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The Dynamics of Capability Upgrading in Indonesian Herbal Medicine Firms

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ABSTRACT

This article examined the dynamics of capability upgrading in Indonesian herbal medicine firms for empirical and future trends analysis. System dynamics modelling was used to examine the dynamics of capability upgrading. The following core ideas emerged from a system dynamics analysis of capability upgrading in Indonesian herbal medicine firms. Capability upgrading in Indonesian herbal medicine firms can take two forms: i. the linear progression of technological capability ladders from traditional herbal to standardised herbal and phytopharmaceutical medicine, and ii. the non-linear progression of technological capability upgrading by directly producing standardised herbal through R&D and then moving up to create phytopharmaceutical medicine. Innovation collaboration and management coordination led by top management were key enablers of the company's success in capability upgrading. Capability upgrading can be accelerated by incorporating advanced knowledge bases (such as biotechnology), the entrepreneurial activities of leading firms, and government institutional/regulatory support. The study's findings confirmed the concept of technology upgrading in the capability ladder, which begins with 'operational capability', progresses to 'technical capability', increases to 'design and engineering capability', and finally develops to 'technology development capability'. The study's limitation was the design of the feedback structure based on the capability upgrading perspective. The different perspectives for further study are possible.

I. INTRODUCTION

A. Background and Objective

Herbal medicine is commonly used by Indonesian consumers, the so-called *Jamu* or traditional medicine. The quality of traditional medicine has improved in recent years, resulting in more effective and upgraded herbal medicine products. Traditional herbal medicinal products that have been upgraded are classified as follows: standard herbal medicine and modern herbal medicine or phytopharmaceutical drugs. Traditional herbal medicine is generally produced by household/micro businesses and small enterprises, while standard herbal medicine and modern herbal

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medicine or phytopharmaceutical drugs are manufactured by medium and large firms. The capability upgrading has been intensified in Indonesia since 2000. The number of upgraded herbal medicine products manufactured by herbal medicine firms has continued to increase.

The article is further studies from previous works (Aminullah et al., 2017, Aminullah, 2018) by conducting the different approaches using system dynamics modelling, validated by previous works, and enriched with additional statistical data. New knowledge was revealed under the title of "Dynamics of capability upgrading in Indonesian herbal medicine firms". The core ideas are capability upgrading in Indonesian herbal medicine firms can be realised by two routes: i) the linear moving up of technological capability ladders from traditional herbal to standardised herbal and phytopharmaceutical medicine, and, ii) the non-linear dynamic of technological capability is upgrading by directly producing standardised herbal using R&D and then moving up to create phytopharmaceutical medicine.

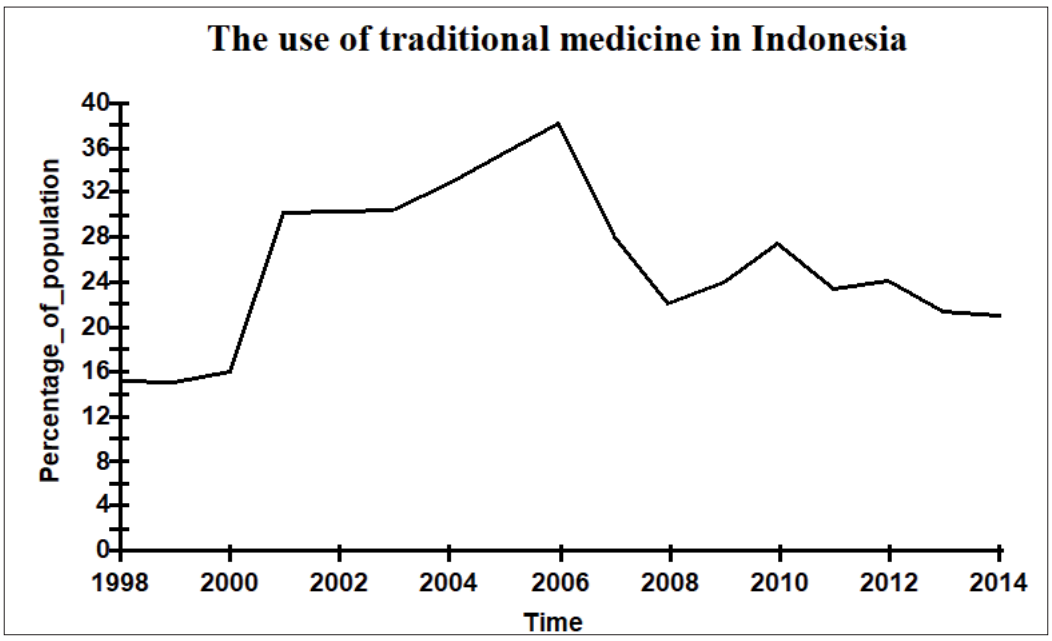
The dynamics of capability upgrading were analysed by using system dynamics modelling. The stages of modelling and validation were designed according to the standard method of dynamic system modelling as follows: i. method of model building applied the technique of "from story to structure" method (Kim & Anderson, 1998). The model construction was built from data or evidence's behaviour to be the causal loop model. ii. The validated model passed four orderly tests: empirical structure test, theoretical structure test, stability structure test, and patterns of prediction behaviour test (See Appendix). iii. The model worked through computer simulation by utilising Powersim software to explain how and why the patterns of nonlinearity on system behaviour occurred, caused primarily by the design of feedback structure inside the system.

This article is organised as follows: i. evidence of the population using herbal medicine, reflecting the market demand for herbal medicine that has been booming during the Covid-19 pandemic; ii. construction of herbal medicine firms' upgrading framework was then developed into the multiple loops model for empirical and future trends analysis; iii. explanation of firms' capability upgrading by case study results; iv. further explanation on the dynamic of firms' capability upgrading by using simulation results; and v. conclusion of the study.

B. Population Using Herbal Medicine

In applying the technique of the "from story to structure" method, this research started from the trends of the population using traditional medicine, mostly dominated by traditional medicine, in Indonesian terms called *Jamu*. Figure 1. shows that the percentage of the population using traditional medicine rose from 16% and 24% in the period 2000–2014. The peak of traditional medicine usage reached 38% in 2006, showing a declining trend up to 2014. The percentage of the population using traditional medicine has shown a stable trend of around 20% since 2010. The rapid increase in the population using traditional medicine in the 2000s was triggered by Indonesia's economic crisis. Those who are unable to buy modern medicine at high prices turned their attention to traditional medicine (Mustamu, 2000). Some factors affecting the use of traditional medicine in Indonesia have been documented in literature: belief factor (Ervina & Ayubi, 2018), individual preference (Jennifer & Saptutyningsih, 2015), no side effects and its benefits (Maryani et al., 2016), older age, living in the rural area and married status (Supardi & Susyanty, 2010).

