intensity tend to be located in an industrial park or is well-endowned so that their electricity is provided through private electrical substations. A similar story applies to water system. One main conclusion we can draw from these plots is that the labor intensive industries may find it hard to gain access to privately provided infrastructure. A similar line of argument can explain negative signs of the coefficients for hi-tech industries.

On the other hand, the slope of the fitted lines for the effects from highways is as expected, i.e. upward sloping. This finding is consistent with the notion of spillovers and increasing returns. As we expect stronger spillovers from more capital intensive industries, we would expect stronger impacts on investment and labor productivity due to increasing returns. The readers may be alarmed by the statistically significant coefficients that are negative for labor intensive industries. Our interpretation is that this is not an evidence showing that highways are not good for labor intensive industries. It is likely that, thanks to increasing returns of more capital intensive industries, higher labor productivity leads to higher wages. This rise in wages implies higer cost of production for more labor intensive industries. Therefore, instead of boosting investment and labor productivity, public investment in highways can drive the less capital intensive industries out from the districts. This can explain the negative signs of the coefficients. Moreover, this is consistent with our data that the number of districts with labor intensive industries doubled in 2006 compared with the number in 1996, whereas the number of districts with capital intensive industries remained pretty much the same.

3.4.3 Comments

A number of extensions to our current analysis can be pursued. First, an instrumental variable regression can give a good solid justification for considering regression in (9) as coming from a panel data model with unobserved individual characteristics. Second, one can generalize (9) to a semiparametric model such as a partly linear model considered in Robinson (1988). This generalization with instrumental variables can be done with theoretical support from Robinson and Thawornkaiwong (2010) who showed that their semiparametric estimate of the slope parameters are root-n-consistent with standard asymptotic Gaussian distribution. They also proposed a consistent nonparametric estimate of the asymptotic covariance matrix analogous to the one in (7) can be obtained. Thrid, given the popularity of economic geography, it is interesting to see the importance of transportation costs by justifying a hypothesis that highways can have a network effect. An approach one can take is to consider a SAR type of model which allows direct spillovers of explanatory variables in a regression model.

4 Policy implications

What should the Thai government do to jumpstart the Thai economy on the transformative route of "upgrading"? How can the Thai government promote sustained, productivity-driven growth that will pave Thailand's way out of the Middle Income Trap for good? We propose that the key to success lies in strategic investment on infrastructure that aims to exploit increasing returns, when and where possible.

Starting point: the need for overarching strategies for the nation

Our empirical studies reveal that the benefits of public infrastructure investment on private sector's investment and labor productivity are qualitatively and quantitatively different, both across industries and types of infrastructure. These variations should point to the need of overarching strategies at the national level, so that the government can direct its investment to the right kind of infrastructure at the right place in order to fulfill the national-level development objectives.

Despite the pressing need to avoid being trapped at the middle income stage, Thailand's existing strategic plans - particularly, the National Economic and Social Development Plan - do not seem to give enough priority on the issue of sustainable income development compared to other countries facing similar situations. For example, Malaysia's New Economic Model (NEM) and Vision 2020 explicitly aim to raise productivity, move the country "up the value chain", transform the country to the "knowledge-based economy", and rise to the "developed" country status by 2020.

Recommendation 1: "hub" for capital-intensive industries

Our study has found an evidence supporting the presence of "increasing returns" in Thailand's manufacturing sector, especially in capital-intensive industries. This has an important policy implication on how the government should invest: the presence of "increasing returns" suggests that the government focus its investment on particular areas, whereas "constant returns" implies that the government does not have to concentrate its investment on any areas since there is nothing to be gained from clustering of economic activities.

To exploit "increasing returns", the government should aim to create "external economies" - especially through knowledge spillovers, which provide basis for domestic innovation and knowledge accumulation. Our empirical findings suggest three key focuses for the government:

- **Specialized high-tech hubs:** Aiming to exploit increasing returns, the government should aim to promote hubs of industries with high knowledge spillovers, namely capital-intensive industries that employ advanced technology in their production. Other countries have benefited from establishments of specialized high-tech hubs, to name a few: Japan's Tsukuba Science Town, Taiwan's Hsinchu Science and Industrial Park, Singapore's Biopolis, and India's Software Technology Park. These specialized hubs provide environments conducive for innovation and serve as breeding ground for high-tech startup firms. This policy direction can help support high-potential firms to "move up the value chain", resulting in higher valued added creation for the domestic economy.

- **Strategic infrastructure investment:** The government should give priority to: (1) building infrastructure that is interconnected in nature (i.e. highways, telecommunications, etc.), because such *network-type* infrastructure can facilitate knowledge spillovers, thus giving rise to extenal economies; (2) building infrastructure that is not easily affordable by private sector; and (3) building new infrastructure to connect with existing network of infrastructure, aiming to benefit from the larger size of infrastructure network.

- **Creating new "industrial hubs":** Given the benefits of clustering, the government should identify high-potential areas and upgrade these areas to become new "industrial hubs" - that is, hubs for similar or related industries, so that they can reap localized benefits such as availability of specific inputs and labor. For example, we may get some clues from spatial plots with regard to high-potential areas. We can see that for textile industry, there has been some evidence of significant value added creation spreading throughout the Northeastern Region. However, these setups have much lower capital intensity compared to their counterparts in the lower part of the Central Region. This suggests that there might be some benefits from creating textile hubs in the Northeastern Region to push textile manufacturing to another level, building on the top of what is already there.

Recommendation 2: "zoning" for industries with low capital intensity

To achieve growth that is more sustained and inclusive, the government must not leave out industries with lower capital intensity, which are usually of small or middle size, for two key reasons. First, these industries play an important role in supplying intermediate inputs in domestic production chains. Strength of domestic support industries means less dependence on imported inputs, which implies more domestic sustainability. Second, these industries contribute significantly to employment in rural areas. Supporting these industries can make Thailand's growth more inclusive and prevent income disparity among population to widen even further.

To make its investment in support of these industries more efficient, the government should consider establishing "zoning" for similar or related industries, where the government provides basic infrastructure support as needed to help reduce these firms' costs. Given that firms in these industries generally do not require cutting-edge or costly facilities, and that similar or related industries should demand similar infrastructure, government infrastructure provision in these zones can be made in an efficient manner. The government can implement this strategy in conjunction with existing tools at hand - for example, the government can target its BOI benefits more specifically in terms of industries and areas.

5 Conclusion

Thailand is certainly not yet well-positioned to fully benefit from the Asian Century and the deeper integration of regional production networks to be expected soon. The emergence of China also presents to us both challenges in terms of competition and opportunities to collaborate and rise with the dragon. To prepare the country for these future developments, the Thai government needs to rethink many of its policies and long-term strategies to pave Thailand's way out of the Middle Income Trap for good.

In an attempt to find Thailand's way out, this paper explores the role of public infrastructure investment in promoting growth that is sustainable and productivity-driven. We carefully compile our micro-level data on firms and infrastructure and develop our methodology, which is essentially a panel regression with some extension, to take care of three major empirical issues, namely: (1) *reverse causality* that runs back from higher growth to higher infrastructure investment; (2) possible *measurement errors* due to the use of micro-level data; and (3) *spatial dependence* that is usually not taken care of in the literature, despite its irrefutable presence in the real world and its significant impacts on the consistency of our estimates. We verify the positive effects of infrastructure investment on private investment. And interestingly, we find that the benefits of infrastructure investment on labor productivity do not work through capital deepening, contrary to the traditional, neoclassical view that normally presumes constant returns. We find the prime importance of network-type infrastructure, as represented by highways in our analysis, for capital-intensive industries that often benefit greatly from increasing returns, particularly through knowledge spillovers.

These findings lead us to recommend the government to promote "hubs" for capital-intensive industries and establish "zoning" for those with lower capital intensity, with the overarching goal to achieve growth that is not only sustainable and productivity-driven but also inclusive in nature. But physical infrastructure development is not everything; as we have said, it is only a *necessary* but not sufficient condition for success. Long-term improvements in Thailand's economic well-being also require drastic social infrastructure measures - including but not limited to educational reforms, legal improvements especially with regard to property rights and regulatory burdens for businesses, as well as improvements on government's efficiency and good governance. These all-round "upgrading" policies will ensure Thailand a safe, undisrupted trip on the road to prosperity over the years to come.

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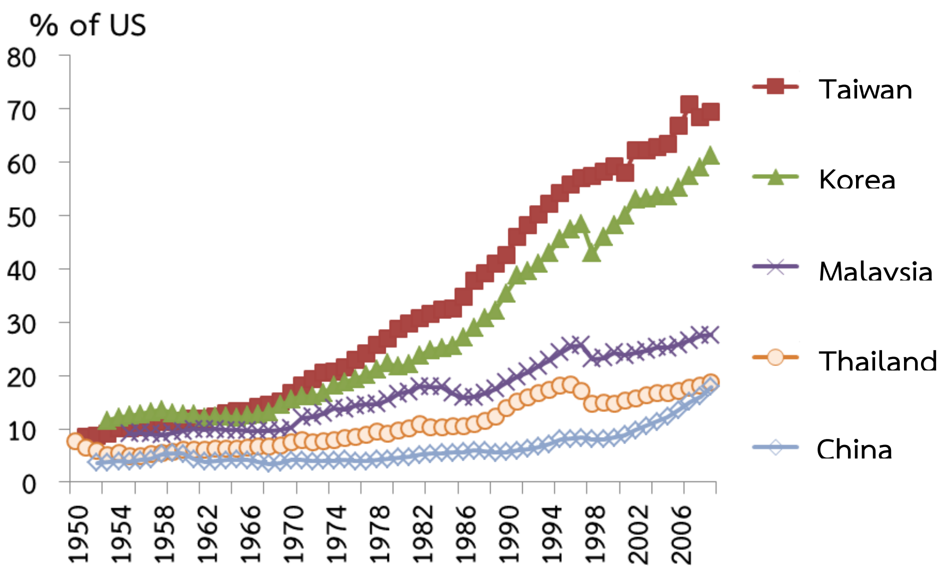
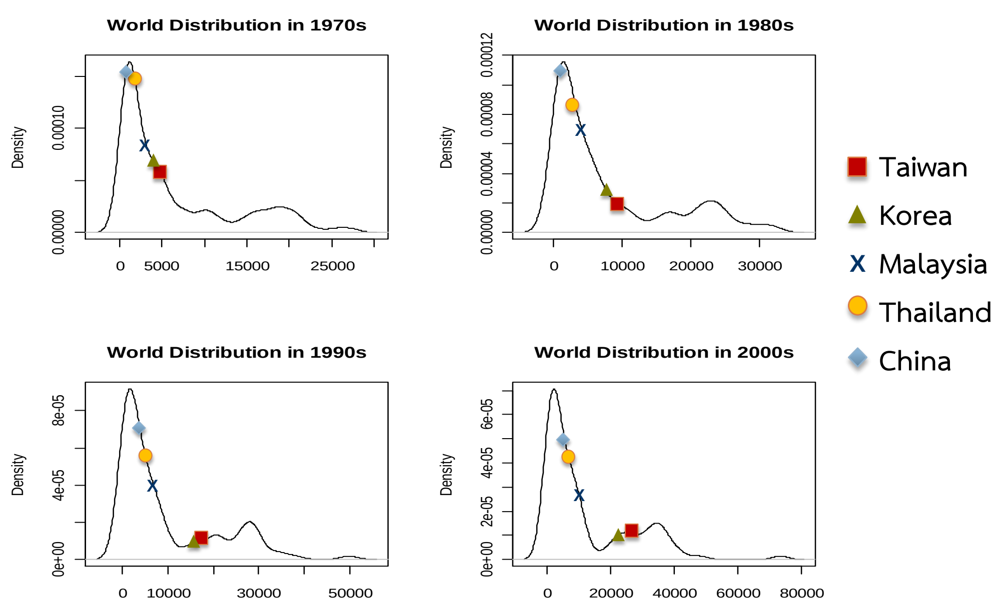
Figure 1: Real GDP per capita (PPP, % of US)



