2021 International System Dynamics Conference

25-30 July 2021 – Chicago, US

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Title: A business transition model for sustainability-oriented industrial innovation and feedback on employment, inequality, and inflation

Abstract:

This paper presents the IN4.0-SD, a novel system dynamics model to capture the dynamic interplay of industrial innovation, inequality, and inflation. The IN4.0-SD is a closed system economic model composed of three agents: traditional factory, licence-business, and household. Licence-business and traditional factory are both assumed to supply one product to the economy and fundamentally differ among each other in their business model. While the traditional factory produces and sells capital goods making revenue out of sales, licence-business detaches the concept of production from sales moving toward an intangible economy, charging for a fee licence of their tools that can be distributed via a network economy. Licence-business is assumed to be a key driver for change in the assets structure in both the traditional and licence-business companies, both in terms of productivity, efficiency, and labour requirement for operations. Simulations show the level of flexibility of the model in addressing a variety of scenarios, playing at the threshold of technology development, inequality rise, massive unemployment and providing an archetype for sustainability type models. The model can provide a good base when applied to sustainability type scenarios that deal with energy transitions, climate change mitigation, and socio-technical transformations.

Keywords: sustainability-oriented innovation, inequality, inflation, employment, productivity, sustainable supply chain.

Introduction

Industrial innovation is probably one of the most important factors influencing social systems change since James Watt patented the first steam engine in 1781 (Pasqualino and Jones 2020, Maxton and Randers 2016). Innovation is the main driver for productivity growth in our society, supporting exponential growth in the economy via activating a variety of self-reinforcing feedback loops of assets and knowledge accumulation, and expanding investments over time (Arthur, 1994). However, no real material growth is possible in a finite planet, leading toward overshooting planetary boundaries, and being cause of anthropogenic emission, and climate change (IPCC 2019, Meadows et al 1972, Meadows et al 2003). One answer to deal with the sustainability transition is more innovation, leading towards massive change in the structure of capital, substitution of labour with machines, and a drastic change in business models from a traditional production factory to a knowledge-based economy often trading information in a non-tangible continuous growth of value in the society (Capra and Luisi 2016).

Sustainability is an essential duty for companies to perform in the current scenario due to risks caused by traditional manufacturing practices, and rules imposed by stakeholders and government (Chowdhury et al, 2020). As a result, an increasing number of companies around the world have invested in sustainability, in order to understand how sustainable issues are impacting traditional way of doing business, the environment and quality of life (Demartini and Taticchi, 2021).

This challenge and other sustainable issues are summarized by the Sustainable Development Goals (SDGs) framework (United Nation 2015) set by United Nations – this is a universal, integrated set of ambitions goals designed to address 17 key interlinked challenges on people, business and planet (Amato, 2021). The 17 goals rely on different targets, from climate change (SDG#13), sustainable production and consumption (SDG#12) up to industry innovation and infrastructure (SDG#9) just to mention the most business-oriented ones. This framework has been adopted by different companies as an initiative to set their strategy, interaction with society and corporate communication (Van der Waal et al, 2021). To achieve these goals, companies have to adopt a "corporate sustainability" view by implementing sustainable strategies and business models to lead an organizational and technical transformation impacting on diverse competitive dimensions: efficiency, productivity, inequality and innovation.

Concerning innovation, from this traditional concept has been driven an evolved stream of research on sustainability-oriented innovations (SOIs) and this potentially covers the entire range of SDGs (Maletič et al, 2016; Gasde et al, 2020). The challenge for companies is to design innovation strategies to support a wide variety of stakeholders and at the same time improve well-being in the society, deals with redistribution of resources and equality among rich and poor, and maintains key target economic variables (e.g. inflation) to stable positive levels behind these sustainability initiatives.

Geradts and Bocken (2019) stated that SOIs can get many forms - development of new or improved product, service, process and business model which bring benefits to the environment or the society at large (Geradts and Bocken, 2019). Process Innovation refers to the solutions adopted to improve the process goods and services (Adams et al., 2016). It aims at improving the eco-efficiency of the company. The major focus is on cleaner production. Organisation Innovation refers to the reorganization of the routines and structures within firms to focus people and organisation.

Like sustainability, SOI involves different dimensions (Adams et al., 2016): i) operational optimization - "doing more with less" by taking into account regulations, eco-efficiency and greening; ii) organizational transformation - "doing good by doing new things", by going beyond greening; iii) systems building - "doing good by doing new things with others", by focusing on collaboration capabilities (Adams et al., 2016). Voegtlin and Scherer (2017) identify two classes of SOI: (i) "Innovations that avoid harming people and the planet", and (ii) "Innovations that improve conditions for people and the planet". They also highlighted the dual nature of SOIs (this is similar in SDGs too): one innovation can have a positive impact on one dimension of the triple bottom line (TBL) (or one SDG) and be harmful for another.

While corporations have been dealing with innovation by changing the way they produce and provide value to society, central banks and government are starting to give more attention to the issue of inequality between rich and poor, being very much concerned on the ability of the production-consumption chain to never stop, supporting companies to generate maximum possible employment (Pollitt 2019, Mercure et al 2018). To do so, government have the tendency to target stable and positive inflation over time in the range of few point percentile. A stable economy should have positive inflation for a variety of reasons, including the possibility generate the liquidity to pay debt to lenders, pay wages, and be resilient to environmental and social shocks (Pasqualino 2020). In the meanwhile, concern for growing inequality between the rich and the poor is growing, since this can generate systemic risk leading to instability and even collapse in the current way we think of the economy (Jackson and Victor 2019).

In order to address these issues, we propose a theoretical system dynamics closed system economic model to capture both Industrial Innovation, Inequality and Inflation (IN4.0-SD). The purpose is to develop the simplest possible model that that captures different combinations of interplay among these variables and their interrelationships via scenario analysis. The IN4.0-SD is a closed system economic model composed of three agents: traditional factory, licence-business, and household. Licence-business and traditional factory are both assumed to supply one product to the economy and fundamentally differ among each other in their business model. While the traditional factory produces and sells capital goods making revenue out of sales, licence-business detaches the concept of production from sales moving toward an intangible economy, charging for a fee licence of their tools that can be distributed via a network economy. Licence-business is assumed to be a key driver for change in the assets structure in both the traditional and licence-business companies, both in terms of productivity, efficiency, and labour requirement for operations. Simulations show the level of flexibility of the model in addressing a variety of scenarios, playing at the threshold of technology development, inequality rise, massive unemployment and providing an archetype for sustainability type models. The model can provide a good base when applied to sustainability type scenarios when dealing with energy transitions, climate change mitigation, and socio-technical transformations.

In Authors opinion, it is important to provide a pragmatic and organizational change which is not disruptive or radical to support companies in the transition towards a more sustainable industrial system (e.g., reduce waste and pollution, improve material and energy efficiency, or reduce unemployment). SOIs should enable “co-benefits and reduce trade-offs”, therefore the idea is to mitigate the negative impacts of existing solutions or, even better, make a positive impact. In light of the above, the IN4.0-SD provides a great deal of flexibility in its parameterization and supports a wide range of scenarios that can help address the potential roles of SOI in industry, as well as addressing the feedback effects on the economy as a whole, providing inputs to both inflation growth, employment and distributional income effects.