The use of traditional medicine in Indonesia is in coexistence with the availability of herbal plants. Indonesia has 30,000 types of herbal plants, 7000 expectedly effective for medication, and around 20% have been explored for production (Siahaan & Aryastami, 2018). The herbal medicine market, by category, is segmented into herbal pharmaceuticals, dietary supplements, functional foods, and beauty products. The global herbal pharmaceutical segment led the herbal medicine market with USD 51 billion in 2017 (Marketwatch, 2019). Indonesia ranks fourth as a herbal medicine producer after China, India, and Korea. The potential value of herbal medicine sales in the country reaches IDR 20 trillion, and



Source: Indonesia Bureau of Statistics

Figure 1. Trends of the population using herbal medicine

exports worth IDR 16 trillion, while world herbal sales reach US $ 60 billion yearly (Sumaryati et al., 2020). The Indonesian and global demand for herbal medicine has been booming during the Covid-19 pandemic (Ang, Song, Lee, and Lee, 2020), which inevitably needs firms' upgrading capability based on R&D availability.

II. LITERATURE REVIEW AND ANALYTICAL FRAMEWORK

A. R&D Availability and Capability Upgrading

Viewed from R&D availability, firms have two options for developing new products or processes, either through formal or informal R&D. The firms carry out formal R&D if they officially manage, allocate resources, and direct their R&D activities to create new products or processes inside their R&D unit. Firms with formal R&D can engage in in-house R&D or practice some R&D outsourcing. In contrast, firms conduct informal R&D where they unofficially manage, allocate resources, and direct their innovation activities to create new products or processes without having a formal R&D unit. The firms with informal R&D can be distinguished from firms that do not have R&D units or non-R&D firms. Informal R&D can be found occasionally in large firms, while non-R&D is found in SMEs. Both firms with informal R&D and non-R&D are the firms that engage in innovation activities without R&D. Generally, they can be found in Low and Medium-Tech (LMT) and Low-Tech (LT) firms. Informal R&D activities are found in continuous innovation (Graziadio & Zawislak, 1997), driven by the need to solve problems. Most of the new ideas to solve the problem are generated by blue-collar employees, using creativity, experience, and knowledge. Such innovation can be explained using non-R&D variables, such as marketing, design, or hiring employees in tertiary-level work for innovations (Hervas-Oliver et al., 2011).

The innovation can be categorised into product, process, organisation, marketing, position, and paradigm innovations. Product innovation is a change in the products and services offered; process innovation is a change in the way products and services are created; organisation innovation is a change in the ways products and services are organised; marketing innovation is a change in the ways products and services marketed; position innovation is the change of

the context of products and services framed; and the paradigm innovation is a fundamental change in the mental models of the established products and services (Bessant & Tidd, 2007). In managing innovation without formal R&D, firms may use internal and external sources of innovation. Internal sources of innovation can be obtained from the problems/failures in work found by the people (management and workers), appearing in the equipment, detected by the information system, and occurring within the organisation. External sources of innovation can be input/feedback from people (customers, suppliers, competitors) or learned from the development of science, technology, networks, institutions, markets, and organisations outside the firm's boundary (Malerba, 2004). How firms engage in innovation can occur from the simple to complex modes, from learning by doing, using, and interacting (DUI), moving towards learning by integrating and porting (IP), and then performing R&D in the field of science, technology, and innovation (STI) (Kodama et al., 2014). Finally, viewed from the types of learning, it is found that innovative learning can be passive, active, and proactive learning (Aminullah et al., 2018).

Capability upgrading perspective

Capability upgrading can be viewed from various perspectives. Seen from the global value chains (GVC) perspective, there are four types of upgrading: process, product, functional, and chain upgradings (Kaplinsky & Morris, 2002). From a learning capability perspective, upgrading is categorised into four-I mechanisms: imitation, integration, incorporation, and internal development of best practices (Wang, 2014). From the TNC subsidiary angle, upgrading is grouped into assembly, process engineering, product development, and R&D (Hobday & Rush, 2007). From the catch-up process, there are four mechanisms of upgrading. Those are position, depth, scope, and efficiency (PDSE) catch-up (Guo & Zheng, 2019). More specifically, based on knowledge depth, the trajectory of firm upgrading are as follows: simple activities, minor improvement, major improvement, engineering, early R&D, and mature R&D. Viewed from a policy perspective, the characteristics of policy effectiveness for industrial technology upgrading are: long-term policy coordination, needs-based policy instrument, and policy priority and commitment (Intarakumnerd & Liu, 2019). The essence is that industrial capability upgrading depends on the contextual relevance of specific industrial status and challenges in each country.

Given various perspectives of viewing capability upgrading, the top ladder of upgrading is R&D capability. For the intensive R&D of pharmaceutical and medical sectors, capability upgrading is generally a shift in the focus of R&D activity; for example, the Indian pharmaceutical industry shifted from internal chemistry-based R&D to collaborative biological-based R&D to move to a high-value market (Kale, 2019). The Korean pharmaceutical industrial upgrading moves from imitation to innovation through the development of phytomedicine as modern drugs developed by scientific traditional medicines (Hwang, 2019). Herbal medicine upgrading is essentially the moving up technology capability ladder; it can be started by innovation with and/or without R&D, and the end is innovation with R&D activity (Aminullah, 2018). Based on the directions of R&D activity, there are two directions of the R&D process: i. seeking solutions from science, and ii. learning from basic operations towards advanced knowledge (Aminullah, 2020).

First, the seeking solutions from science are as follows: (i) technology transfer and commercialisation can be the transfer of technology from public research institute or university to industry or the commercialisation of public research institute or university's patents by industry; (ii) technology diversification as developing new technology from existing one, driven by the needs for better technology to support industrial development. For example, developing high-precision tools and machinery from forest machinery technology, based on the needs for forest equipment, and the high-precision tools diversified into the ICT equipment industry by Nokia; (iii) seeking technology market niche driven by technology innovation and developing the networks of commercialisation for innovative products, for creating the cluster of demand/market niches as an integrated

industrial ecosystem. For example, seeking and creating market networks of unique (i.e. halal) technology products to meet the cluster of firms or industry demand, which put obligatory halal in their material sources, production process, and commercial products (Aminullah, 2020).