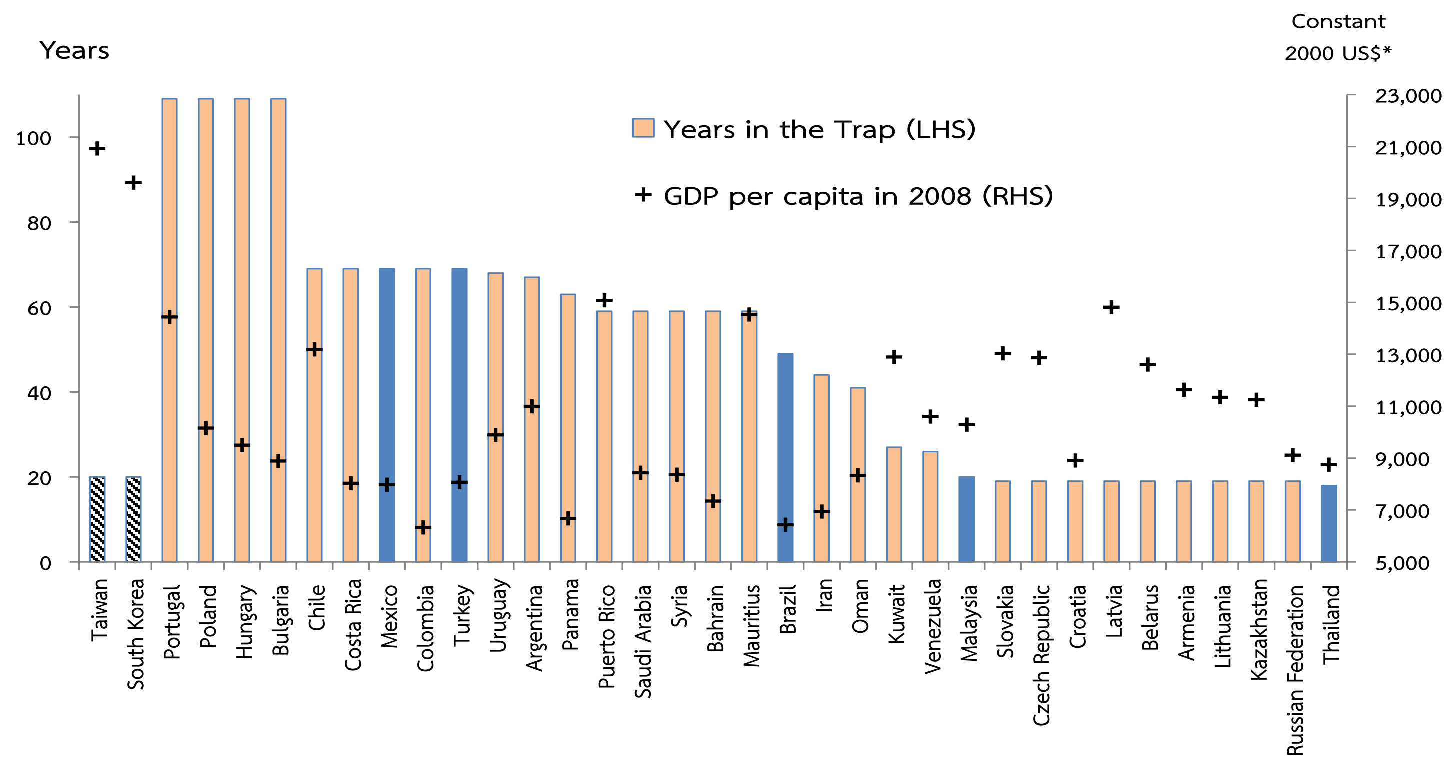
Source: Penn World Table 7.0

Figure 2: Kernel estimation of world income distribution



Source: Penn World Table 7.0

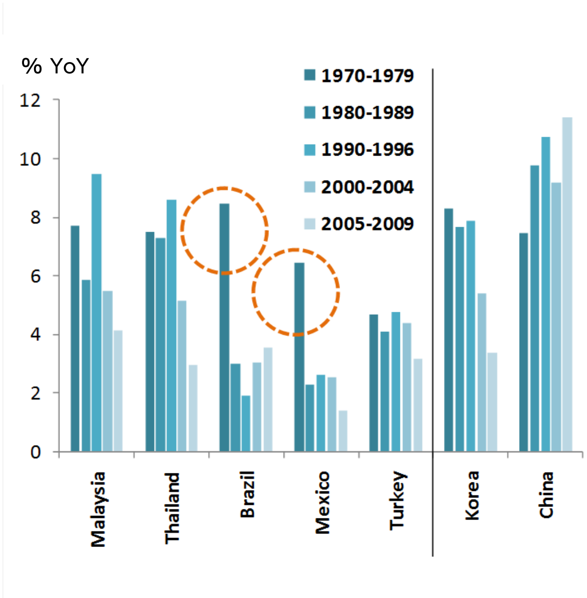
Figure 3: Years in the Middle Income Trap



Source: Maddison (2010)

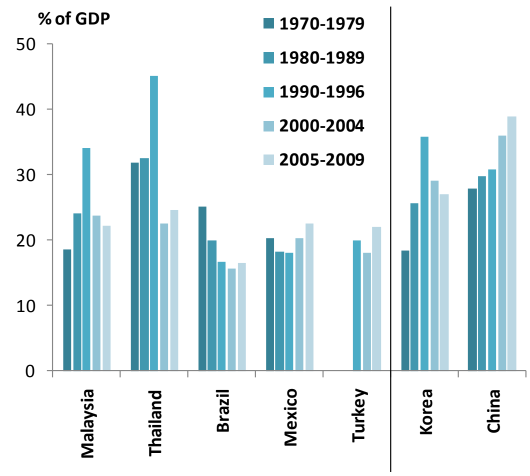
Note (1): Authors define a country to be "upper-middle income" if its GDP per capita falls within 20-49 percent of the US for a particular year, and define the country to be in the Middle Income Trap if it remains in the "upper-middle income" group for 10 years or longer.
Note (2): *1990 International Geary-Khamis dollars (constant 2000 US$); the two leftmost countries, namely Taiwan and Korea, are not in the Trap – they are included only for comparison.

Figure 4a: GDP growth (% YoY)



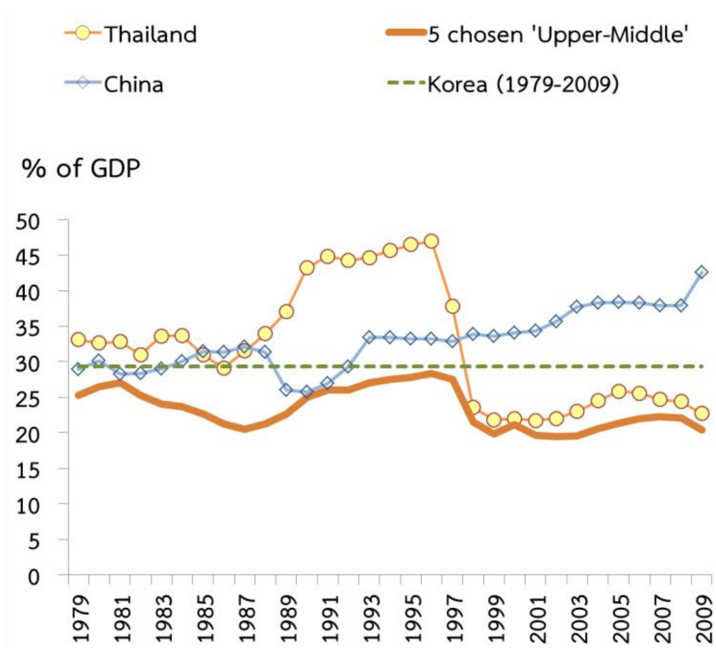
Source: World Development Indicators (2011)

Figure 4b: Gross investment (% of GDP)



Source: World Development Indicators (2011)

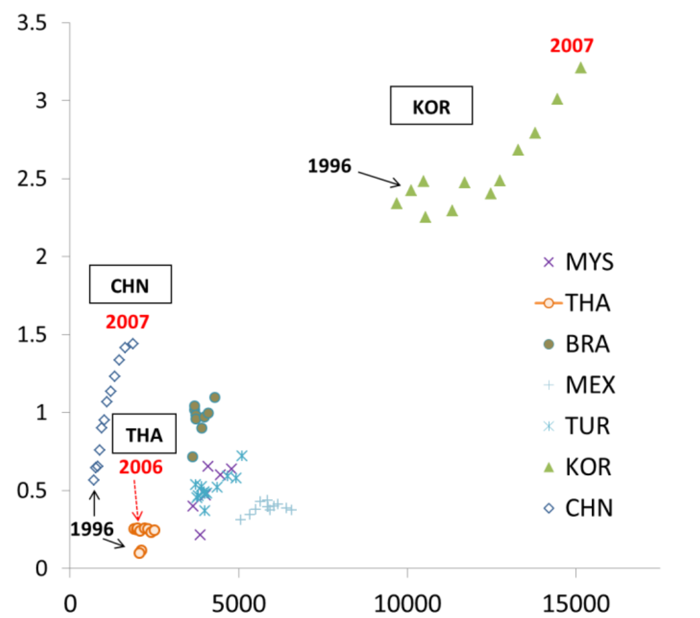
Figure 4c: Gross investment (% of GDP)