The paper is structured as follows: the next section depicts the state of the art related to SOI from both an industrial and wider economic perspectives. Section 3 explains the IN4.0-SD model structure as well as the building blocks of the model. Section 4 provides sensitivity and scenario analysis, Section 5 discusses the results of the paper, and Section 7 draws the conclusions from this study.

Sustainability Oriented Innovation within organizations

SOI, supports systems change in terms of both organization’s culture, philosophy, and values, with the purpose of establishing social and environmental benefit beside the profit (Maletič et al. 2016). The companies that use the resources constantly rely on its dynamic capability to reconfigure its resources. Inigo and Albareda (2019) conducted a comprehensive study on the way in which the three stages of innovation ((i) adaptation, (ii) expansion and (iii) transformation) impacts companies’ performance while aiming at achieving sustainability. The insights stemming from their analysis showed that there exist two synergic interactions between the strategic sustainability of the firm and their level levels of dynamic capabilities towards SOI. These include path dependence and self-reinforcement each supporting and maintaining sustainability practices within organizations.

In order to address how the defined pathway could be adapted consistently with the nature of a system it is important to collect data and gather knowledge of the current state of the system. In fact, innovation strongly depends on the availability of knowledge (Du Plessis, 2007) and the approach that effectively manages that knowledge (López-Nicolás and Darroch and McNaughton, 2002). Tura et al (2019) applies qualitative research to investigate the challenges of utilizing sustainability knowledge to enhance SOI and propose the solutions to cope with them.

A crucial factor significant to the process of designing innovation is the size of the organizations and the inequality between them. Since the small and medium enterprises (SMEs) face greater restrictions in terms of skills, expertise, and resources (Bos-Brouwers, 2010), the type of their innovative activities is more complicated and less effective than those of the large enterprises (Moore and Manring , 2009). To compensate for these limitations, the SMEs have to collaborate with other entities improve their effectiveness in achieving SOI. In this domain, Wu (2017) classifies SMEs adopting econometric analysis by looking at the empirical assessment on interrelationship among socially responsible supplier development, SOIs, and sustainable performance. He disclosed that when SMEs adopt SOIs in multidimensional orientation, their sustainability could be significantly meliorated.

Wetering et al. (2017) evaluated the role of information technology (IT) flexibility and its relationship with strengthening SOI capabilities. They suggest that IT should be treated as adaptive technology that co-evolves with organizational capabilities and acts as a facilitator for cooperation.

A common practice for SOI is the so called Natural Inspired Innovation (NII). NII consists of establishing sustainability and organizing research and development (R&D) to innovate organizations and products to mimic those observed in nature. In order to identify the most influential factors on the NII implementation in the corporate context, Mead et al. (2020) used multi-criteria qualitative analysis based on six case studies that attempted to adopt NII in multiple domains. They found that the characteristics of the innovation context, decision-making units, and the innovation itself strongly affect the success of NII projects and suggest that the managers should consider the long-term perspective of investments in NII.

From a market perspective, SOI has also created competition among manufacturers that are forced to keep innovating their businesses to maintain their market share. Bustamante (2020) analysed industrial processes that adopt SOI to evaluate their impact on the market. This indicated that the process innovation not only can be helpful for external objectives such as revenue generation but also support the business owner to cover a wider scope of industry goals such as more sustainable production and consumption. On the other hand, a continuous rush toward innovating systems and business models can generate concerns and challenges from social aspect including employment and inequality. For example, higher competitiveness and productivity might be reached via replacing human labour and decision making with robots, automation, or algorithms. This can be a threat to individual freedoms and rights, with implications for societal cohesion, employment, and well-being.

The role of innovation for economic growth

The recognition that productivity growth is the most important determinant of long-term economic growth and rising living standards is well established in economics since late 1700 (Schwab 2017; Maxton and Randers 2016; Jackson 2016). Productivity growth represents incremental changes in the ability of one person to produce a certain unit of economic output. Continuous improvement of productivity via technology innovation led John Maynard Keynes to envision a future where the generation of his grandchildren could work only few hours a week to satisfy the consumption needs of the entire society (Keynes 1930).

The fundamental nature of doing business changed drastically during the 1990s at the cusp of the third industrial revolution. Interconnectivity and the fast exchange of information within a global network of individuals supported faster transmission of knowledge in every corner of the world. Computation could be employed for developing more powerful algorithms and software for performing more and more sophisticated tasks (Rifkin 2014). The digitalisation era exploited the knowledge base as driver of real capital innovation and displacement globally. The term 'knowledge economy', an economy driven by the innovation and knowledge of people, was first used by Drucker (1968). According to Capra and Luisi (2016) a new form of capital, very different from the one formed during the industrial revolution and Keynesian time, emerged.

The knowledge economy is (i) founded on global economic activities, (ii) exploits knowledge generation as the main source for productivity growth and competitiveness, and (iii) relies on fast moving networks of financial flows. Such an out of equilibrium knowledge based economy has led today to the so called fourth industrial revolution (Schwab 2017). Arogyaswamy (2020) addressed this threat with respect to high tech giants ('big tech') in Information and Communication Technologies (ICTs). He evaluates the ethical nature of the various innovation challenges ahead of us and shows feedback threat that can emerge for individuals and institutions. There is concern around the spread of inequality between those who own the capital and those who supply the labour. Every industrial revolution brought along concern for employment loss and there is no doubt the economic shift put at risk a large part of the current workforce (Jackson 2016). It is important to understand these social destructive consequences, and the firms should lay the foundation of ethical standards, while promoting a culture of morality (Arogyaswamy, 2020).

Based on (i) SOI development, (ii) economic requirements for productivity growth, (iii) the transition to innovative business models that might rise inequality and expand unemployment, and (iv) the inflation requirements by policy makers, we propose a simple system dynamics model that could help addressing the interplay among these issues. System modelling is a powerful approach that can address both innovation, sustainability and standard economic variables while targeting indicators such as inflation, employment, and inequality. The IN4.0-SD aims at being a first step in this direction, providing a simple dynamics perspective on the potential interrelationships among those multiple dimensions of sustainability.

The IN4.0-SD model

The IN4.0-SD (Industrial Innovation, Inequality, and Inflation – System Dynamics) model is a closed system disequilibrium economic model composed of three macro agents connected among each other via production-consumption requirements, and financial flows. The model accounts for approximately 650 elements including 130 parameters, 50 stocks, and 13 table functions. The purpose is to provide a system framework for the analysis of productivity growth, innovation and address concerns for labour employment and inflation over time.