Second, the direction of learning from basic operation towards advanced knowledge is detailed as follows: (i) Technology learning starts from learning by doing, moving on to learning by using new technology, upgrading to learning by integrating the advanced technology into existing technology, and learning by porting the latest technology into the existing technology. For example, steel-making technology started from learning by doing efficient steelmaking, and then it was made very efficient by using computerisation in the steel-making process. The case of learning is by integrating the latest technology, i.e. integration of LCD technology in computer, while the case of learning by porting is adding IT on numerical control machinery. (ii) Technology convergence is a systemic solution to the limits of existing technology in solving a complex problem that needs the application of science convergence to the so-called technology convergence. For example, a biological-environmental system perspective to solve the degradation of soil fertility contaminated by undegradable waste. The perspective drives the application of bio-based chemical science to create convergence technologies in biofertilisers and bioplastic products. (iii) Technology upgrading (in capability ladder) raises from 'operational capability in basic industrial skill and plant, moves to 'technical capability' to redesign of old product/process, upgrades to 'design and engineering capability to design and redesign system engineering, and competes with an innovative product, then achieves 'technology development capability to create advance/frontier industrial goods through design and redesign high system linkages. An example of moving up the technology capability ladder is shifting from making traditional herbal medicine to producing standardised herbal medicine, then creating phytopharmaceutical herbal medicine based on R&D activity (Aminullah, 2020).

B. Framework of Herbal Medicine Firms' Capability Upgrading

The Indonesian classification of herbal medicine is grouped into three levels: (i) Traditional herbal medicine is a herbal medicine that does not require the capabilities to clear scientific trials for clinical proof but simply by its usage for generations as evidence of safety and efficacy for health purposes. (ii) standardised herbal medicine is a herbal medicine that requires more complex ability, knowledge, and skills as well as more complex equipment to manufacture to pass the scientific evidence through pre-clinical trials, such as the standards for nutritious ingredients, medicinal plant extracts, hygienic manufacture of traditional medicine, and acute and chronic toxicity. (iii) Phytopharmaca or modern herbal medicine, is a herbal medicine comparable to modern synthetic drugs produced by modern manufacturing processes and supported by scientific evidence from human clinical trials. The manufacturing processes are standardised, and products are supported by scientific evidence, qualified clinical trials in humans, scientific testing protocols that have been approved, and qualified testing conducted by competent analysts who meet ethical principles (Searo, 2017).

The moving up of the technology capability ladder in herbal medicine should meet regulatory harmonisation and good quality practices (Mukherjee, 2019). *First*, making traditional herbal medicinal products is the type of innovation without R&D, which is generally produced by small companies and or home industries. The production process should meet good agricultural collection practices (GACP) before getting government authorisation for distribution. The innovation is limited to improving the product's presentation and packaging to meet the market demand. The composition of traditional herbal medicinal products is derived from hereditary knowledge. The production of traditional herbal medicinal products requires simple skills. In terms of capability, it simply needs the operational capability level.

Second, standardised herbal medicine products are the upgrading of traditional herbal medicinal products that have passed preclinical

testing or can be the result of innovation with R&D that meets pre-clinical test requirements and are generally produced by medium and large companies. The production process should meet GACP and pass a pre-clinical test to get government approval for market distribution. The production of standardised herbal medicine products requires expertise in pre-clinical testing for standardised herbal medicines. In terms of capability, the firm needs to have the capability in production technicalities and formula designing.

Third, Phyto-pharmaceutical products are standard herbal medicine products that have been upgraded by passing clinical testing or can be the result of innovation by R&D that meets clinical testing requirements. Large companies generally produce phyto-pharmaceutical products according to good manufacturing practices (GMP) standards. Regarding capability, creating phytopharmaceutical products requires technological development expertise to conduct R&D to create the formula. Based on the aforementioned concept of R&D availability and capability upgrading in the context of herbal medicine, we constructed a herbal medicine firm's upgrading framework, as shown in Figure 2. The move up the technological capability ladder is accelerated by incorporating a knowledge base (such as pharmaceutical biotechnology); the entrepreneurial activities of leading firms have embedded these knowledge bases with institutional support from the government (Hu & Chung, 2015).

Moving up the technological capability ladder can be a non-linear process involving interaction between herbal medicine production and the depletion of traditional knowledge stock. Viewed from a dynamic perspective, the aforementioned herbal medicine firms' upgrading framework was developed into the multiple loops model, as shown in Figure 3. This model was constructed using the principles of the system