Source: World Development Indicators (2011)

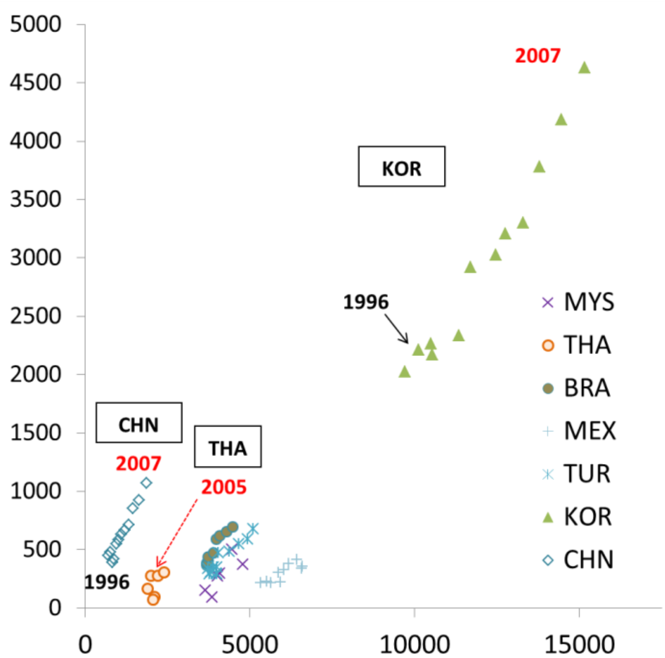
Note: The "5 chosen Upper-Middle" (UM5) includes Malaysia, Thailand, Brazil, Mexico, and Turkey.

Figure 5a:
R&D expenditure
(% of GDP)
versus GDP
per capita



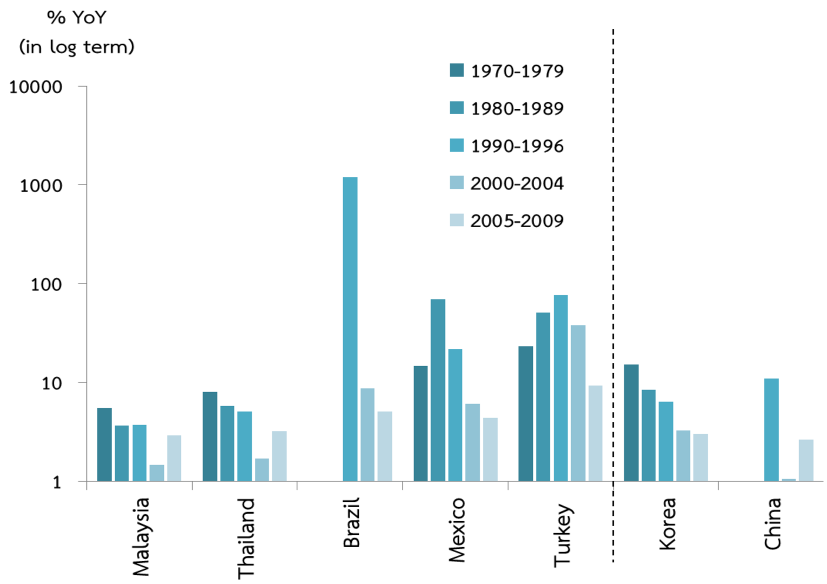
Source: World Development Indicators (2011)

Figure 5b:
Number of
researchers in R&D
(per million people)
versus
GDP per capita



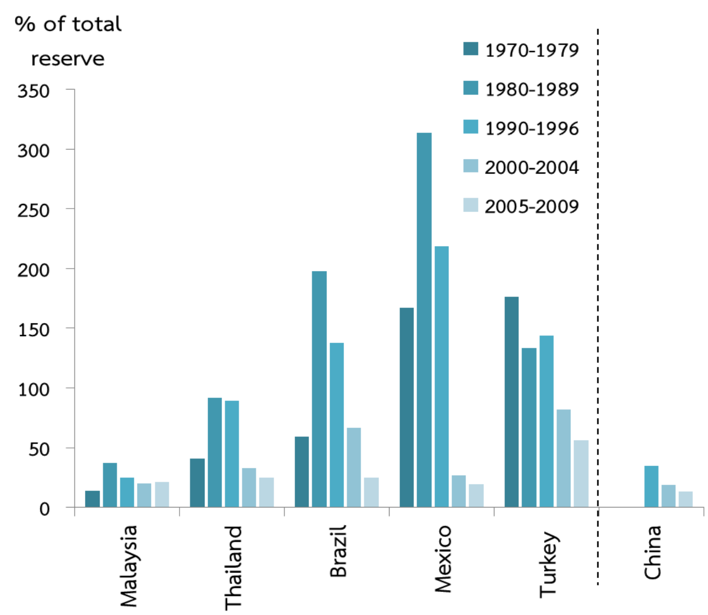
Source: World Development Indicators (2011)

Figure 6a: Inflation rates



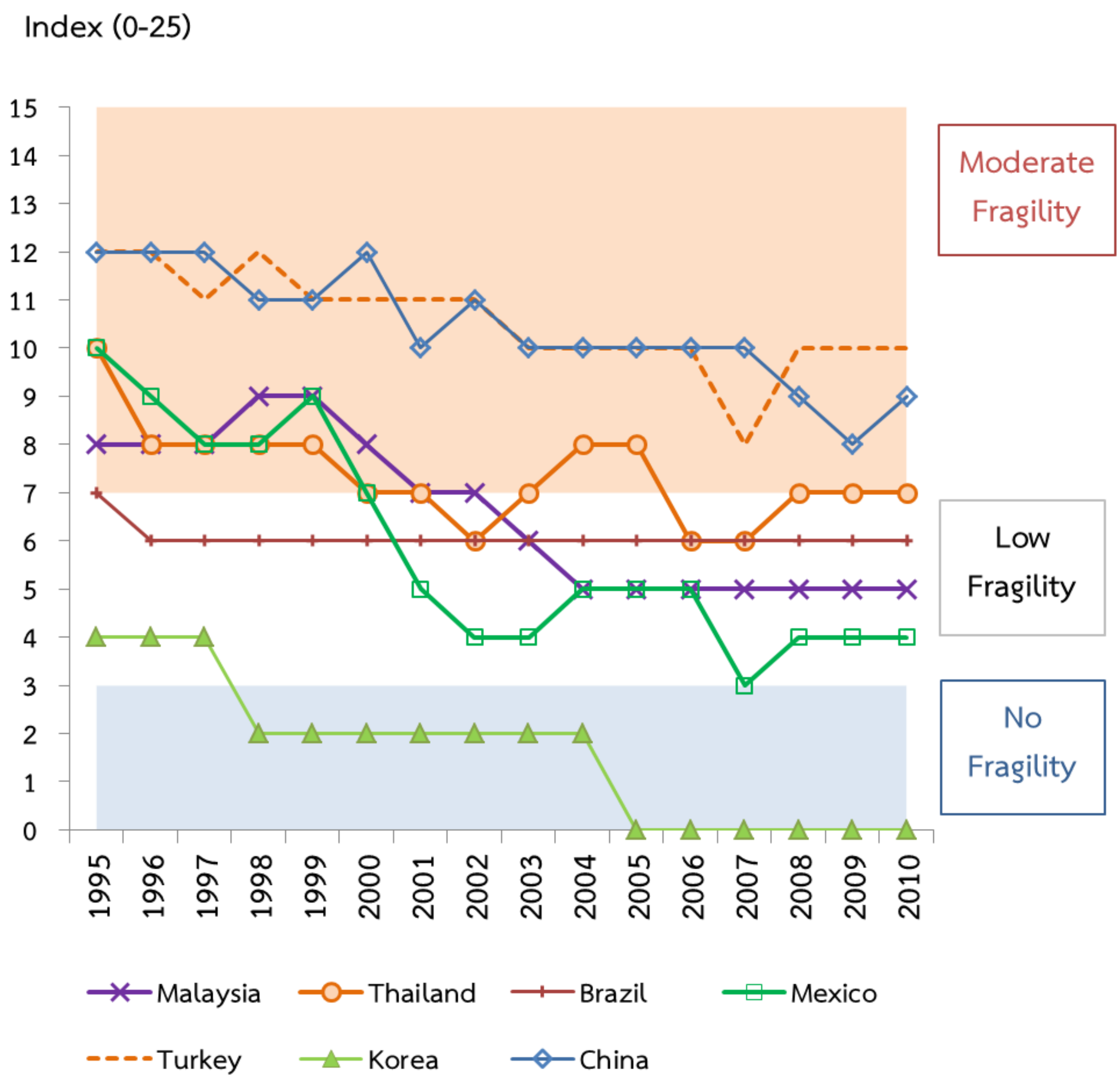
Source: World Development Indicators (2011)

Figure 6b: Short-term external debt



Source: World Development Indicators (2011)

Figure 7: State Fragility Index



Source: Marshall (2009), Center for Systemic Peace

Note: The State Fragility Index (SFI) rates each country by its level of fragility in both effectiveness and legitimacy across four dimensions: security, governance, economic development, and social development (Marshall, 2009).