System Boundaries

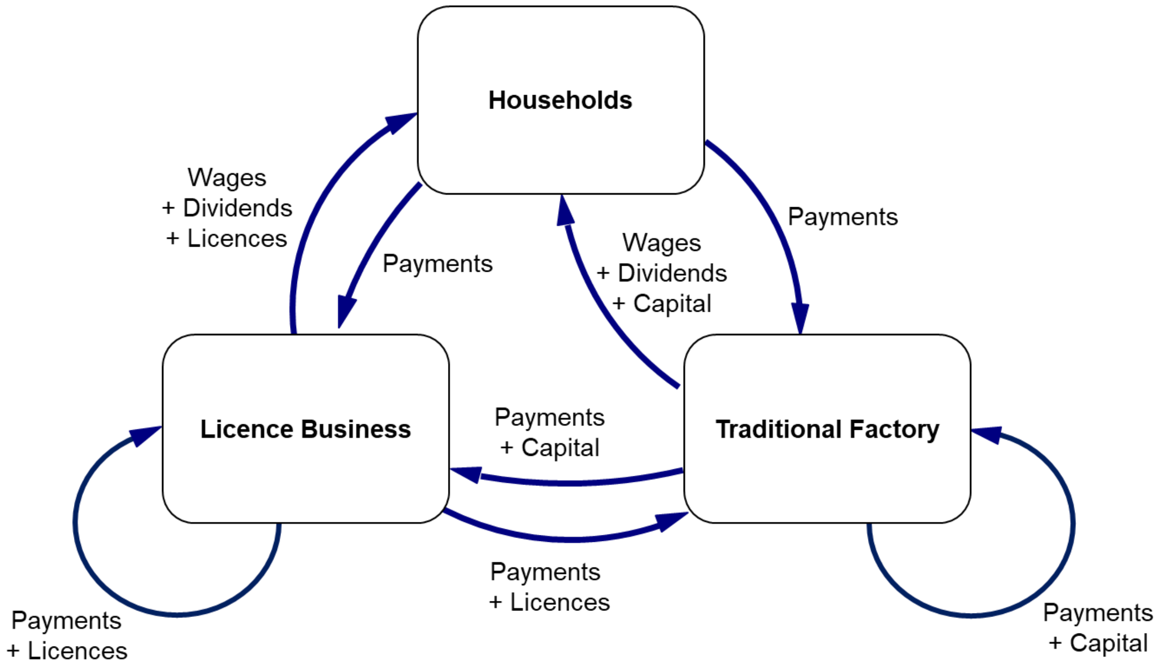
Figure 1 shows the system boundaries of the IN4.0-SD as composed of three macro-agents as follows:

1. Traditional Firm (TF: a firm that uses capital, licenced services and labour for the production and sales of capital goods. The existence of an inventory between production and shipment is assumed. TF endogenously sets prices and wages, employees labour, orders and produces capital, and buys licenced services from the relative sector. This latter is assumed being a driver for both capital productivity and labour requirement of capital. Their business model relies on traditional consumption and production, and makes revenues based on the sales of

products (shipments), pays labour and dividends to the Household sector, purchases capital which flows back to the TF sector and licences to the Licence-Business sector.

2. Licence Business (LB) sector: a firm that operates by detaching the concept of production from the concept of sales and revenue. LB uses capital, licenced services and labour to respond to a series of open queries from their clients free or charge. This is used to support product adaptations to the client needs and assures high service performance as customer service. The revenue is generated via an innovation diffusion model requiring firms to employ new licences to improve their productivity and impact on their labour requirements. The model is thus driven by the reinforcing feedback of technology diffusion as modelled in each sector. All payments go the respective sectors.
3. Household (H) sector: household consumes both output from LB and from TF. It manages their finances via receiving payments as labour and dividends from the firms, and purchases output from both.

Figure 1 – System Boundaries



Key Exogenous drivers and governing dynamics

As shown in Figure 1, the model accounts for two major exogenous drivers that are considered being outside the boundaries for the purpose of the model. These are:

1. Household demand for capital: the demand for capital is a function of a variety of factors that lie outside the boundaries of the system. These might include population change, human preferences in consumption, ability of specific rich individuals to invest money across the globe and so on. These factors are considered as pushing the system toward growth, even though any type of curve can be assumed, including growth followed by stagnation, or even decline. However, the availability of cash to the household is fundamental variables influencing the willingness to expand their capital assets (e.g. no quantity can be purchased without liquidity, which can never go negative). As a result, households balances their cash availability to the point of reducing their desired for capital assets when cash do not suffice.

2. Availability of new licences entering the system: it is well known that one single company can potentially create a multitude of intangible products that can be licences separately, generating different revenue streams to the parent company. The IN4.0-SD does not model the creation of new products explicitly, rather the adoption of those products by the each sector. As a result, each the three sectors assumes an exogenous curve describing the new licences in the market, being both a proxy for change in company and products size operating in each sector.

The dynamics are governed by the three reinforcing feedback loops and supported by the above-described exogenous factors. The three reinforcing loops are dependent on the service attractiveness (or word of mouth) reinforcing loop present in all the three sectors when purchasing new licences software. This pushes the system in a state of a constant disequilibrium driving change in every sector of the IN4.0-SD economy. As far as the exogenous curves defining new products in the market and household demand are greater than those paying for products, then the system will be driven by dynamics of growth. In the opposite case this can lead to stagnation, and at the limit, collapse.

Model structures

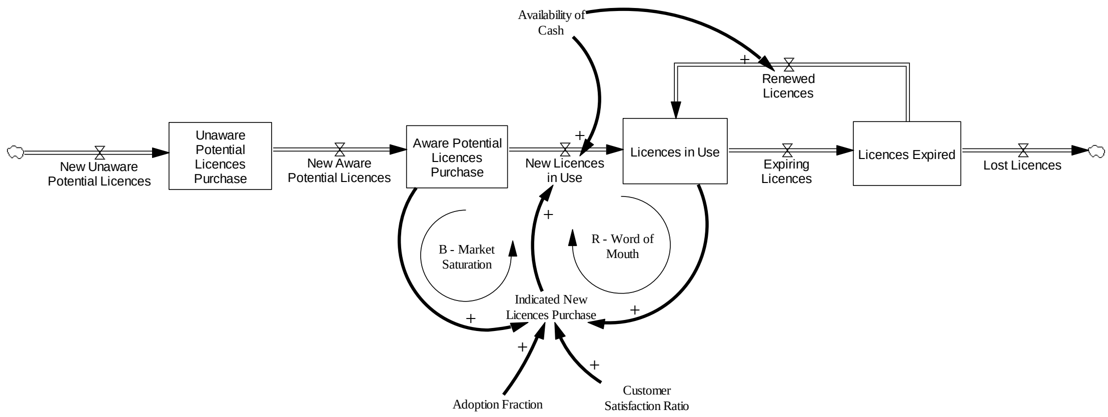
This section describes the structures applied in each of the three sectors of the model. In particular, LB and TF are assumed being composed of nine sub-sectors. Eight of these are common among the two (i.e., Licences, Capital, Labour, Price, Wages, Cash, Labour Requirement and Capital Productivity). In terms of output, TF uses Production (and shipment) whereas LB uses Customer Service. Household is instead composed on only three subsystems: i.e. (Capital, Licences, and Cash). All models are connected among each other in terms of supply-demand structure, and payment structure. The system is initialized based on cash and flow balance (e.g., all revenue equals all cash outflows for each model). All cash flows from one sector must be an inflow as revenue to another sector of the model. The balance applied at the beginning of the simulation is an unstable equilibrium (e.g., the model departs from that due to its endogenous structure driven by reinforcing loops). As a result, financial stock and flow consistency is assured at any point in time.