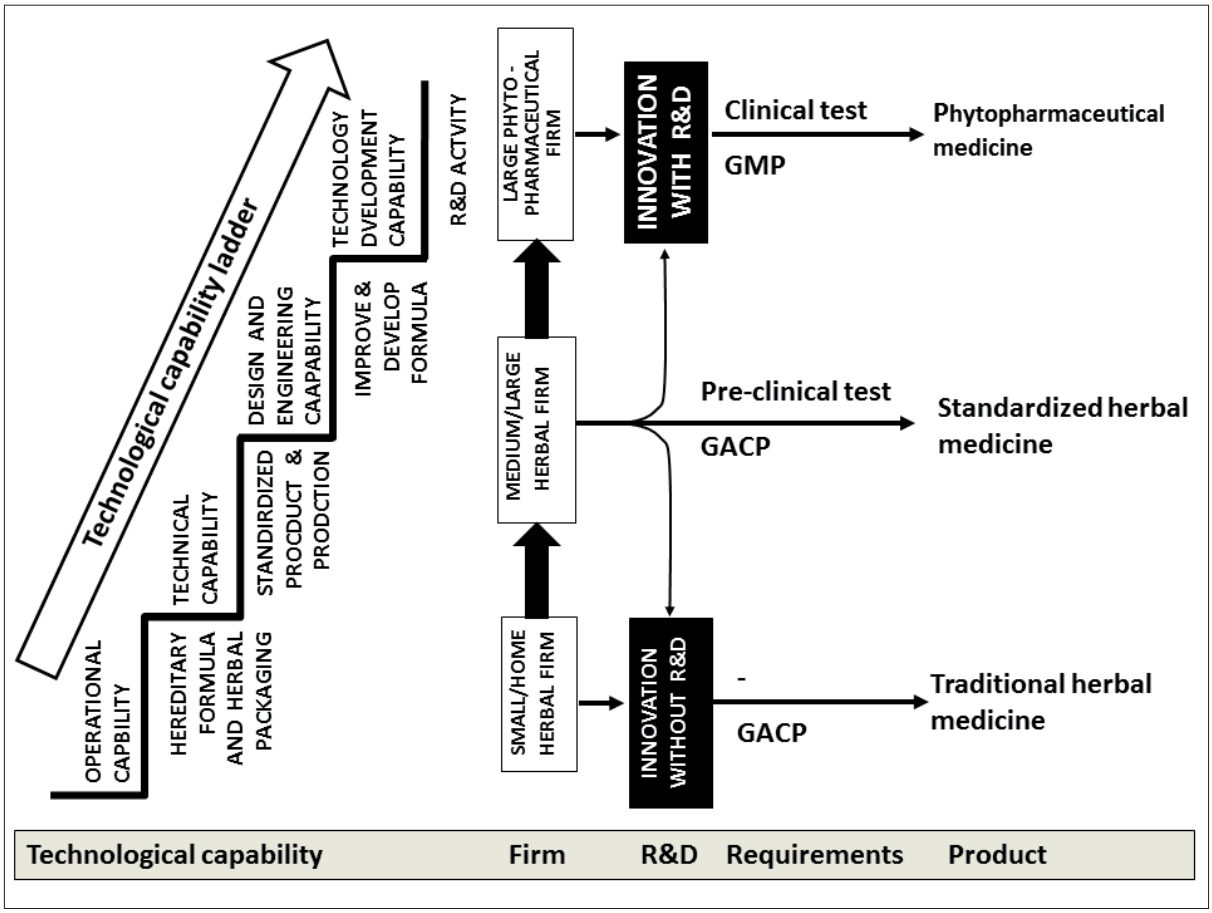


Figure 2. Herbal medicine firms' capability upgrading framework

(Forrester, 1990). The elements of the model comprise the production of traditional herbal medicine (THM), standardised herbal medicine (SHM), and phytopharmaceutical herbal medicine (PPM), which are constrained by the stock of traditional knowledge collection (TKC). The TKC will deplete and increase THM, SHM, and PPM productions. SHM's product can be produced by i) upgrading THM's product by conducting and passing pre-clinical testing and ii) creating a new THM product resulting from new formula for SHM based on R&D activities. PPM's product can be produced by i) upgrading SHM's product by conducting and passing clinical testing, and ii) creating a new PPM product resulting from new formula for PPM based on R&D activities.

III. HERBAL MEDICINE FIRMS' CAPABILITY UPGRADING AT FIRM LEVEL

The capability upgrading of herbal medicine at the firm level is further explained by Aminullah et al. (2017) by viewing from a different perspective or by using the analytical framework in section 2.2.

Company A.

A family-owned company produces traditional herbal medicine (THM) for the domestic market. It is a medium-scale company employing 50 workers, mostly at the high school level. The company has one graduate degree in pharmaceuticals to deal with the administrative requirement set by the food and drug control agency. The company produces traditional herbal medicines from its recipes based on family heritage containing the main ingredient (*Phaleria macrocarpa*).

As a medium size company engages in innovation covering product, process, marketing, and paradigm innovations, product innovation is to create product diversification, where the diversified recipes are developed from the main ingredient. Process innovation is to upgrade product quality by applying nanotechnology in the production process and meeting the requirements of traditional herbal medicine production. Marketing innovation is increasing sales value by applying online marketing through websites. Paradigm innovation is trying to introduce "reverse efficacy testing", where the sequence of efficacy testing is reversed by

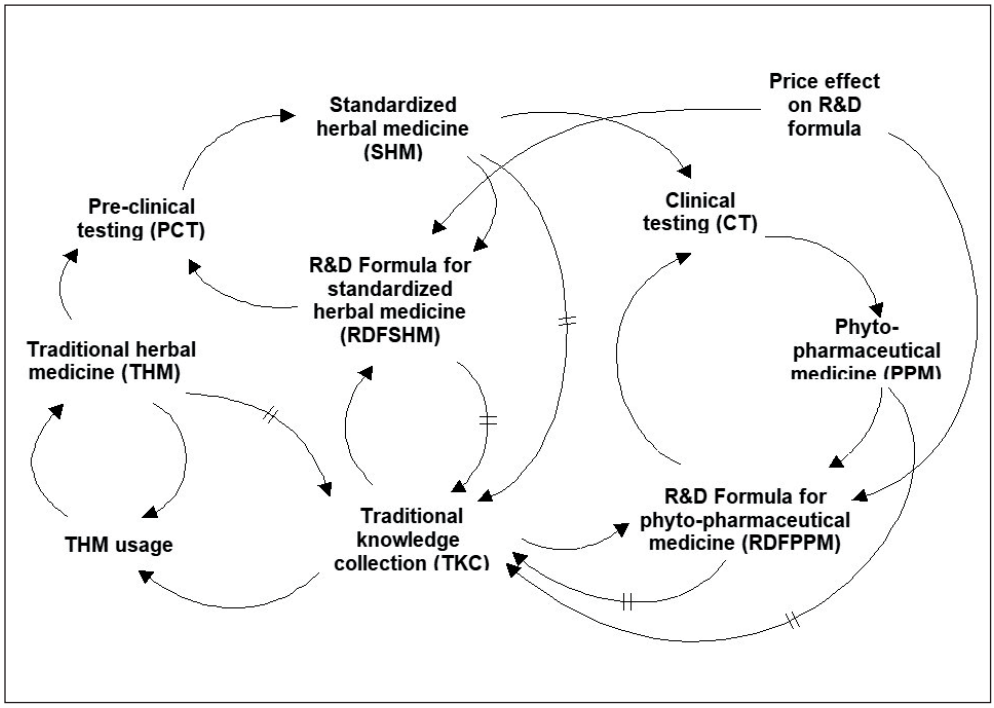


Figure 3. Dynamics of herbal medicine firms' capability upgrading

jumping to clinical testing instead of starting from pre-clinical testing.

Herbal medicine upgrading has been done by innovating without R&D. The sources of innovative ideas mostly come from consumers' needs who visit the company's health services house and the company's owner. The role of company owners as top management is dominant in driving, including product, process, marketing, and paradigm innovations. By applying new process technology (nano technology-fine powders and nano liquid), the company's innovation also upgraded the products' image from herbal in ordinary packaging to become herbal in premium packaging.

To shift from the production of traditional herbal medicinal products requiring simple skills to the production of standardised herbal medicine products requiring expertise in pre-clinical testing, firms have been making some efforts to move up technological capability ladders. Those are i) human capital enhancement by conducting regular training to meet requirements gap in the production of traditional herbal medicines, ii) innovation coordination was done under the leadership of the director, and iii) innovation collaboration where the company collaborated with external experts in conducting preclinical research and external laboratory in doing product testing to meet the requirements of health authority for certification.

Company B.

A large company produces standardised herbal medicines and pharmaceuticals for the domestic and international markets. The company's employees were around 500 people, with several researchers engaged in R&D of 70 people, where 60% of them are pharmacists and 2 PhD degrees). The company develops various herbal formulations based on in-house R&D. The traditional and standardised herbal medicine developed by the company are recognised by its main ingredient (*Curcuma zanthorriza*) and invented by engaging R&D.