Figure 8: Linkages between infrastructure investment and growth

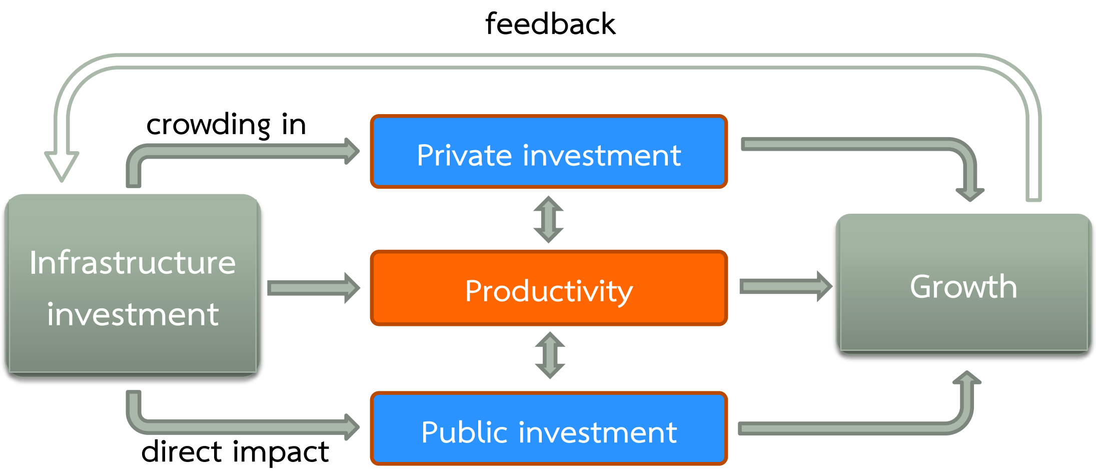
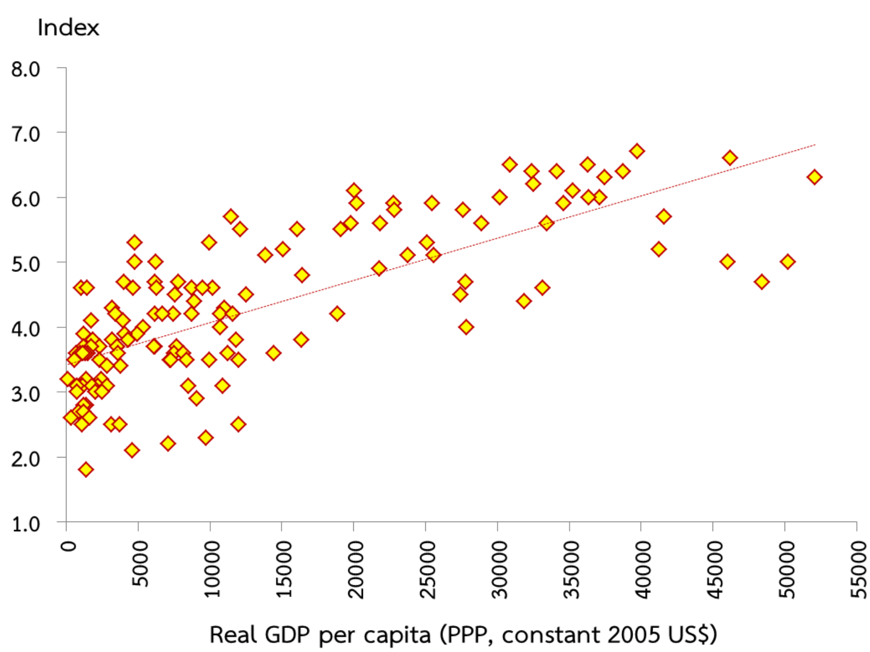


Figure 9: Positive correlation between overall infrastructure quality and real GDP per capita



Source: WEF's Global Competitiveness Report 2011-2010, Penn World Table 7.0

Figure 10a:
Spatial distribution of
value added
in 1997 (left)
and 2007 (right)

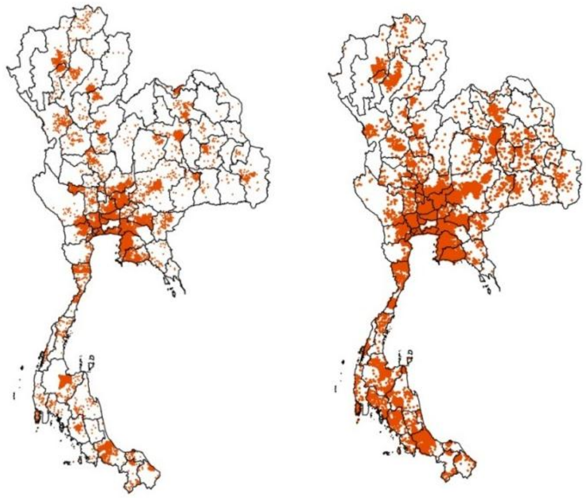
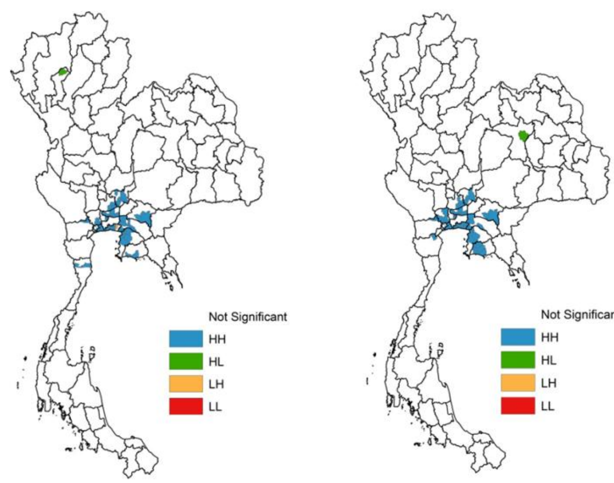


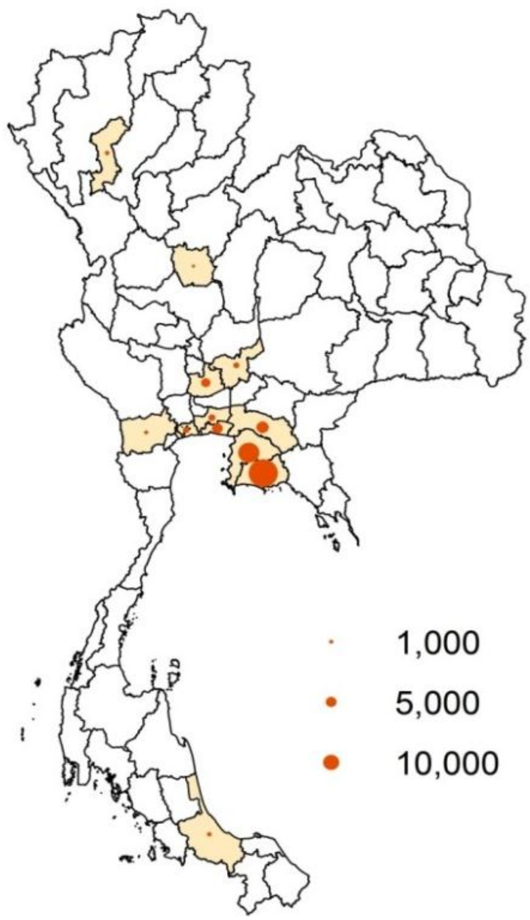
Figure 10b:
Clusters of value added
(Anselin's Local Moran's I)
in 1997 (left)
and 2007 (right)



Source: The 1997 and 2007 Thailand Industrial Census

Note: Figure 11b shows Local Moran's I statistic. HH denotes ; HL denotes; LH denotes; LL denotes;

Figure 11: Land use permitted for industrial operation inside industrial estates within each province (unit: rai)



Source: Industrial Estate Authority of Thailand

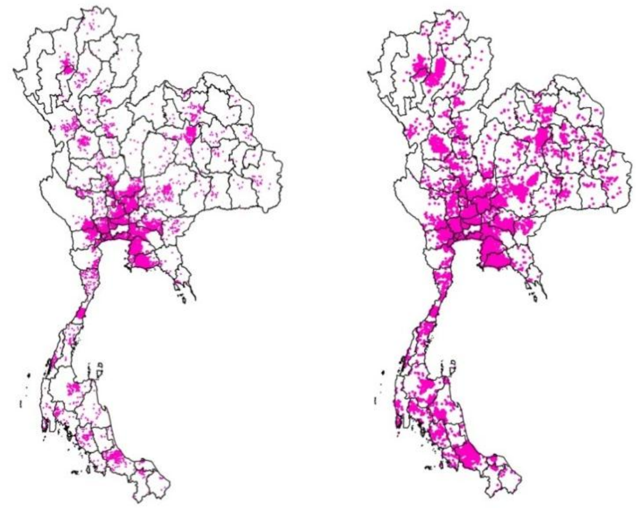


Figure 12a:
Private investment
in 1997 (top)
and 2007 (bottom)

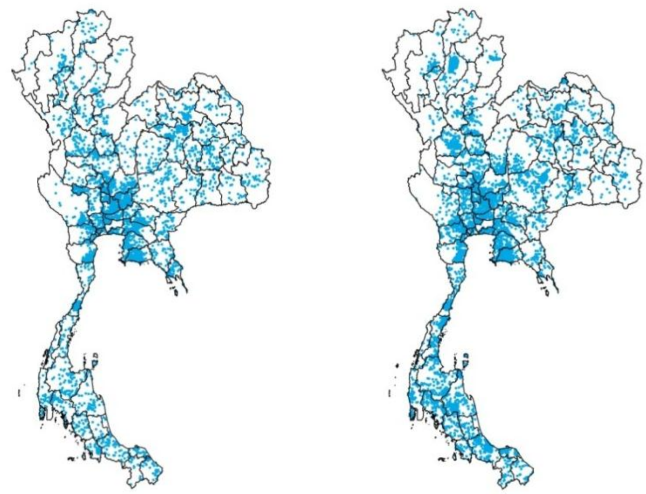


Figure 12b:
Capital intensity
in 1997 (left)
and 2007 (right)

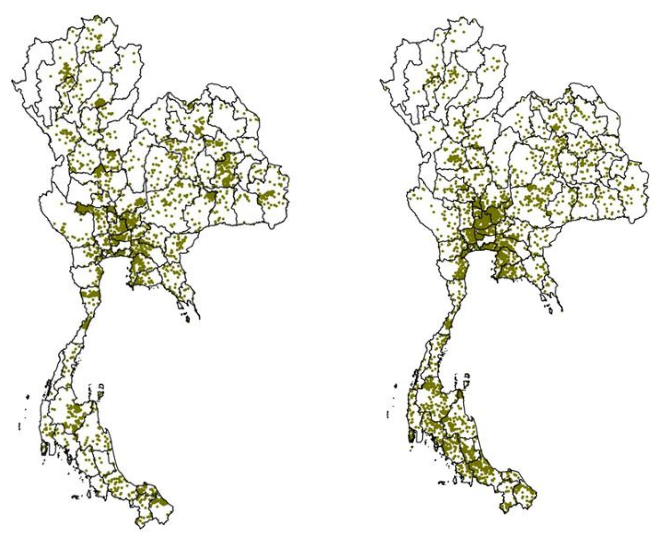


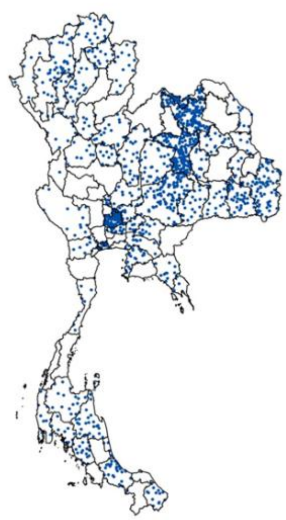
Figure 12c:
Labor productivity
in 1997 (left)
and 2007 (right)

Source: The 1997 and 2007 Thailand Industrial Census
Note: Refer to Section 3.1 for definitions and discussions of these variables.