Licences sub-dimension

Figure 2 shows a simplified stock and flow diagram of the Licences subsystem used for all the three sectors of the IN4.0-SD. This subdimension presents a reinforcing loop typical of technology diffusion (or pandemic) models, where the amount of licences in use pulls larger and larger licences purchases from the stock of aware potential customers. This dynamic is also constrained by the ability of LB to supply a good service and efficiency to their customers, as well as from the availability of cash of each client sector that must comply with their finances. Licences expire at every time unit, requiring either to renew that licence (thus generating additional revenue), or simply leave the product.

As mentioned above, the dynamics of growth of this system is dependent on the continuous expansion of the Aware Potential Licence Purchases stock. Without an inflow to this stock, the overall dynamic of the system would be exponential growth and collapse. The innovation (intended here as introduction in the system of new products to licence) is applied exogenously. The indefinite growth in the system is dependent only on the ability of new licences to grow faster than those that are lost over time.

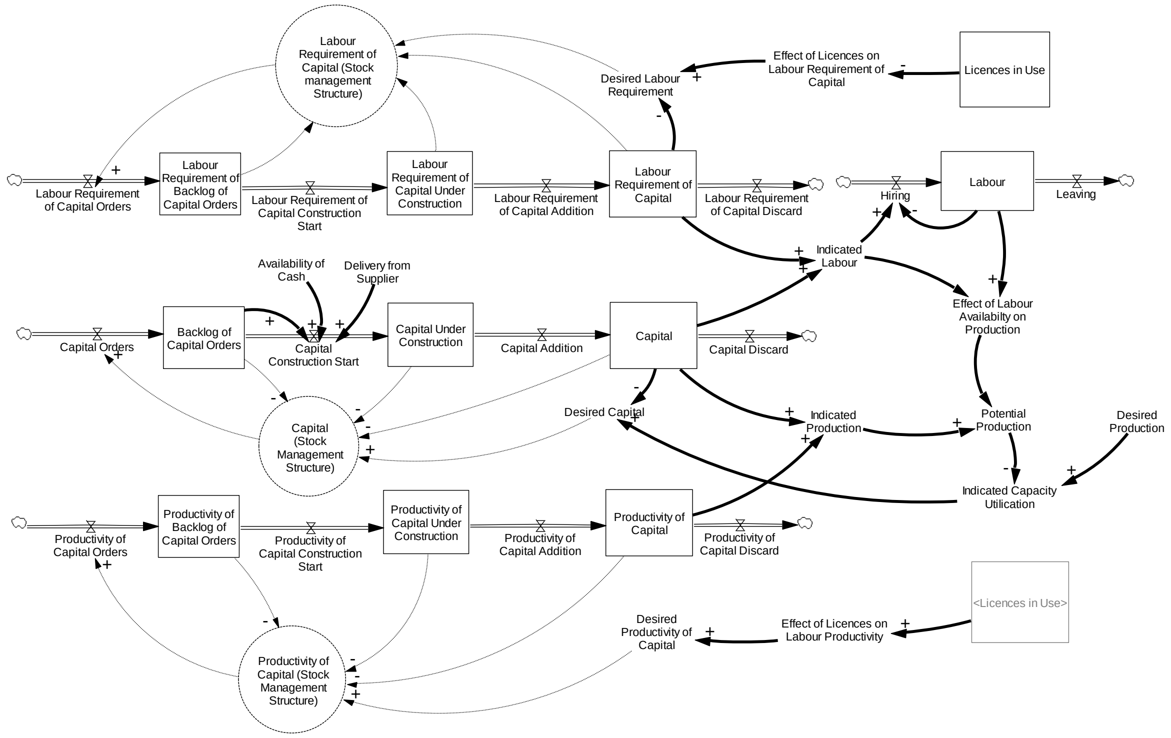
Figure 2 - Licences sub-dimension for LB, TF, and H sectors



Capacity Management and Licences impact structures

Figure 3 shows a combination of four sub-dimensions (Capital, Labour, Productivity of Capital Labour Requirement of Capital) and shows the structure of the production function as part of either Customer Service (for LB) or Production and Shipment (for TF) of the firm sectors in the IN4.0-SD. The desired production (as described in Figure 4) is the driver of the capacity management structure. If capacity builds up efficiently, each sector shall be able to supply the sufficient quantity of services to keep customers happy and allow for stable business growth in the economy, as driven by both exogenous and endogenous dynamic disequilibrium factors.

Figure 3 – Capacity Management and Licences impact structures



The two key variables determining production are Labour and Capital. In IN4.0-SD, the capital structure is the one that drives the entire capacity management, including labour, which is assumed to adapt to the desired labour level as driven by capital capacity. For example, in a business as usual world, if a university wants to produce more research will start from the infrastructure (buildings, labs and so on). This will require long term capacity planning, such as ordering new infrastructures, constructing them, and then making these operative. While having space for labour, it is possible to expand the labour force.

The important factor determining the value of the IN4.0-SD is to close the feedback between Licences in Use and the requirement of Labour as well as the actual possible productivity of that capital. In this particular case, Licences growth is assumed to have a negative impact on Desired Labour Requirement of Capital (i.e. the ratio between Labour and Capital required to fulfil desired production), and increase Desired Capital Productivity (i.e. expected amount of output with a single unit of capital). A standard stock management structure and co-flows are used here to assure that the properties of newly ordered capital are maintaining along the capital vintage structure. It is worth noting that while the outflows from backlog are dependent either on the shipments from the TF and the cash availability of each sector, both capital addition and capital discard are calculated as a SMOOTH3 of the flow upstream to the capital vintage structure. Thus, both Capital Under Construction and the Capital stocks should be considered as third order vintage delays, as well as their co-flows determining Labour Requirement of Capital and Capital Productivity.

Based on these premises, the Indicated Production $IndP$ is calculated as:

$$IndP = K \times \pi(\omega) \qquad Unit: \frac{Capital\ Units}{Day}\ or\ \frac{Tickets}{Day}$$

Where K is the stock of capital and π is the productivity of that capital as a non-linear function of the quantity of licences ω.

In a similar way capital drives labour such that Indicated labour $IndL$ is calculated as:

$$IndL = K^* \times \varphi(\omega) \qquad Unit: People$$

Where K^* is the desired capital, and φ the labour requirement of that unit of capital as non-linear function of the quantity of licences ω. In so doing Labour adjusts to the Indicated labour over time, despite being constrained on the ability of the company to afford it.