Herbal medicine upgrading has been done by innovating with R&D. Company conducts its pre-clinical testing to meet the standards of herbal medicines. The company continues to move up the technological capability ladder by conducting clinical testing to achieve phytopharmaceutical medicine. The company also has been conducting R&D collaboration with a foreign university in bio-molecular, especially on epigenetic mapping of the natural compound. Such a moving up technological capability ladders is managed by human capital enhancement embedded in the organisation to implement a variety of programs: supply and operation academy, cross-functional team, higher degree scholarship, innovation coordination, continuous improvement, a roadmap of innovation, seed development program, collaborative innovation, and R&D collaboration.

Types of innovative activities inside the company are product, process, and position innovations. Product innovation is to develop new products by funding advanced research collaboration with a foreign university. Process innovation is to apply continuous improvement to increase efficiency in the business process of the organisation. Position innovation is to create health supplement products from herbal. Thus, it changes the position of herbal medicines to become health supplements. In managing innovation, the company's source of innovation is new ideas from internal interaction by building a culture of innovation inside the company.

Company C.

A large company produces pharmaceutical medicines and all types of herbal medicine from traditional herbal, standardised herbal, and phyto-pharmaceutical medicine for the domestic and international markets. This is a public company where the government owns the dominant share. As a vertically integrated company, its span of business covers production, distribution, and retails. The total number of employees is around 8 thousand, with 31 R&D personnel composed of 4 master/doctoral, 17 pharmacists, and 10 undergraduates.

Capability upgrading was successfully practised by moving up technological capability ladders from traditional to standardised and finally to achieve phyto-pharmaca (herbal

medicines). The firm moved up technological capability ladders by applying several ways: i) doing innovation with R&D spending around 1% sales, ii) building human capital enhancement by incorporating the HRD program built-in organisation, iii) establishing project team in R&D activities under the coordination of top management role for new product development; and iv. regular training for R&D staff innovation coordination meetings for problem-solving and R&D collaboration with university and public research institutions at stage 7th in technology realisation levels.

Types of innovation are mainly product novation based on R&D collaboration with universities and public research institutes (PRIs). The company funds universities and PRIs to conduct R&D on the herbal formulation. The company prefers to engage in R&D collaboration in the seventh stage of technology level readiness or pre-commercialised level. In line with product innovation, the company operates process innovation by applying ICT at all levels of vertically integrated business organisation. The sources of innovation are marketing/customers, feedback from plant or production units, R&D units, and regular meetings.

IV. DYNAMIC OF HERBAL MEDICINE FIRMS' CAPABILITY

A. Trajectory of population using traditional herbal medicine

The trajectory of the population using THM would be stable at around 15–20%, as depicted in Figure 4. The population using THM would increase from 30 to 60 million with the increase of the Indonesian population from 212 to 327 million from 2000 to 2050. There were two peaks of an increase in the usage of traditional medicines. *First*, the rapid increase in population data using traditional medicine in the 2000s was triggered by Indonesia's economic crisis. The people who could not buy modern medicine at a high price turned their attention to traditional medicine (Mustamu, 2000). The decrease of people in using traditional herbal medicine in 2010–2020 was related to the enforcement of national health insurance for all Indonesian people, who could buy generic medications at low prices, not only low-income people, including those with high income as well.

Second, model simulation has shown that the rapid increase in the population using traditional herbal medicine reoccurred in 2020, which was a coincidence with the outbreak of the Covid-19 pandemic. Covid-19 drove the emergence of innovative health technologies; there were 55 health technology innovations, including innovation in herbal medicine for Covid-19 handling (Aminullah & Erman, 2021). The demand for medicinal plants for maintaining the body's immunity increased rapidly, such as *Curcuma xanthorrhiza*, *Curcuma longa*, and *Zingiber officinale*. The increase in demand led to the higher price of medicinal plants triggered by the scarcity of supply. The demand for phytopharmaceutical medicine for immune enhancement increased sharply. Those are medicines mainly contained *Echinacea folium*, *Morondae fructus*, and *Philanthy folium*. The increase in demand at the upper level of the price set by government regulation on phytopharmaceuticals led to a high return on company investment in phytopharmaceutical R&D.

B. Changing Trends Toward Modern Herbal Medicine Usage

Traditional herbal medicine usage

Indonesia has around 20,000 medicinal plant species identified as potentially useful for medication. In 2000, around 5% of the potential species were commercialised in various types of herbal medicine products (see Figure 5). The number of herbal medicine types increased rapidly from 2000–2010, when low-income people hit by the economic crisis, sought traditional herbals as alternatives for high-price pharmaceutical drugs. From 2010 to 2020, the number of herbal medicine types has slightly decreased in line with the population's use of traditional herbal medicine, as depicted in Figure 1. The usage of traditional herbal medicine embeds the Indonesian culture of medication. It is the reason the number of traditional herbal medicine types would stable around 2000 for the period of 2030–2050.