Figure 13a:
Total investment on highways
during 1997-2006
(1 dot = 4 billion baht)

Figure 13b:
Total investment on electricity
during 1997-2006
(1 dot = 30 kW)

Figure 13c:
Total investment on water
during 1997-2006
(1 dot = 500 million baht)



Source: Department of Highways (DOH), Provincial Electricity Authority (PEA), and Provincial Water Authority (PWA)

Note: Refer to Section 3.1 for definitions and discussions on these variables.

Figure 14: Centroids of districts with textile industry in 1996 and 2006

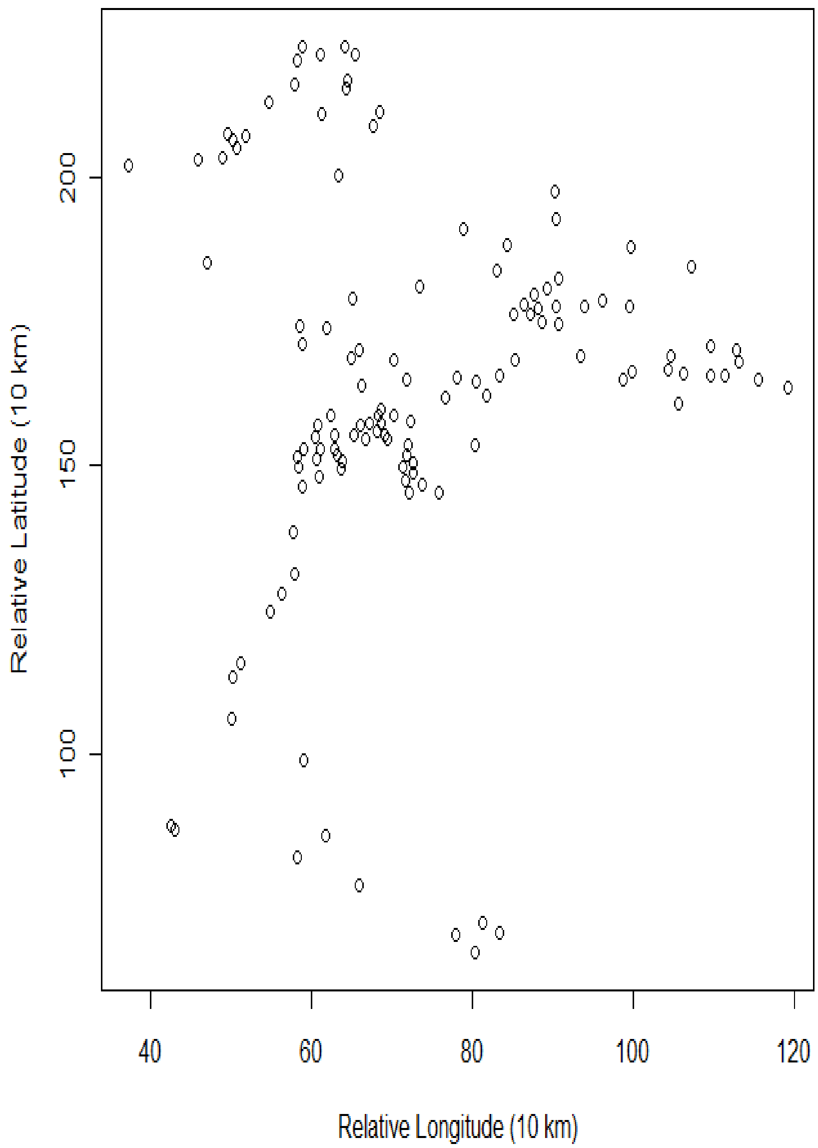
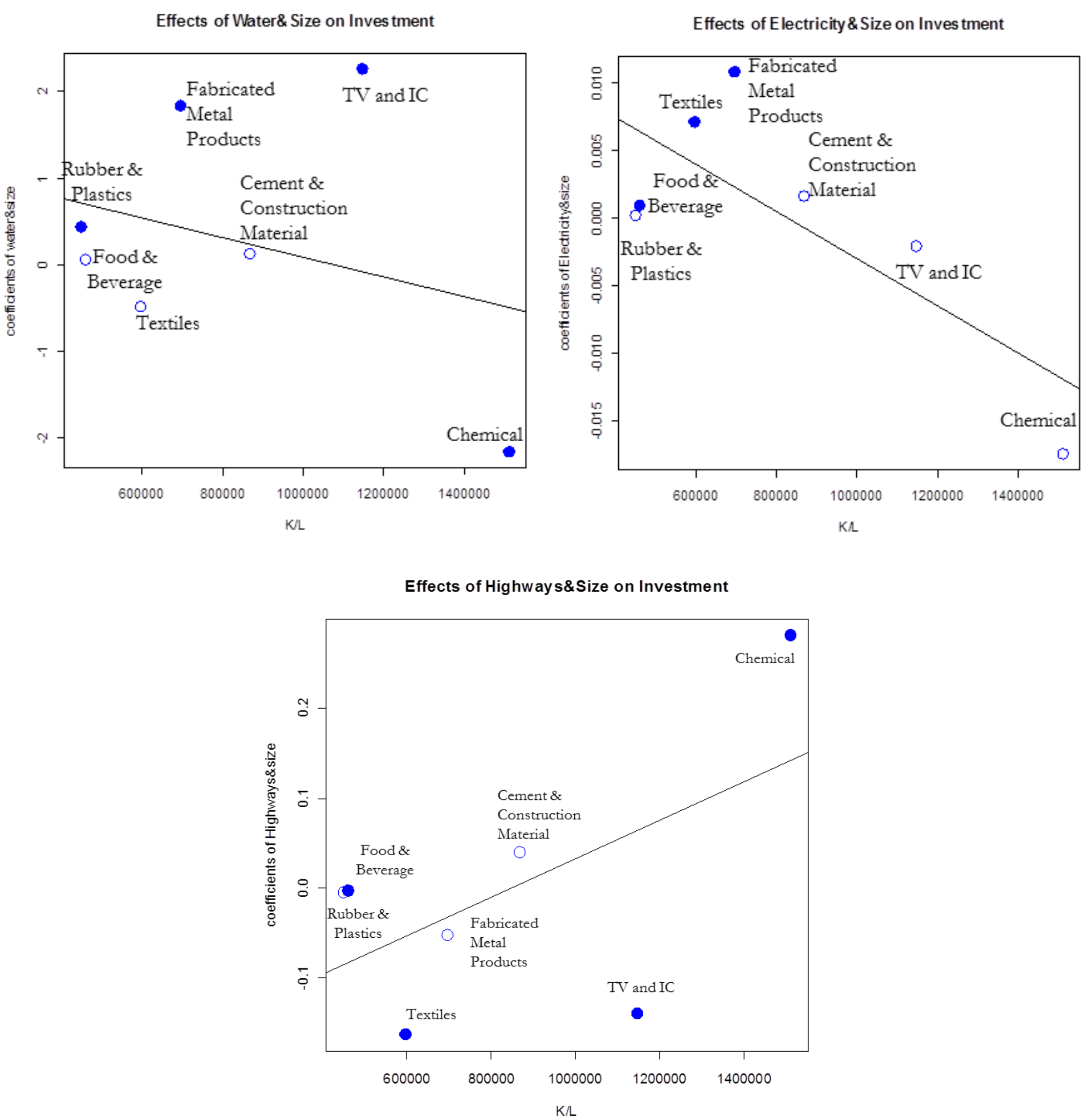
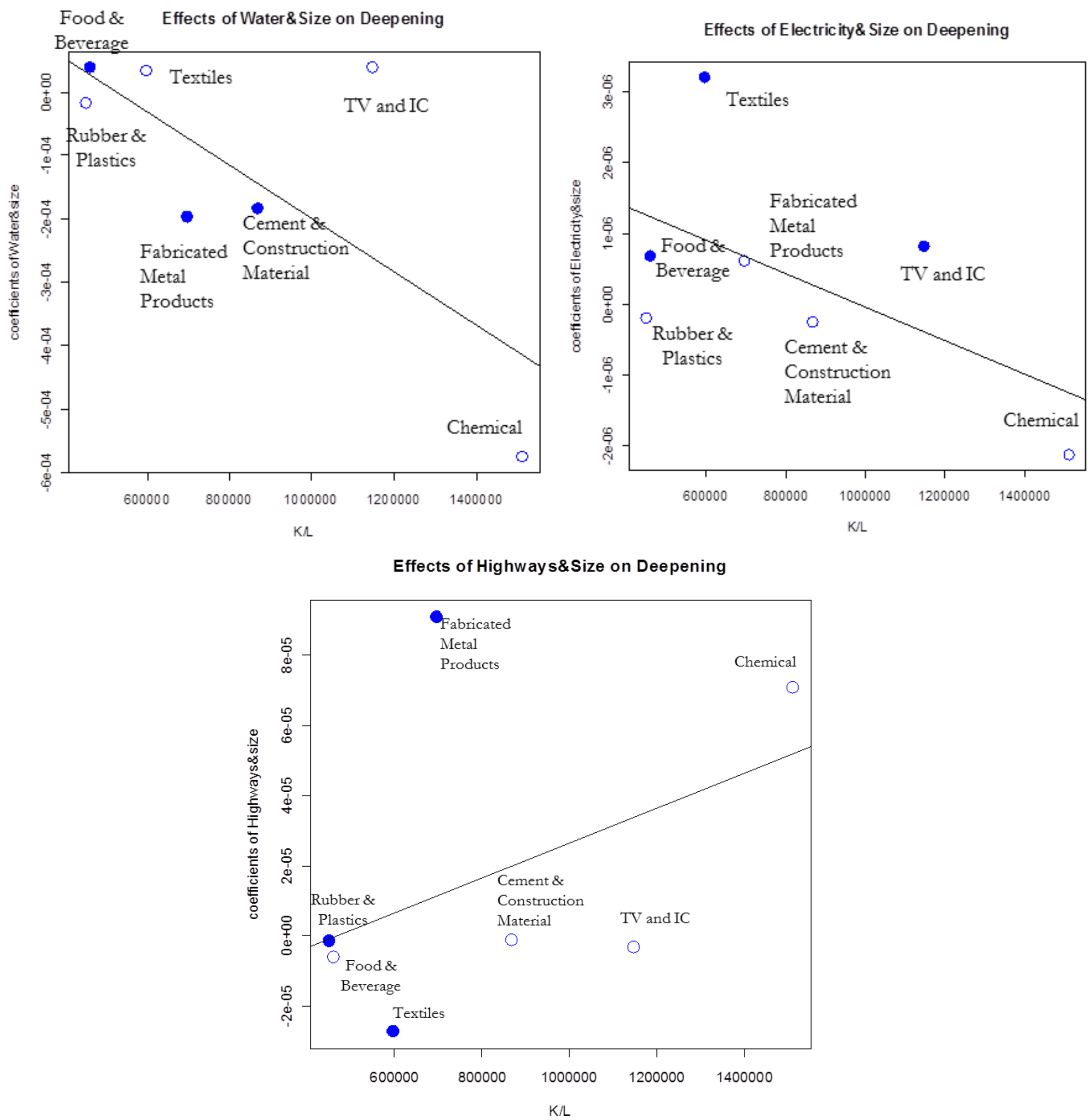