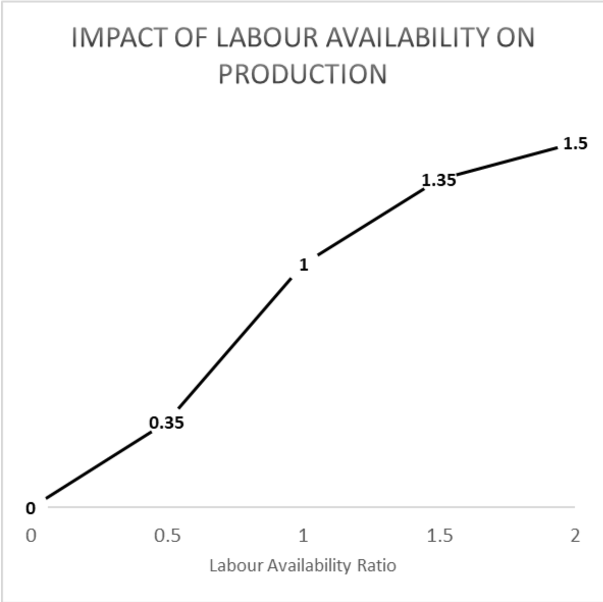
The resulting Production function based on available capacity (both capital and labour) is thus determined as:

$$P = IndP \times \vartheta\left(\frac{L}{IndL}\right) \qquad Unit: \frac{Capital\ Units}{Day}\ or\ \frac{Tickets}{Day}$$

Where $\vartheta\left(\frac{L}{IndL}\right)$ is a non-linear relationship determining the impact of labour availability on production as described in Figure 4.

The production P provides is different from those available in the standard economic literature (e.g., Cobb-Douglas, Constant Elasticity of Substitution, or Leontief) as reviewed in Pasqualino and Jones (2020a, and Pasqualino and Jones 2020b) providing greater flexibility while at the same time assuming non-linear dynamics system assumptions on business dynamics.

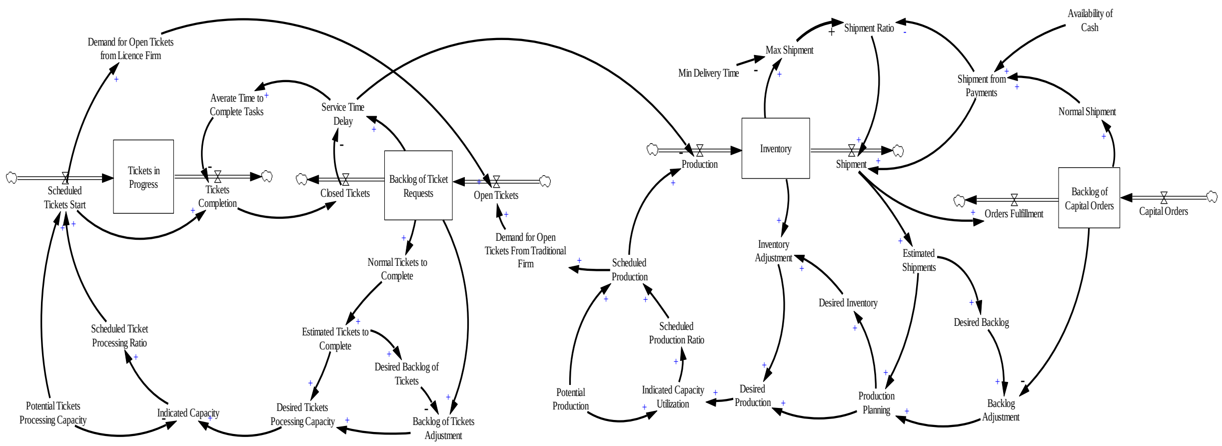
Figure 4 – Table function describing the impact of labour availability on production



Production and Customer services

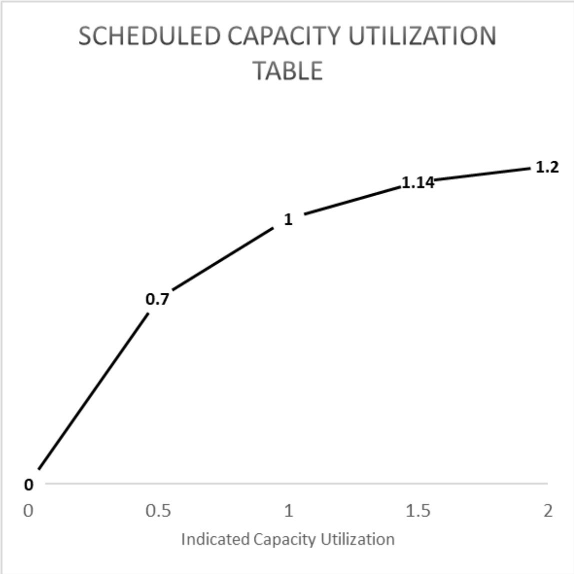
Figure 5 shows the production backlog and how new orders are generated in each model. The capital orders in TF (right hand side of Figure 5) are calculated as the sum of the capital orders from each sector (see Figure 3). The orders accumulate in the backlog, and decreases due to shipments. The desired production structure accounts for both the estimation of future orders, and adjustment from backlog and inventory based on future requirement. Estimation is based on the TRND() function, mimicking the behaviour of firm to adopt econometric method, based on imperfect data, and remaining biased by past performance rather than future estimates (Sterman 2000).

Figure 5 – Production, Shipments, Opening Tickets and Customer Service feedback



The ratio between desired and potential production determines the Indicated Capacity Utilization that is corrected with a capacity utilization table function according to the shape of Figure 6. Thus, if demand decreases below supply, the behaviour is to remove a little more backlog than required thus keeping labour busy and exploiting time in low demand. However, when demand is above capacity, it is assumed that workers can increase their capacity to accommodate demand but not so flexibly due to friction in human endurance.

Figure 6 – Scheduled capacity utilization table function



In IN4.0-SD it is assumed that when production is scheduled it is often the case that these require a series of adjustments of the software to the evolving performances of firms, to help them target their production level. These can range from requests to produce items that have new features to solving bugs in their system. Thus, LB opens a new ticket, and plans capacity to be able to solve them.

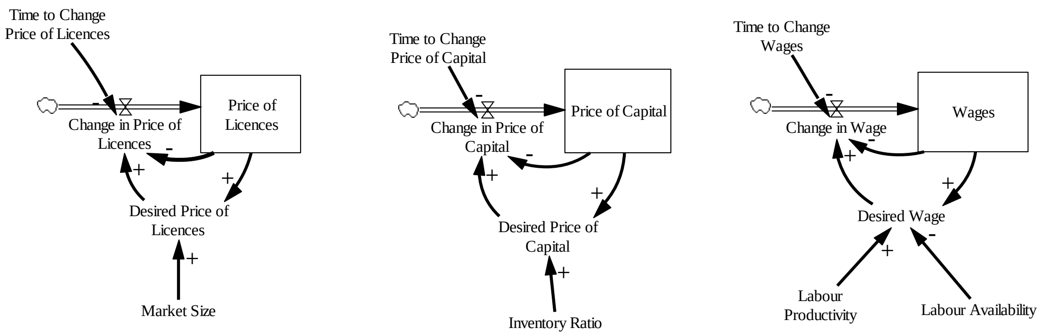
This brings to the tickets processing capacity management, leading back to requirements of new capital, and licences to meet those requirements. In a similar way to TF, LB schedules capital and labour to start solving tickets. Being LB also relying on licences to solve tickets, it also ends up opening further tickets that have to be accounted for production. It is assumed that tickets take an average time to be closed, and delivered, thus reducing backlog and supporting their clients with efficient production. However, if for whatever reason the LC software cannot solve them, the service reduction is reflected in lower capacity of TF to deliver their production to inventory, and increases the delay time of LB to solve those tickets. This is a self-reinforcing loop can generate instability in IN4.0-SD.