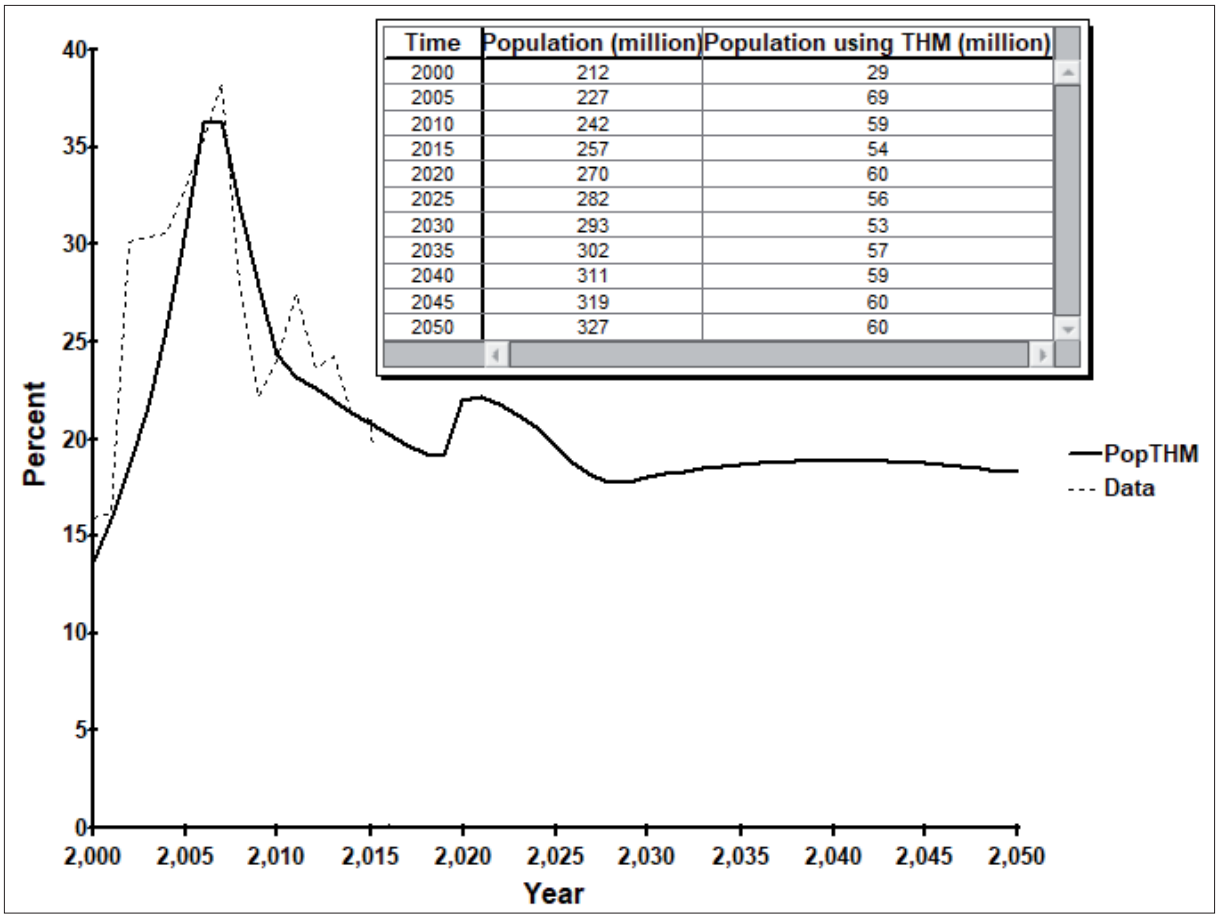


Figure 4. Trajectory of population using traditional herbal medicine (Pop THM)

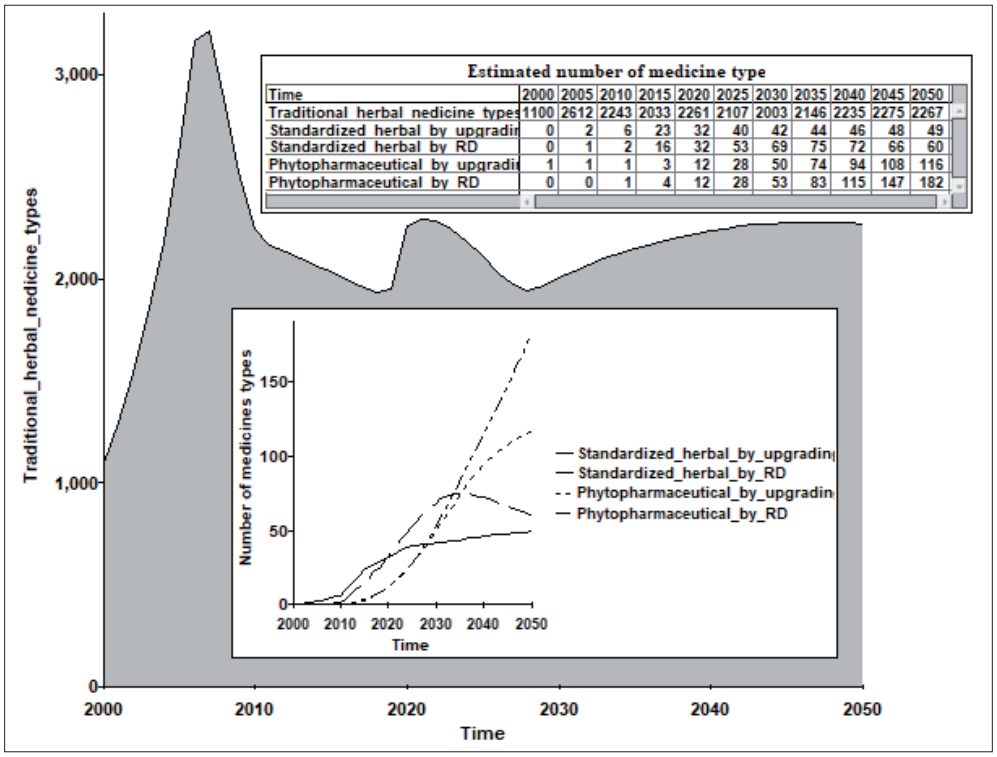


Figure 5. Changing trends in herbal medicines usage (2000– 2050)

Standardised herbal medicine usage

The explanation in section 3 supported that standardised herbal medicine can be produced non-linear, either by upgrading the traditional herbal medicine through pre-clinal testing or by conducting R&D from traditional knowledge collection. Standardised herbal medicine has been regulated since 2005. The simulation estimated that the standardisation of herbal medicine types reached 64 in 2020. It is estimated that the number will reach 109 by 2050. The number of standardised herbal medicine by upgrading would increase moderately and will reach 49 types by 2050. Meanwhile, the number of standardised herbal medicine by R&D will increase rapidly and reach the peak of 75 types by 2035. After 2035, the trends of standardised herbal medicine by R&D will decrease because of upgrading some into phytopharmaceutical medicine.

Phytopharmaceutical medicine usage

The first phytopharmaceutical medicine by R&D was launched in 2005. Up to 2020, there have been 24 types of phytopharmaceutical products. The case study findings support that the products are mostly created through engaging in R&D by a large pharmaceutical company. Some phytopharmaceutical products were produced by upgrading the existing standardised herbal medicine, which was previously invented by engaging in R&D. The case study findings show that collaborative R&D with overseas and domestic universities on phytopharmaceutical has been intensive and would become the driver of new inventions in the future. By 2050, the estimated number of phytopharmaceutical products by R&D will be 182, and phytopharmaceutical products by upgrading will be 116, respectively.

C. MOVING-UP FIRM'S TECHNOLOGICAL CAPABILITY

Moving-up firms' technological capability in producing herbal medicines is depicted in Figure 6. *First*, from 2000 to 2005, the capability of producing traditional herbal medicine was dominant, and the effort to upgrade to producing standardised herbal medicine was initiated during that period. In line with the enacted government regulation on herbal medicine, the production of standardised herbal medicine and phytopharmaceutical medicine has started since 2005. *Second*, from 2005–2020, after the economic crisis, increased demand for affordable traditional herbal medicine and the search for traditional medicine to prevent Covid-19 pandemic disease occurred. The capability of producing standardised herbal medicine. *Third*, from 2020 onward, the capability of phytopharmaceutical and standardised herbal medicine will be dominant. Phytopharmaceuticalicine will be the driver of herbal medicine used in the future.