Figure 15a:
Effects of public infrastructure investment on private investment



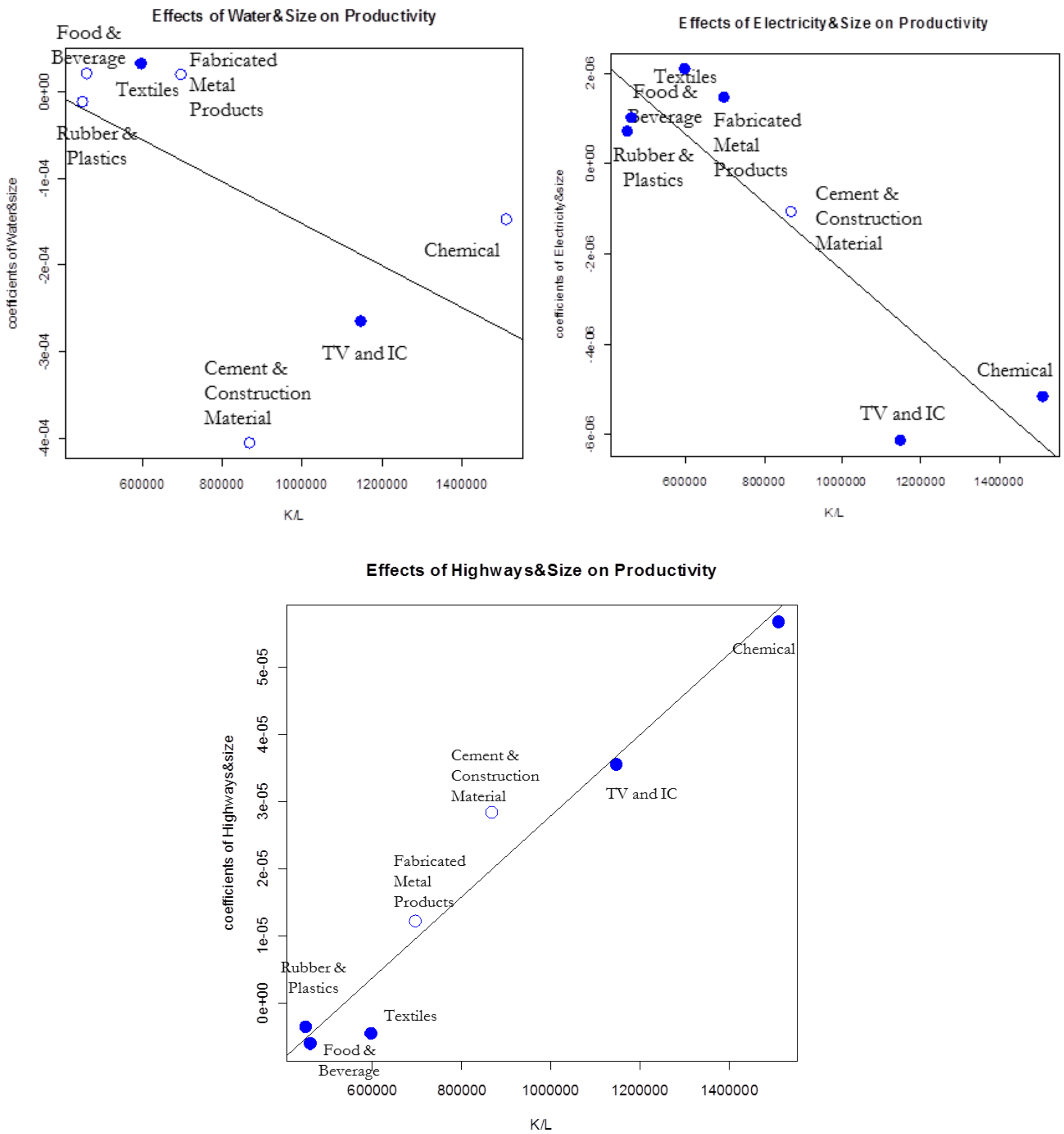
Note: Opaque dots denote statistically significant estimates.

Figure 15b:
Effects of public infrastructure investment on capital deepening



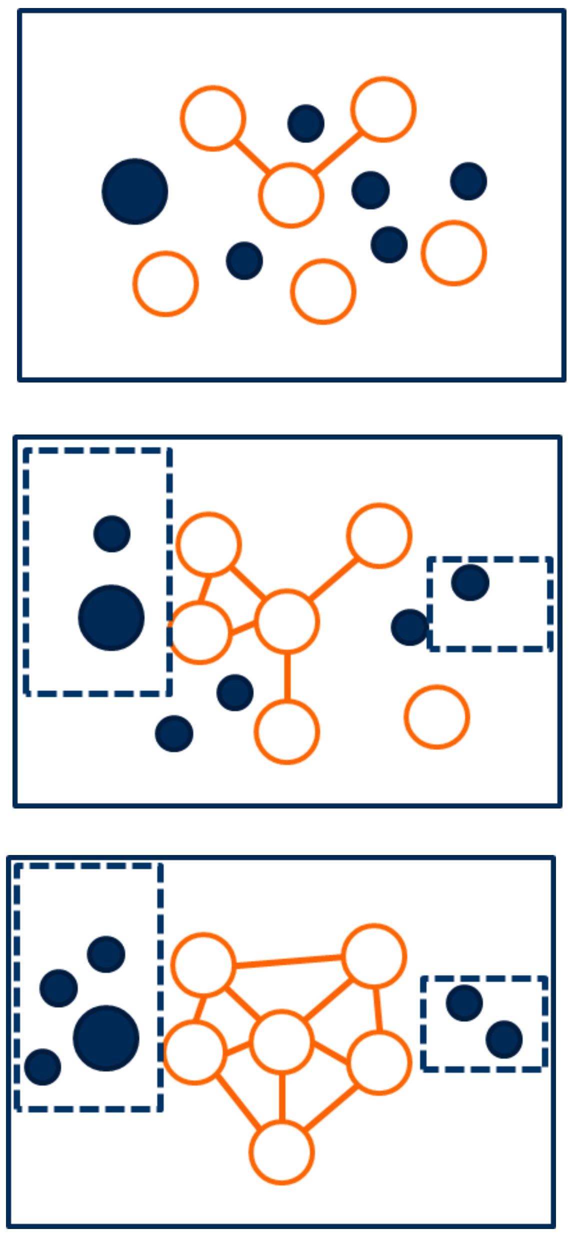
Note: Opaque dots denote statistically significant estimates.

Figure 15c:
Effects of public infrastructure investment on labor productivity



Note: Opaque dots denote statistically significant estimates.

Figure 16:
Schematic representation of “hub” and “zoning”



- Disorganized *status quo* – capital intensive industries (blue dots) mixed with those with lower capital intensity (dots with orange contour)

- “hubs” for capital intensive industries with infrastructure linkages
- “zoning” for industries with low capital intensity

Table 1: Countries in the Middle Income Trap

Region	Countries	Percent of US GDP in 2008	GDP per capita in 2008 (constant 2000 US$)[1/]	Years in Upper-Middle	World Bank's 2010 Classification[2/]
Western Europe	Portugal	46.3	14,436	Since 1900	High
Eastern Europe	Poland	32.6	10,160	Since 1900	High
	Hungary	30.5	9,500	Since 1900	High
	Bulgaria	28.5	8,886	Since 1900	Upper Middle
Former Yugoslavia and Czechoslovakia[3/]	Slovakia	41.8	13,033	Since 1990	High
	Czech Republic	41.3	12,868	Since 1990	High
	Croatia	28.6	8,904	Since 1990	High
Former USSR[4/]	Latvia	47.5	14,816	Since 1990	Upper Middle
	Belarus	40.4	12,607	Since 1990	Upper Middle
	Armenia	37.3	11,630	Since 1990	Lower Middle
	Lithuania	36.4	11,342	Since 1990	Upper Middle
	Kazakhstan	36.1	11,245	Since 1990	Upper Middle
	Russian Federation	29.2	9,111	Since 1990	Upper Middle
Latin American countries	Puerto Rico	48.3	15,074	Since 1950	High
	Chile	42.3	13,185	Since 1940	Upper Middle
	Argentina	35.3	10,995	Since 1942	Upper Middle
	Venezuela	34.0	10,596	Since 1983	Upper Middle
	Uruguay	31.7	9,893	Since 1941	Upper Middle
	Costa Rica	25.8	8,032	Since 1940	Upper Middle
	Mexico	25.6	7,979	Since 1940	Upper Middle
	Panama	21.4	6,675	Since 1946	Upper Middle
	Brazil	20.6	6,429	Since 1960	Upper Middle
	Colombia	20.3	6,330	Since 1940	Upper Middle
East Asian countries	Malaysia	33.0	10,292	Since 1989	Upper Middle
	Thailand	28.1	8,750	Since 1991	Upper Middle
West Asian countries	Kuwait	41.4	12,894	Since 1982	High
	Saudi Arabia	27.1	8,435	Since 1950	High
	Syria	26.8	8,360	Since 1950	Lower Middle
	Oman	26.7	8,332	Since 1968	High
	Turkey	25.9	8,066	Since 1940	Upper Middle
	Bahrain	23.6	7,348	Since 1950	High
	Iran	22.3	6,944	Since 1965	Upper Middle
African countries	Mauritius	46.6	14,529	Since 1950	Upper Middle
Note: Countries below are currently not in the Trap - included only for comparison					
Other selected Countries	Taiwan	67.1	20,926	1973-1992	High
	South Korea	62.9	19,614	1976-1995	High
	China	21.6	6,725	Since 2007	Upper Middle