Prices and wages

IN4.0-SD endogenously models wages and prices using system of pressures based on past performance (See Figure 6). The pressures for wage change are generated from both (i) labour availability (the difference between required labour, and labour currently employed), and (ii) labour productivity (the resulting output generated by each person). If labour availability increases (there is too much supply for labour demand) then wages will tend to decrease. However, if workers can produce more than before it is assumed that this can lead to pressures increasing wage over time.

Prices are assumed being not impacted by costs (e.g. wages do not feeds back to price). Rather these are assumed to being driven by market forces alone. On the side of TF, it is assumed that when desired inventory (the inventory required to assure desired supply) is higher than actual inventory, this will generate inflationary pressures to increase price. With regards to LB, it is instead assumed that the price increases are proportional to the growth rate of the market, assumed as a key driver for determining customer interest and service supply. These assumptions can be challenged in many ways. For example, the larger a market the lower might be the price to support economies of scale and further distribution of output. These factors can be assessed in the current version on the model, and their relative pressure for inflation increases.

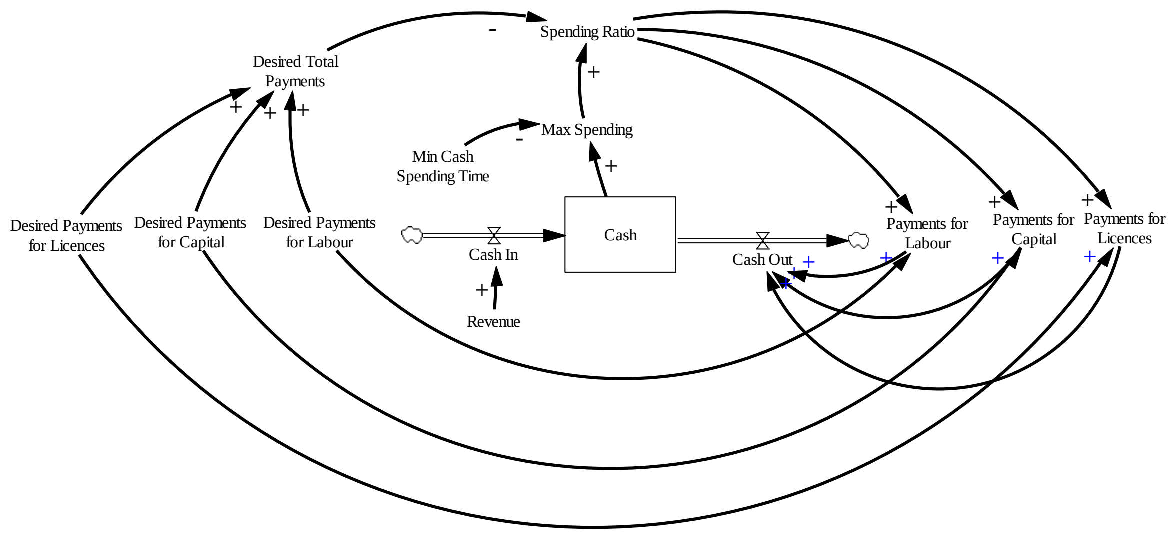
Figure 6 - Prices and Wages



Cash and Financial decisions

Closing the feedback loops from real to financial and back to real dimensions, Figure 7 shows the modelling of cash availability and their impact on decision making. On the one hand, the indicated levels of purchases of licences and capital as well as the supposed payments to labour determine a total payment due. These are compared to the max spending with available cash. Every time cash is not sufficient to pay for the entire sum desired by the sector, this should be accounted in terms of financial decision determining reduction of actual purchases and supporting balance in the cash structure.

Figure 7 - Cash and financial decisions



Model limitations

The model is a stylised economy model and as such does not represent significant factors of the real economy. For example, despite the variable Cash is considered explicitly in the model, and uses revenue as inflow and payments as outflow, the model ignores factors such as debt, interest rates, and cost of capital. In particular, borrowing is considered as being free of charge and supports the agents of the model to remain solvent at all the time in the simulation.

Large sectors such as banks, government, or other institutions are ignored. Also, the environmental and limits to growth factors are not considered both in terms of population change (limits to labour employment), resources and energy system change. Thus, this model represents a stylized economy that provide great disequilibrium flexibility to model transition economies. The model can then be extended to wider domains in particular to be useful in the context of global sustainability.

Sensitivity analysis

Initialization

The inputs and time frame of the model are normalized to generic values. Wages and Prices are initialized at time 0 to 1 (i.e., it costs 1 dollar to purchase 1 unit of output or pay one person). In addition, initial parameters of (i) capital requirements, (ii) licences requirements, and (iii) labour force are given arbitrarily to assure that the model can start in perfect financial balance for all sectors (i.e., each sector pays as much as receives as income). This allows to choose a group of parameters and run behavioural experiments to demonstrate the results of the model.

Sensitivity 1 – Exogenous factors

Table 1 shows the parameters used to run the sensitivity based on the exogenous factors to the model. These controls the growth or degrowth rate in demand from households and entrants in the licence market. All parameters have been varied between -1% (exponential decay) and +1% (exponential growth) over time.

Table 1 – Parameters' variations for exogenous factors sensitivity experiment

Parameter	Meaning	Range Min	Range Max
Exogenous exponential change in household capital demand	Supports the demand of capital thus pulling growth in the system via Traditional-Factory output	-1% Reduces demand over time	+1% Increases demand over time
Exogenous exponential change in new entrant in licence market for Household (H)	Supports the creation of more licences products, that over time are introduced to market for Households	-1% Reduces entrants in the market over time	+1% Increases entrants in the market over time
Exogenous exponential change in new entrant in licence market for Traditional Factory (TF)	Supports the creation of more licences products, that over time are introduced to market for Traditional-Factory	-1% Reduces entrants in the market over time	+1% Increases entrants in the market over time
Exogenous exponential change in new entrant in licence market for Licence-Business	Supports the creation of more licences products, that over time are introduced to market for Licence-Business	-1% Reduces entrants in the market over time	+1% Increases entrants in the market over time