First, the traditional herbal medicine ladder. Industrial capability upgrading in traditional herbal medicine is to innovate without R&D, which generally focuses on continuous product innovation to i) climb up the layer of standardised herbal medicine, and ii) expand market segments by developing product variants according to consumer taste, product presentation following consumer demand, and product packaging for the high-end market segment. The small companies and or home industries upgrade their production process to meet GACP before getting government authorisation for distribution. The composition of traditional herbal medicinal products is derived from hereditary knowledge, and some use the source of scientific knowledge on medicinal plants. Even though making traditional herbal medicine products requires simple skills to operate the production process, firms must utilise pharmacists' scientific skills to meet government regulations.

Second, standardised herbal medicine ladder. Industrial capability upgrading in standardised herbal medicine is to innovate either or without R&D, which generally focuses on: i) product innovation to climb up the ladder of phytopharmaceutical medicine, and ii) process and functional innovation to expand market segments, i.e. nanotechnology application in the production process and digitalisation of marketing function. Innovation without R&D through upgrading traditional herbal medicine products by meeting preclinical testing, while innovation with R&D is creating herbal formulas through scientific research and

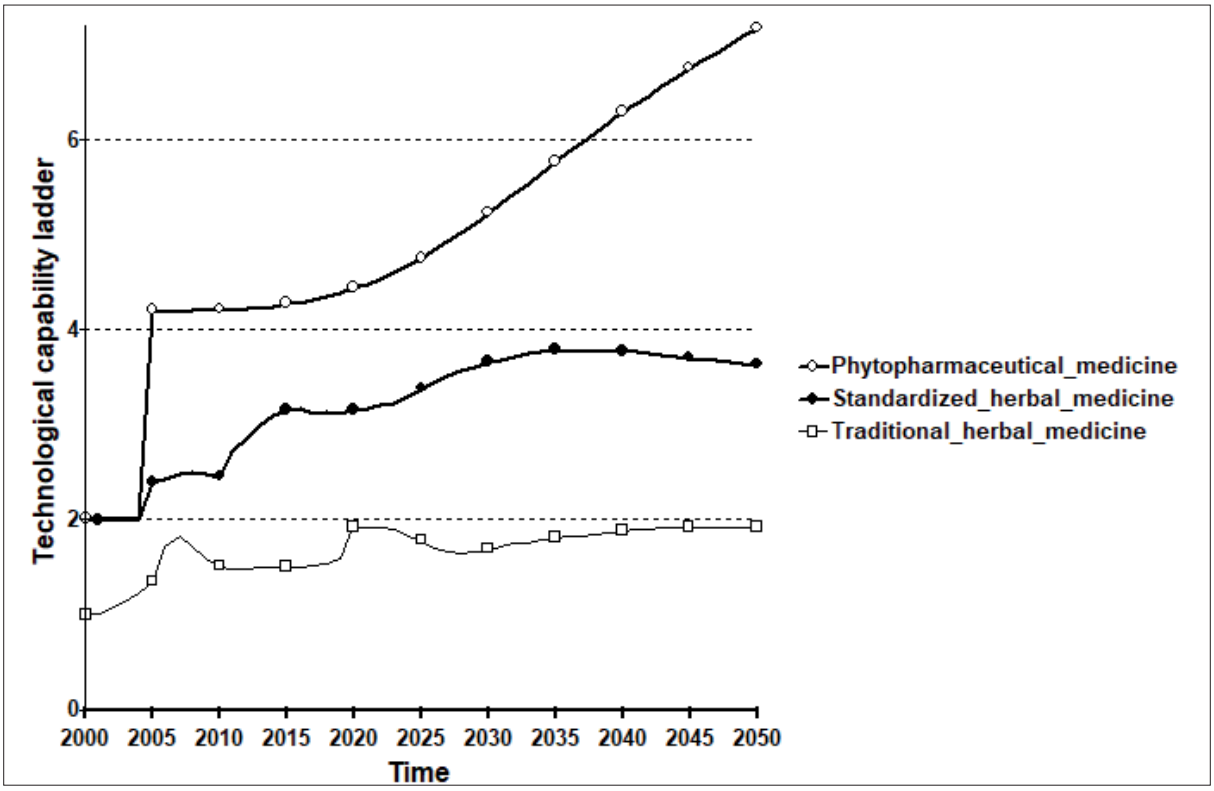


Figure 6. Dynamics of firms' capability upgrading in herbal medicine

meeting pre-clinical testing. The large companies have the capability in standardised production technicalities and in-house preclinical testing, as well as formula designing through R&D. Some medium-scale companies' laboratory hose do not have in-house preclinical testing facilities, which would outsource preclinical testing. It could be facilitated by public research institute or private commercial laboratory.

Third, the phytopharmaceutical medicine ladder. Industrial capability upgrading in phytopharmaceutical medicine is to intensify innovation with R&D and meet clinical testing. Intensification of phytopharmaceutical medicine R&D in large companies by applying four types of upgrading: process, product, functional, and chain upgradings in Global Value Chains (GVC) perspective. Process upgrading guarantees that the production process meets GACP and GMP standards. Product upgrading is to create new products by applying advanced R&D methods (e.g. genetic engineering) and R&D collaboration. Functional upgrading is to adopt automation, digitalisation, and the fourth industrial revolution (4.0) in R&D, production, and marketing functions. The chain of upgrading is to expand the business chain from herbal medicine to health supplements.

V. CONCLUSION

The study concluded that the role of top management was decided to bring the company capability upgrading. The enabler factors of the company's success in capability upgrading were innovation collaboration and management coordination led by top management. The process of capability upgrading can be accelerated by incorporating: an advanced knowledge base (such as biotechnology), the entrepreneurial activities of leading firms, and institutional/regulatory support from the government. System dynamic analysis suggested that capability upgrading in Indonesian herbal medicine firms can be realised by two routes: i) the linear moving up of technological capability ladders from traditional herbal to standardised herbal and phytopharmaceutical medicine, and ii) the non-linear dynamic of technological capability upgrading by directly producing standardised herbal by using R&D

and then move-up to create phytopharmaceutical medicine.

The results of the study confirmed that the concept of technology upgrading in the capability ladder raised from 'operational capability in basic industrial skill and plant, moves to 'technical capability' to redesign of old product/process, upgrade to 'design and engineering capability to design and redesign system engineering and to compete with an innovative product, then achieve 'technology development capability to create advance/frontier industrial goods through design and redesign high system linkages.