Source: Maddison (2010)

Note: [1/]PPP Millions, 1990 International Geary-Khamis dollars (constant 2000 US$); [2/] World Bank's classification is based on GNI per capita in US$ (Atlas methodology); [3/] Yugoslavia was dissolved in 1992; [4/] USSR was dissolved in 1991.

Table 2: Three routes to prosperity
and example of countries that followed each

Route	Example countries
"Upgrading" – industrial reforms, emphasis on advanced technology and exports	• Singapore (1981) • Taiwan (1993) • Korea (1996)
Integration (European Union)	• Estonia (2003) • Hungary (2007)* • Czech (2006)* • Slovak (2007)* • Poland (2009)*
Income from supply of natural resource (esp. petroleum)	• Trinidad &Tobago (2003) • Equatorial Guinea (2004) • Saudi Arabia (2004)*

Note: These are sample countries that our income classification criteria indicate that they have ascended beyond the "upper-middle income" range of 20-49 percent of US real GDP per capita, thus attaining the "high income" status. Their first years as high income countries are indicated in parentheses. When marked by asterisk (*), the income criteria used are World Bank's, signifying the case where the country is identified as "upper-middle income" according to our criteria but "high income" according to World Bank's.

Table 3: Summary of the seven chosen manufacturing industries

ISIC	Sectors
15	Food and Beverage
17	Textiles
24	Chemical
25	Rubber and Plastics
26	Cements and Construction Materials
28	Fabricated Metals
32	TV and IC

Table 4: The ξ test statistics in Robinson (2008)

ISIC	Sectors	Capital	Capital Intensity	Labor Productivity
15	Food and Beverage	0.5519	0.1722	1.1410
17	Textiles	0.5501	0.5900	0.5432
24	Chemical	0.0890	0.0745	0.0602
25	Rubber and Plastics	0.0589	0.7340	9.2928
26	Cements and Construction Materials	0.0113	0.6909	2.2775
28	Fabricated Metals	0.3404	0.1166	0.0118
32	TV and IC	0.0594	0.9458	0.5920

The 85-th, 90-th, and 95-th percentiles of x_1^2 are 2.0723, 2.7055 and 3.8415, respectively.

Table 5a: Effects of public infrastructure investment on private investment

	Rubber and Plastics	Food and Beverage	Textiles	Basic Metals	Cement and Construction material	Television and IC	Chemical
Constant	**2.331E+06**	**4.413E+04**	**-4.088E+06**	**1.963E+06**	**3.311E+06**	**4.806E+06**	**2.194E+06**
	(2.660E+06)	(1.408E+06)	(3.204E+06)	(2.568E+06)	(1.459E+06)	(3.031E+07)	(5.474E+06)
m = (6,12)	(1.750E+06)	(1.270E+06)	(1.272E+06)	(1.412E+06)	(1.109E+06)	(1.692E+07)	(1.148E+06)
m = (10,20)	(1.547E+06)	(1.321E+06)	(1.356E+06)	(1.053E+06)	(1.095E+06)	(1.676E+07)	(1.062E+06)
Highway	**-2.527E+04**	**3.548E+04**	**1.183E+05**	**1.323E+04**	**2.335E+03**	**1.381E+05**	**1.944E+04**
	(5.417E+04)	(3.582E+04)	(7.791E+04)	(5.316E+04)	(3.546E+04)	(8.207E+05)	(1.144E+05)
m1	(3.253E+04)	(2.636E+04)	(4.325E+04)	(2.958E+04)	(3.513E+04)	(5.249E+05)	(8.239E+04)
m2	(2.949E+04)	(2.547E+04)	(4.086E+04)	(2.439E+04)	(3.267E+04)	(5.939E+05)	(5.905E+04)
Electricity	**4.094E+03**	**3.383E+04**	**3.105E+04**	**2.635E+04**	**1.303E+04**	**1.037E+04**	**1.904E+04**
	(1.655E+04)	(1.246E+04)	(1.975E+04)	(1.355E+04)	(1.144E+04)	(1.026E+05)	(2.530E+04)
m1	(2.098E+04)	(1.337E+04)	(7.101E+03)	(1.755E+04)	(2.196E+04)	(6.813E+04)	(4.073E+04)
m2	(1.903E+04)	(1.157E+04)	(6.146E+03)	(1.528E+04)	(1.952E+04)	(6.682E+04)	(2.468E+04)
Water	**-1.239E+05**	**-2.861E+05**	**3.802E+05**	**-5.974E+05**	**2.335E+03**	**3.225E+06**	**8.471E+05**
	(3.792E+05)	(2.279E+05)	(3.856E+05)	(3.321E+05)	(3.546E+04)	(6.354E+06)	(6.724E+05)
m1	(2.765E+05)	(1.406E+05)	(2.800E+05)	(2.295E+05)	(2.265E+05)	(7.347E+06)	(4.674E+05)
m2	(2.444E+05)	(1.255E+05)	(2.986E+05)	(1.988E+05)	(2.136E+05)	(8.122E+06)	(3.933E+05)
Size	**-5.805E-01**	**-1.214E-01**	**4.746E+00**	**-4.917E+00**	**-5.144E+00**	**1.224E+00**	**-5.274E+00**
	(4.260E-01)	(9.284E-02)	(6.467E-01)	(1.087E+00)	(3.827E-01)	(3.690E+00)	(2.268E+00)
m1	(1.001E+00)	(1.095E-01)	(1.418E+00)	(2.065E+00)	(5.590E-01)	(2.686E+00)	(3.400E+00)
m2	(8.032E-01)	(8.725E-02)	(1.158E+00)	(1.960E+00)	(3.312E-01)	(2.726E+00)	(2.132E+00)
Size * Highway	**-5.062E-03**	**-2.762E-03**	**-1.625E-01**	**-5.228E-02**	**3.998E-02**	**-1.395E-01**	**2.813E-01**
	(4.363E-03)	(2.785E-03)	(1.873E-02)	(2.950E-02)	(1.882E-02)	(6.645E-02)	(8.027E-02)
m1	(7.359E-03)	(4.302E-03)	(4.727E-02)	(4.420E-02)	(4.070E-02)	(4.254E-02)	(2.616E-01)
m2	(6.582E-03)	(3.610E-03)	(3.191E-02)	(4.060E-02)	(3.656E-02)	(4.248E-02)	(1.686E-01)
Size * Electricity	**1.698E-04**	**9.149E-04**	**7.049E-03**	**1.084E-02**	**1.602E-03**	**-2.138E-03**	**-1.753E-02**
	(6.502E-04)	(3.296E-04)	(2.654E-03)	(2.428E-03)	(1.957E-03)	(6.262E-03)	(7.630E-03)
m1	(8.923E-04)	(5.594E-04)	(4.784E-03)	(3.676E-03)	(5.908E-03)	(5.309E-03)	(2.778E-02)
m2	(5.847E-04)	(4.873E-04)	(8.191E-07)	(2.276E-03)	(5.618E-03)	(4.533E-03)	(1.781E-02)
Size * Water	**4.302E-01**	**5.527E-02**	**-4.885E-01**	**1.827E+00**	**1.242E-01**	**2.263E+00**	**-2.166E+00**
	(5.808E-02)	(2.146E-02)	(1.171E-01)	(2.693E-01)	(1.298E-01)	(6.421E-01)	(5.520E-01)
m1	(1.588E-01)	(4.890E-02)	(3.156E-01)	(4.838E-01)	(3.272E-01)	(3.757E-01)	(1.625E+00)
m2	(1.114E-01)	(4.514E-02)	(3.390E-01)	(3.431E-01)	(3.054E-01)	(2.999E-01)	(1.058E+00)
No. of Obs.	120	368	126	106	267	31	81
R-Squared	0.413	0.125	0.671	0.597	0.881	0.541	0.372

Note: Slope estimates are in bold; standard errors in parentheses – with non-robust ones in the top row and robust ones below computed using truncation vectors m1 and m2, respectively.