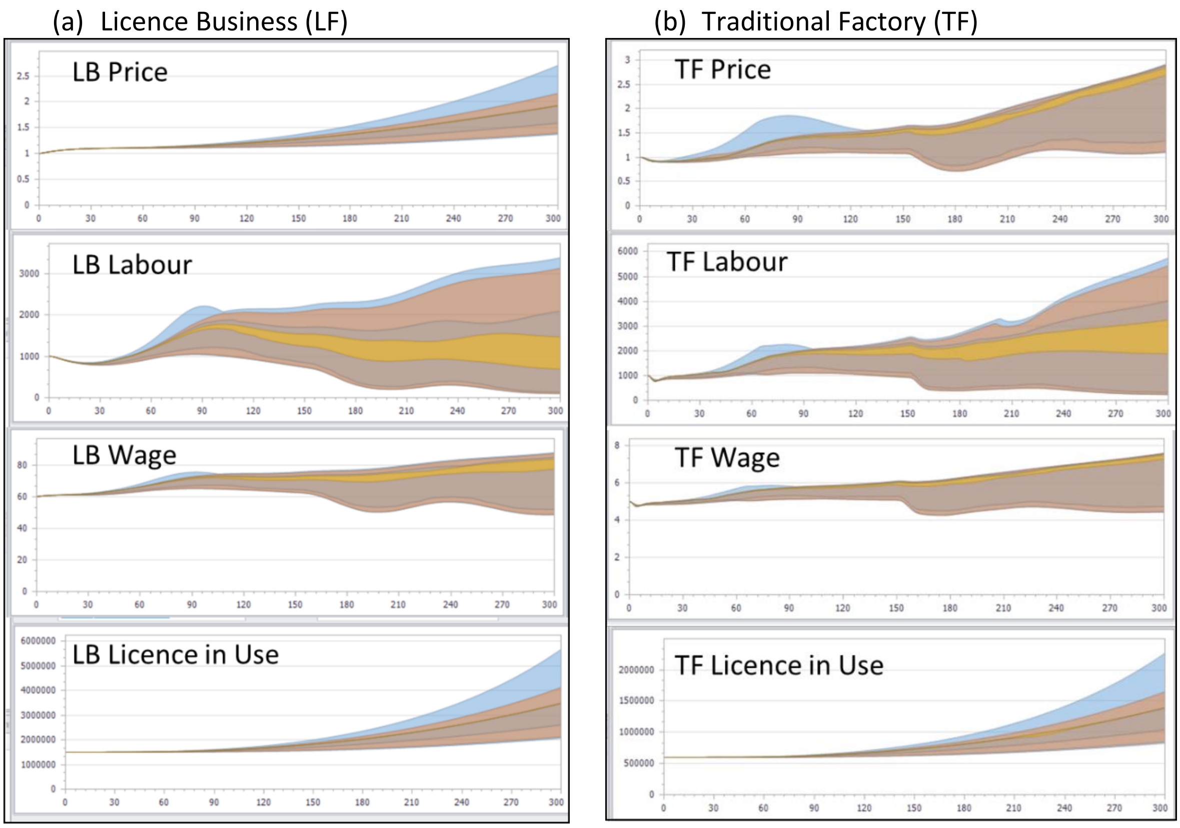
Figure 9a[1] and Figure 9b show the results of the sensitivity analysis for LB and TF respectively. The results show that the model is highly sensitive to change in demand, since this affects both Inflation(i.e., prices), licences in use, employment and wages. In both cases Licences in Use (in the

[1] The charts provide a graduation of 4 colours depending on the percentage of runs that fell in that particular range. These are (i) Yellow – 50% of runs, (ii) Brown – 75% or Runs, (iii) Red – 95% of runs, blue – 100% of runs.

model used as proxy for technology change and driver for labour requirements and capital productivity) grows steadily following different patterns of growth. Given the rise in demand, inflation grows for LB. On the other Hand, the model shows a tendency for inflation growth also for TF, thus showing that in most cases inventory is in deficit in comparison to demand.

Wages shows significant variability, and mostly staying within the +/-20% from initial values. On the other hand, labour shows great variability from +500% to -99% over the time period of the simulation. It is worth noting that the model starting relationships were those explained in the diagrams of Figures 2 to 7) Thus the base run, considers that every licence in use increases would determine labour requirement reduction per unit of capital. However, if the demand growth from households grows enough to create more jobs than those that are cut off because new technology, than employment will rise. However, there is also the risk that jobs will be impacted negatively despite growth. Since wage (payment per one person) is relatively stable, then a decrease in labour employment would meant a real systemic crash in the global economy.

Figure 9 – Sensitivity of the model to exogenous factors



Sensitivity 2 - Sectorial parameters

Table 2 shows the parameters considered as variation for the sensitivity experiment for the understanding of sectorial behaviour. In this case we opt for two sensitivity analysis, first running and experiment for the parameters input o the LF sector all rest as equal, and the secondly doing the same for the TF sector. In addition to one parameter common to the previous experiment (exponential growth or decay of new entrant in the licence market), we now address three elasticities used to change the strength in the relationships between licences and (i) capital productivity, (ii) labour requirement of capital, and (iii) efficiency of the licence business. In addition we test the different fraction of adoption rate from slow growth (1%) to fast growth (10%).

Table 2 - Parameters' variations for sectorial factors sensitivity experiment

Parameter	Meaning	Range Min	Range Max
Exogenous exponential change in new entrant in licence market	Supports the creation of more licences products, that over time are introduced to market	-1% Reduces entrants in the market over time	+1% Increases entrants in the market over time
Elasticity of Labour Requirement to Licences	Determines the impact of innovation on requirement for labour per capital unit	-1 Decreases the amount of labour requirement	0 Constant amount of labour requirement
Elasticity of Capital Productivity to Licences	Determines the impact of innovation on productivity of each capital unit	0 Constant amount of capital productivity	1 Increases the among of capital productivity
Elasticity of Open Tickets to Licences	Determines the impact of innovation on the tickets creation for Licence-Business	-1 The efficiency of workers in LB improves over time requiring less assets capacity and labour	0 The efficiency of workers in LB remains constant over time
Normal Licences Adoption Fraction	Controls the speed of the adoption rate based on Licence already in use	1% Minimum adoption fraction is 1%	10% Maximum adoption fraction is 10%