The limitation of the study was the methodology of system dynamics, which was intended to explain the patterns of problematic behaviours caused primarily by the design of the feedback structure inside the system (Kunc et al., 2018). In this study, the feedback structure was based on the perspective of capability upgrading. Different perspectives lead to different designs of the feedback structure. Other system dynamic models are possible based on different perspectives (for further study).

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APPENDIX: MODEL VALIDATION

• ***Model***

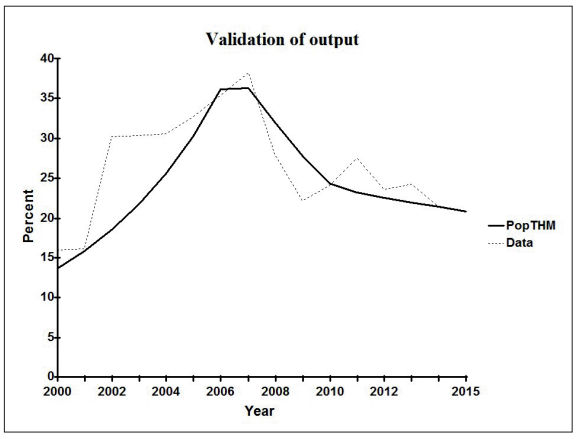
The model-building method applied the "from story to structure" method (Kim & Anderson, 1998). The model construction was built from data or evidence's behaviour to be the causal loop model. The dynamic patterns of evidence behaviours referred to the trends of the population using traditional medicine and were supported by the case study's results.

• ***Validation***

The validated model passed four orderly tests: empirical structure test, theoretical structure test, stability structure test, and patterns of prediction behaviour test. The order of testing from one to four is decisive; if the test fails at one stage, then model construction must start from the beginning (Barlas, 1996).

Stage 1: Empirical structure visualisation.

The corresponding visualisation between simulation results and real data is shown in the figure below.



Stage 2: Theoretical structure explanation

The model structure behind the aforementioned evidence's behaviours has constituted the interaction of components: input (herbal medicine capacity), process (routes from to traditional herbal medicine, standardised herbal medicine, and phytopharmaceutical herbal medicine), output (herbal medicine products), and feedbacks (multiple loops inside the process).

Stage 3: Stability of model structure

The consistency between model structure (stage 2) and model outputs (stage 1) was checked by the following model equations and documentation.

Stage 4: Patterns of outputs behaviours

Outputs were displayed on three figures (4 to 6) inside the main article; the outputs showed the logical behaviours without performing overshoot or collapse behaviours.

Model equations

```
init  FPPM = 0.05
flow  FPPM = +dt*RDFPPM-dt*RPPM2
doc   FPPM = Formula for PPM
init  FSHM = 0.1
flow  FSHM = -dt*RSHM2+dt*RDFSHM
doc   FSHM = Formula for SHM
init  POP = 212
flow  POP = +dt*rPOP
doc   POP = Population
init  PPM = 0.01
flow  PPM = -dt*dPPM+dt*RPPM
doc   PPM = Phytopharmaceutical herbal medicine by
      upgrading
init  PPM2 = 0
flow  PPM2 = -dt*dPPM2+dt*RPPM2
doc   PPM2 = Phytopharmaceutical medicine by R&D
init  SHM = 0
flow  SHM = +dt*RSHM-dt*diSHM
doc   SHM =  standardised herbal medicine by upgrading
init  SHM2 = 0
flow  SHM2 = +dt*RSHM2-dt*dSHM2 -dt*RPPM
doc   SHM2 = standadized herbal medicine by R&D
init  THM = 4
flow  THM = +dt*RTHM-dt*RSHM-dt*dTHM
doc   THM = Traditional herbal medicine
aux   diSHM = SHM/10
aux   dPPM = PPM/20
aux   dPPM2 = PPM2/25
aux   dSHM2 = SHM2/15
aux   dTHM = THM/5
aux   RDFPPM = FPPM*MPCp*cRDFPPM*PRICE
aux   RDFSHM = FSHM*MPCp*cRDFSHM*PRICE
aux   rPOP = POP*cPOP
aux   RPPM = DELAYINF(SHM2,1,1,0)*cCT
aux   RPPM2 = cCT2*FPPM
aux   RSHM = THM*oSHM
aux   RSHM2 = cPCT*FSHM
aux   RTHM = THM*MPCp*cTHM
aux   cCT = 0.05+STEP(0.06,10)
doc   cCT = Clinical test
aux   cCT2 = 0.005+STEP(0.008,2010)
aux   cPCT = 0.01+STEP(0.046,2010)
doc   cPCT = Pre-clinical test
```


```
init  FPPM = 0.05
flow  FPPM = +dt*RDFPPM-dt*RPPM2
doc   FPPM = Formula for PPM
init  FSHM = 0.1
flow  FSHM = -dt*RSHM2+dt*RDFSHM
doc   FSHM = Formula for SHM
init  POP = 212
flow  POP = +dt*rPOP
doc   POP = Population
init  PPM = 0.01
flow  PPM = -dt*dPPM+dt*RPPM
doc   PPM = Phytopharmaceutical herbal medicine by
      upgrading
init  PPM2 = 0
flow  PPM2 = -dt*dPPM2+dt*RPPM2
doc   PPM2 = Phytopharmaceutical medicine by R&D
init  SHM = 0
flow  SHM = +dt*RSHM-dt*diSHM
doc   SHM =  standardised herbal medicine by upgrading
init  SHM2 = 0
flow  SHM2 = +dt*RSHM2-dt*dSHM2 -dt*RPPM
doc   SHM2 = standadized herbal medicine by R&D
init  THM = 4
flow  THM = +dt*RTHM-dt*RSHM-dt*dTHM
doc   THM = Traditional herbal medicine
aux   diSHM = SHM/10
aux   dPPM = PPM/20
aux   dPPM2 = PPM2/25
aux   dSHM2 = SHM2/15
aux   dTHM = THM/5
aux   RDFPPM = FPPM*MPCp*cRDFPPM*PRICE
aux   RDFSHM = FSHM*MPCp*cRDFSHM*PRICE
aux   rPOP = POP*cPOP
aux   RPPM = DELAYINF(SHM2,1,1,0)*cCT
aux   RPPM2 = cCT2*FPPM
aux   RSHM = THM*oSHM
aux   RSHM2 = cPCT*FSHM
aux   RTHM = THM*MPCp*cTHM
aux   cCT = 0.05+STEP(0.06,10)
doc   cCT = Clinical test
aux   cCT2 = 0.005+STEP(0.008,2010)
aux   cPCT = 0.01+STEP(0.046,2010)
doc   cPCT = Pre-clinical test
```