Table 5b: Effects of public infrastructure investment on capital deepening

	Rubber and Plastics	Food and Beverage	Textiles	Basic Metals	Cement and Construction material	Television and IC	Chemical
Constant	**-8.870E+01**	**8.559E+02**	**-6.628E+02**	**3.337E+03**	**-9.075E+02**	**5.102E+03**	**-1.134E+03**
	(1.658E+03)	(2.588E+03)	(6.794E+02)	(1.198E+03)	(1.076E+03)	(5.212E+03)	(3.584E+03)
m1	(1.430E+03)	(2.500E+03)	(5.758E+02)	(1.186E+03)	(9.184E+02)	(4.454E+03)	(1.954E+03)
m2	(1.329E+03)	(2.545E+03)	(5.533E+02)	(1.136E+03)	(8.555E+02)	(4.223E+03)	(1.451E+03)
Highway	**3.392E+01**	**1.191E+01**	**3.183E+00**	**-5.267E+01**	**3.220E+01**	**1.162E+02**	**5.612E+01**
	(3.376E+01)	(6.582E+01)	(1.652E+01)	(2.481E+01)	(2.615E+01)	(1.411E+02)	(7.489E+01)
m1	(5.853E+01)	(3.949E+01)	(1.573E+01)	(2.015E+01)	(2.145E+01)	(1.105E+02)	(6.067E+01)
m2	(5.896E+01)	(3.646E+01)	(1.180E+01)	(1.783E+01)	(2.228E+01)	(1.039E+02)	(6.047E+01)
Electricity	**-6.963E+00**	**9.897E+00**	**-2.653E-01**	**3.292E+00**	**6.316E+00**	**-2.705E+01**	**-6.978E+00**
	(1.032E+01)	(2.290E+01)	(4.188E+00)	(6.323E+00)	(8.440E+00)	(1.764E+01)	(1.656E+01)
m1	(8.710E+00)	(1.186E+01)	(5.174E+00)	(4.314E+00)	(6.271E+00)	(1.630E+01)	(1.464E+01)
m2	(7.905E+00)	(1.133E+01)	(4.100E+00)	(3.887E+00)	(5.007E+00)	(1.533E+01)	(1.140E+01)
Water	**-2.194E+02**	**-3.618E+02**	**2.994E+01**	**6.182E+01**	**1.328E+02**	**-1.305E+03**	**5.070E+02**
	(2.364E+02)	(4.189E+02)	(8.176E+01)	(1.550E+02)	(1.505E+02)	(1.093E+03)	(4.402E+02)
m1	(1.904E+02)	(1.702E+02)	(6.324E+01)	(6.509E+01)	(9.374E+01)	(6.144E+02)	(4.075E+02)
m2	(1.844E+02)	(1.593E+02)	(6.811E+01)	(5.877E+01)	(8.407E+01)	(5.505E+02)	(3.073E+02)
Size	**1.801E-04**	**-5.349E-05**	**2.170E-04**	**-6.028E-03**	**8.370E-05**	**-2.056E-04**	**-2.048E-03**
	(2.655E-04)	(1.706E-04)	(1.371E-04)	(5.071E-04)	(2.823E-04)	(6.345E-04)	(1.485E-03)
m1	(9.147E-05)	(6.916E-05)	(3.538E-04)	(1.086E-03)	(1.883E-04)	(3.085E-04)	(1.091E-03)
m2	(7.458E-05)	(5.677E-05)	(3.219E-04)	(1.063E-03)	(1.901E-04)	(2.942E-04)	(6.925E-04)
Size * Highway	**-1.620E-06**	**-6.204E-06**	**-2.735E-05**	**9.102E-05**	**-1.171E-06**	**-3.266E-06**	**7.084E-05**
	(2.719E-06)	(5.117E-06)	(3.972E-06)	(1.377E-05)	(1.388E-05)	(1.143E-05)	(5.255E-05)
m1	(1.039E-06)	(3.972E-06)	(4.746E-06)	(1.897E-05)	(9.889E-06)	(5.773E-06)	(1.029E-04)
m2	(9.836E-07)	(3.795E-06)	(4.316E-06)	(1.787E-05)	(1.063E-05)	(5.032E-06)	(6.558E-05)
Size * Electricity	**-1.991E-07**	**6.710E-07**	**3.203E-06**	**5.995E-07**	**-2.582E-07**	**8.098E-07**	**-2.126E-06**
	(4.053E-07)	(6.058E-07)	(5.627E-07)	(5.995E-07)	(1.443E-06)	(1.077E-06)	(4.995E-06)
m1	(1.606E-07)	(4.194E-07)	(8.191E-07)	(8.111E-07)	(6.979E-07)	(5.244E-07)	(1.112E-05)
m2	(1.364E-07)	(3.789E-07)	(8.073E-07)	(7.560E-07)	(7.305E-07)	(3.419E-07)	(6.986E-06)
Size * Water	**-1.813E-05**	**3.903E-05**	**3.372E-05**	**-1.979E-04**	**-1.841E-04**	**3.889E-05**	**-5.756E-04**
	(3.620E-05)	(3.944E-05)	(2.482E-05)	(1.257E-04)	(9.572E-05)	(1.104E-04)	(3.614E-04)
m1	(1.558E-05)	(2.688E-05)	(4.382E-05)	(9.976E-05)	(6.812E-05)	(4.553E-05)	(6.936E-04)
m2	(1.232E-05)	(2.447E-05)	(4.604E-05)	(8.739E-05)	(1.063E-05)	(3.132E-05)	(4.575E-04)
No. of Obs.	120	368	126	106	267	31	81
R-Squared	0.030	0.008	0.404	0.605	0.247	0.149	0.113

Note: Slope estimates are in bold; standard errors in parentheses – with non-robust ones in the top row and robust ones below computed using truncation vectors m1 and m2, respectively.

Table 5c: Effects of public infrastructure investment on labor productivity

	Rubber and Plastics	Food and Beverage	Textiles	Basic Metals	Cement, Construction material	Television and IC	Chemical
Constant	**2.576E+03**	**-2.922E+02**	**-2.684E+02**	**-1.019E+03**	**-1.248E+03**	**-7.423E+03**	**4.015E+02**
	(1.405E+03)	(9.568E+02)	(4.882E+02)	(8.037E+02)	(1.180E+03)	(1.021E+04)	(2.114E+03)
m1	(1.220E+03)	(9.375E+02)	(3.519E+02)	(7.988E+02)	(8.252E+02)	(4.382E+03)	(1.666E+03)
m2	(1.220E+03)	(9.260E+02)	(3.477E+02)	(6.940E+02)	(7.090E+02)	(3.603E+03)	(1.201E+03)
Highway	**3.019E+01**	**-1.849E+01**	**2.460E+01**	**2.433E+01**	**2.310E+01**	**8.513E+01**	**6.071E+00**
	(2.862E+01)	(2.433E+01)	(1.187E+01)	(1.664E+01)	(2.868E+01)	(2.765E+02)	(4.419E+01)
m1	(2.617E+01)	(3.832E+01)	(8.485E+00)	(1.092E+01)	(2.653E+01)	(1.194E+02)	(3.681E+01)
m2	(2.416E+01)	(3.822E+01)	(8.472E+00)	(1.065E+01)	(2.880E+01)	(9.465E+01)	(3.305E+01)
Electricity	**-2.328E+01**	**1.759E+01**	**-7.769E-01**	**2.588E-01**	**3.611E+00**	**2.367E+01**	**1.984E+01**
	(8.745E+00)	(8.467E+00)	(3.010E+00)	(4.240E+00)	(9.255E+00)	(3.456E+01)	(9.773E+00)
m1	(1.146E+01)	(6.482E+00)	(2.268E+00)	(2.891E+00)	(8.687E+00)	(1.723E+01)	(5.803E+00)
m2	(1.150E+01)	(6.457E+00)	(2.337E+00)	(2.636E+00)	(8.915E+00)	(1.842E+01)	(5.864E+00)
Water	**-2.024E+02**	**-7.151E+01**	**-5.381E+01**	**8.578E+01**	**-1.318E+02**	**8.170E+02**	**1.302E+02**
	(2.004E+02)	(1.549E+02)	(5.876E+01)	(1.039E+02)	(1.650E+02)	(2.141E+03)	(2.597E+02)
m1	(1.018E+02)	(1.280E+02)	(3.329E+01)	(5.374E+01)	(1.750E+02)	(9.375E+02)	(1.789E+02)
m2	(8.955E+01)	(1.222E+02)	(3.266E+01)	(4.682E+01)	(1.321E+02)	(6.841E+02)	(1.315E+02)
Size	**2.829E-05**	**-2.571E-04**	**-6.157E-04**	**-1.488E-03**	**-2.421E-04**	**3.672E-04**	**-2.204E-03**
	(2.251E-04)	(6.307E-05)	(9.853E-05)	(3.401E-04)	(3.095E-04)	(1.243E-03)	(8.759E-04)
m1	(1.105E-04)	(8.702E-05)	(9.658E-05)	(3.150E-04)	(6.559E-04)	(4.260E-04)	(5.592E-04)
m2	(9.240E-05)	(8.280E-05)	(8.225E-05)	(2.905E-04)	(6.875E-04)	(3.696E-04)	(3.337E-04)
Size * Highway	**-3.590E-06**	**-6.120E-06**	**-4.544E-06**	**1.224E-05**	**2.843E-05**	**3.548E-05**	**5.684E-05**
	(2.305E-06)	(1.892E-06)	(2.854E-06)	(9.234E-06)	(1.522E-05)	(2.239E-05)	(3.101E-05)
m1	(1.210E-06)	(3.506E-06)	(2.536E-06)	(8.965E-06)	(4.946E-05)	(8.175E-06)	(3.389E-05)
m2	(1.051E-06)	(3.293E-06)	(1.499E-06)	(7.597E-06)	(4.965E-05)	(6.225E-06)	(2.027E-05)
Size * Electricity	**7.163E-07**	**1.015E-06**	**2.096E-06**	**1.474E-06**	**-1.065E-06**	**-6.135E-06**	**-5.163E-06**
	(3.435E-07)	(2.239E-07)	(4.044E-07)	(7.600E-07)	(1.583E-06)	(2.110E-06)	(2.947E-06)
m1	(2.992E-07)	(3.775E-07)	(3.261E-07)	(7.208E-07)	(5.240E-06)	(2.322E-06)	(3.749E-06)
m2	(2.818E-07)	(3.529E-07)	(2.421E-07)	(5.751E-07)	(5.157E-06)	(1.720E-06)	(2.001E-06)
Size * Water	**-1.190E-05**	**2.033E-05**	**3.224E-05**	**1.893E-05**	**-4.059E-04**	**-2.646E-04**	**-1.481E-04**
	(3.069E-05)	(1.458E-05)	(1.784E-05)	(8.429E-05)	(1.050E-04)	(2.163E-04)	(2.132E-04)
m1	(8.729E-06)	(2.668E-05)	(1.153E-05)	(7.365E-05)	(3.739E-04)	(1.850E-04)	(2.141E-04)
m2	(9.142E-06)	(2.383E-05)	(9.148E-06)	(5.728E-05)	(3.741E-04)	(1.117E-04)	(1.353E-04)
No. of Obs.	120	368	126	106	267	31	81
R-Squared	0.223	0.208	0.440	0.289	0.193	0.438	0.367

Note: Slope estimates are in bold; standard errors in parentheses – with non-robust ones in the top row and robust ones below computed using truncation vectors m1 and m2, respectively.