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Analysis

The socio-economic drivers of material stock accumulation in Japan's prefectures

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ABSTRACT

Physical economy research has, thus far, focused on the throughput of materials that underpin economic development. The role of stocks of buildings and infrastructure has remained underexplored, yet it is the physical stock that provides service to society. To fill this gap, this research investigates stock dynamics in Japan in relation to population and economic drivers using panel regression and IPAT analyses for the past five decades. We recognize characteristic changes in the strength and relative influence of the drivers throughout time, in different subnational regions, and on the dynamics of buildings compared to transportation infrastructure. We find that material stock accumulation mainly occurred due to growth in economic activity, specifically by tertiary sector demand. Apart from a period of government-driven stock accumulation in the 1990s to stimulate economic growth, as economic and population growth slowed stock accumulation dynamics also changed signaling a new stock saturation trend. Migration from rural to urban areas has recently become an influential driver, leaving behind underused buildings and roads. This analysis provides a case study on how socio-economic drivers and stock accumulation interacted and changed while the country matured, which may have implications for understanding stock dynamics in rapidly industrializing economies.

1. Introduction

Construction material stocks of buildings and transport infrastructure play an important role in society and the economy and are associated with numerous environmental and economic issues. While construction materials in general are relatively abundant and inexpensive, in sheer mass they dominate the material flow accounts of developed nations (Adriaanse et al., 1997; Krausmann et al., 2011; Kovanda and Hak, 2011; Gierlinger and Krausmann, 2012) and rapidly developing giants such as China (Schandl and West, 2012) as well as at the global scale (Krausmann et al., 2009) and because of their sheer magnitude their extraction from the environment, transport, and disposal impose direct environmental and economic concerns (Horvath, 2004; Kennedy et al., 2007). The embodied energy and carbon in construction materials is high (Hammond and Jones, 2008; Müller et al., 2013), and the quality and longevity of building and infrastructure stock determine the throughput of energy and resulting carbon emissions (IPCC, 2014). There is also a substantial maintenance effort required as well as waste flows from decommissioning buildings and infrastructure (Lawson et al., 2001; Kohler and Yang, 2007; Vieira and Horvath, 2008; Hashimoto et al., 2007, 2009). A certain level of stock is required to enable an economy to grow and to provide essential services to businesses and households, which Bettencourt et al. (2007) claim display economies of scale. The spatial characteristics of building and infrastructure stock alter the landscape (Douglas and Lawson, 2000) and play a role in debates about "green" architecture (Humbert et al., 2007), city planning (Norman et al., 2006) and urban metabolism (Kennedy et al., 2011).

Direct Material Consumption (DMC) of construction materials has been calculated for many countries as part of yearly national material flow accounts (Gierlinger and Krausmann, 2012; Krausmann et al., 2011; Schandl and West, 2012; West et al., 2014; West and Schandl, 2013). This inflow indicator has been used in material flow research using various analytical tools such as IPAT frameworks (Schandl and West, 2010, 2012; Steinberger and Krausmann, 2011; West et al., 2014; West and Schandl, 2013) and econometric analysis (Bringezu et al., 2004; Steinberger et al., 2010, 2013) to explain factors that determine growth in material throughput. This research has described different metabolic profiles and identified structural change of economies at different stages of development (Krausmann et al., 2008).

However, explaining the relationship between a society and the construction materials on which it relies requires analysis not only of flows of "additions to stock" in a single year but to take into account the total

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accumulated material stock in use by society. The services that buildings and infrastructure provide to society are numerous, and include housing, transportation, and communication (Pauliuk and Müller, 2014). Demand for increases in material stock (and thus for inflows) depends on the unsuitability of the existing stock – amassed for decades and longer – to effectively provide these services, whether because of limited numerical capacity, insufficient quality, improper location, or due to changing needs and tastes.

Studies of material stock have focused on accounting for in-use stock (Müller et al., 2014; Tanikawa et al., in press provide extensive bibliographies and reviews of these studies) and on the relations of flows and stocks (Gerst, 2009; Gordon et al., 2006; Hashimoto et al., 2007, 2009; Hatayama et al., 2010; Tanikawa and Hashimoto, 2009; Wiedenhofer et al., 2015). Rarely have the studies gone beyond measuring the amounts of flows and stocks used in an economy to investigate the causes, or drivers, of stock accumulation. Those that did simply observed material stock growth in parallel to population or GDP growth trends in an effort to recognize coupling and decoupling trends (Fishman et al., 2014; Liu and Müller, 2013; Müller et al., 2011) or used information on socio-economic demand for stock to model future stocks (Müller, 2006; Bergsdal et al., 2007; Hu et al., 2010; Huang et al., 2013). The limited availability of long-term, detailed data in comparable formats has hampered more complex analysis (Fischer-Kowalski et al., 2011). While international comparisons remain elusive, the recent compilation of a highly detailed database of the material stock of Japan in the 20th and 21st centuries (Tanikawa et al., in press) enables us in this study to examine Japan's stock accumulation at national and subnational level applying the analytical tools previously used exclusively in material flow research.

We use this database to investigate the extent to which trends in population and economic activity have acted as drivers of material stock accumulation in Japan. Japan's 47 subnational constituents, named prefectures (Fig. 1), are characterized by different trends in

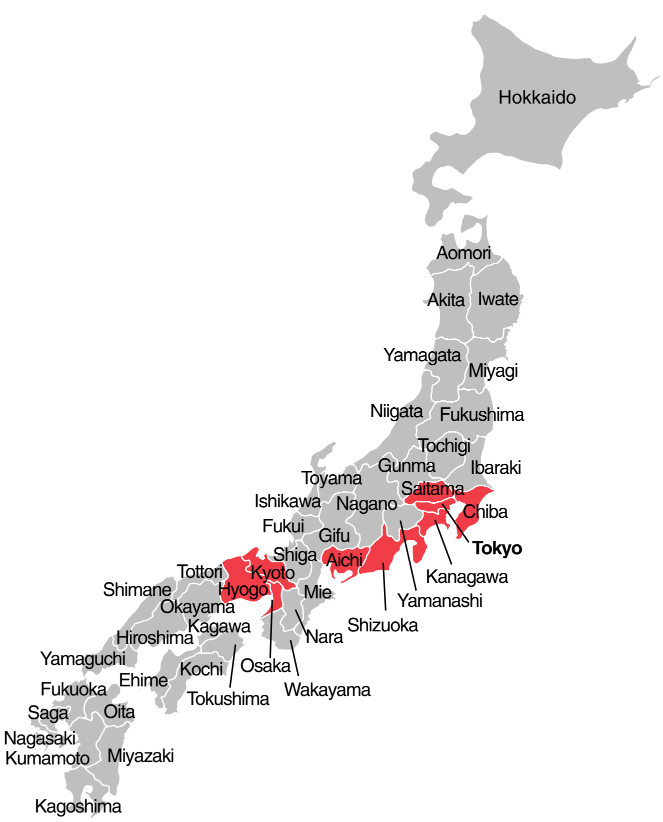

Fig. 1. Schematic of the prefectures of Japan (excluding Okinawa). The Tokyo–Nagoya–Osaka urban strip is differentiated by shade.

population and economic activity, and different geographies. We analyze whether the relationship between population, economy and stock accumulation found at the national level is reproduced at the subnational level in a uniform way. We are also interested to know whether building stock and transport infrastructure stock are influenced by population and economy in different ways.

We employ two analytical methods to approach our research questions, using IPAT and panel analyses to unpack what has determined stock accumulation in Japan's prefectures during the past five decades. The aim of this study is to characterize the relationships between socio-economic drivers and stock accumulation, and specifically to identify which driver is most important, and how the importance of drivers has changed over time. To this end, we focus on comparing the change in material stock to the changes in the different drivers throughout time. We also investigate the influence of social geography to analyze the influence of the location and degree of urbanization of prefectures. With the findings of this research we aim to contribute to the larger debate around economic development and its metabolic causes and consequences.

2. Methods and Data

2.1. Material Stock Data

Material stock data for this research was sourced from a new comprehensive and highly disaggregated material stock database for Japan and its prefectures (Tanikawa et al., in press), compiled bottom-up using detailed GIS (Geographic Information Systems) and statistics-sourced inventories of Japan's buildings and infrastructure. The database contains information about the anthropogenic stock of construction materials in Japan at a spatial resolution of 1 km^2 for the time period 1945 to 2010 in yearly time steps, measured in tonnes. The data can be spliced by material type (for example minerals, metals, or timber) and by function (for example residential buildings, commercial buildings, roads, or railways). For the aims of this study, we employ a subset of the database and focus on buildings and transport infrastructure, which have very close links to economic activity and material standards of living. Other elements of the database, such as dams and sewer pipes, are not used. We analyze the period 1965 to 2010 for which full data coverage exists. Okinawa Prefecture was omitted from our dataset since it was only returned to Japan in 1975 when the US occupation ended and data for Okinawa is therefore incomplete, leaving 46 prefectures to examine. The data is aggregated to the prefecture level and includes the materials cement, aggregate, asphalt, timber, and iron, as well as a category of materials which are minor in sheer mass such as glass, copper, and aluminum.

2.2. Population and Economic Data

Population and gross prefectural product (GPP) for every prefecture were sourced from the Statistics Bureau of Japan (2014). The GPP figures were converted from local currency to 1990 International Dollars by applying currency conversion factors from Maddison (2008) and OECD (2014).

2.3. IPAT Analysis

The $I = P \times A \times T$ identity (Commoner et al., 1971; Ehrlich and Holdren, 1971) explains environmental impact (I) as the consequence of three drivers: population (P), affluence (A), and technology (T). This commonly used method of decomposition analysis of environmental impacts (York et al., 2003) has been used in different variations in studies analyzing drivers of material flows (Steinberger and Krausmann, 2011; Schandl and West, 2012; West and Schandl, 2013). Here we apply the IPAT identity to the analysis of determinants of material stock growth. The evolution of material stock (I) is explained by two drivers: population (P), and affluence measured as GPP per