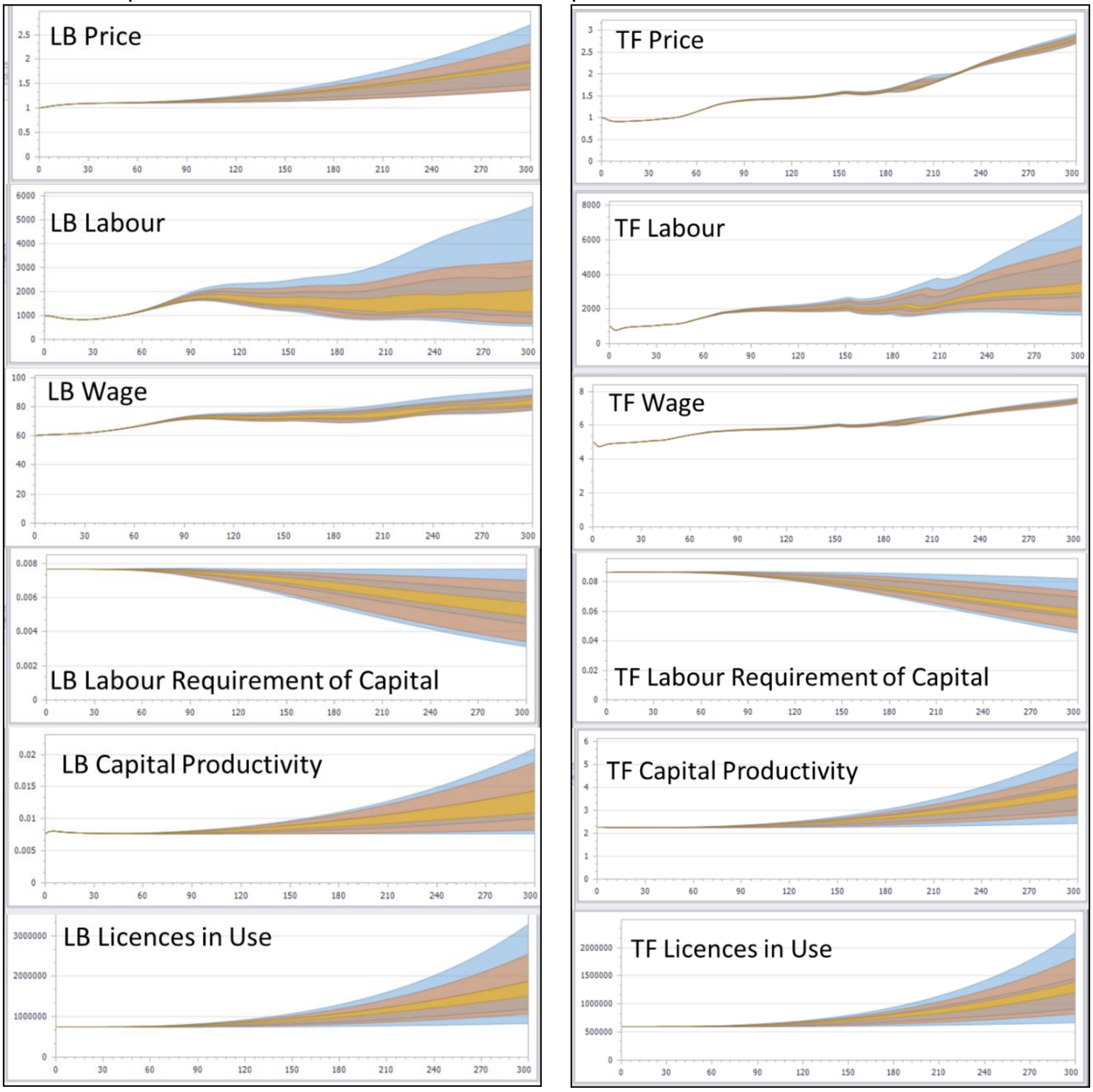
Figure 10a and Figure 10b show the results of the sensitivity analysis for LB and TF respectively. It is worth noting that licences in use directly impact capital productivity growth and reduced labour requirement over time. However, the concerning factor is that while wages remain relative unsensitive to the parameter variation, labour can be strongly influenced over time. In particular it appears that it can be very likely that labour requirement can increase until time 90 and then slowly reduce (the yellow and brown banks are the most likely).

On the other hand while LB price increases due to the reinforcing loop driving more innovation in the sector, the traditional factory business appears to be very unaffected by price variation. This is due to the fact that while changing the composition of capital vs labour to generate production, the sector is efficiently capable of meeting demand in any circumstance, even when employment decreases. In other terms, capital owners, would enjoy money making business investing on the LB rather than on the TF. This is a particularly concerning result when looking at the transition of employment in the future of our society, the rise in inequality, and the increasing gap between the rich and those that provide labour.

Figure 10 – Sensitivity of Licence-Business parameters and Traditional Factory parameters

(a) Variation of LB output based on ONLY LB parameters

Variations of TF output based on ONLY TF parameters



Discussion

The IN4.0-SD model is a simple model which aim is to explain possible dynamics interrelating key industrial and economic variables to support decision making in a complex world towards sustainability. Industrial innovation has been first explained in the real context of SOI, looking at the benefits and requirements for sustainability. However, depending on the actual performance of innovation, feedback effect could exploit loops that can be difficult to control in the context of sustainable development. Governments aim at stable inflation growth and assure maximum possible employment to their populations. However, when innovation modifies the characteristics of the way we run our economy, it becomes important to conceptualize the drivers generating inequality, instability and potential loss of employment in a growing world population. Indeed, as a result of various technological innovations, a range of dysfunctional impacts are threatening social and political stability.

Pasqualino et al. (2015) by calibrating the World3-03 model demonstrated that the model could be used to show that the World3-03 base scenario was considering a higher material (industrial) economy and what was recorder in public available data. Rather, a shift toward the service economy was taking dominance in the real world. This paper explores that particular concept employing similar concepts and demonstrating one option for the growth of that service economy. In addition, it addresses the possible concerns for modelling key economic variables (growth and inflation) while exploring the link between growth and labour employment.

Despite of it, the challenge of climate change requires to produce more with less, reducing waste and stopping using fossil fuels to run businesses. Reacting to climate change in this era will need responses that interconnect the global community on multiple levels. These effects not only impact on the socio-geographic issues, but also on industry creating huge operational problems. Simpler ways to run businesses can be based on low material content economy, thus pushing toward a services economy using business models explained as those outlined in this paper.

Of course, there are huge combinations of business models that can be adopted and should be modelled, including combination of both TF and LB in the same organization. Factors such as taxes and government interventions can potentially influence the stability of the system, regulations can apply constraints to the natural evolution of systems, and these must be all taken into account simultaneously in order to reach sustainability and a zero-carbon economy by 2050. Policy makers can play a fundamental role amplifying or reducing these effects by means of public investments and/or tax incentives, removing legislation, technological or financial barriers through effective policy measures, leading to steady economic growth with business opportunities across the whole economy. However, it is important to underline that there is a critical element that should be carefully analysed, this is the development of policy considering the technological advancement in recycling and waste processing and the interaction between the negative (i.e., pollution, emission) and positive (i.e., technological innovation) externalities.

Also, the model completely ignores the dynamics that led to the 2007-2008 financial crisis, such as inter-banking, debt foreign exchange and so on, making the model far to be usable for policy advice. However, it is from the small scale that big results can be achieved. The structure proposed in the IN4.0-SD can be used as part of larger models of capital growth and integrated in the context of climate modelling and integrated assessment with ease. As a result the simplified structure of price modelling adopted here might be not suitable for addressing great challenged in the financial system. One potential future application could be to be used as fundamental structure of the ERRE model (Pasqualino and Jones 2020a, Pasqualino and Jones 2020b), used to approach energy transition, linkages with food and finance. The ERRE is a large and more sophisticated models built upon the World3-03 and earlier version of the System Dynamics National model from Sterman (1981).

However, the ERRE still employs a standard neo-classical production function. The structure proposed in IN4.0-SD can potentially solve the limitation of the ERRE providing a step forward in the understanding of complex systems such as the global economy and its relationships with inequality and the planetary boundaries.

Conclusions

Innovation and technology have driven companies and countries to prosperity in the last decades. However, today there are global challenges to be faced such as ecological and social sustainability. Exploring the ethical, environmental, and economic nature of the various issues related to industrial innovation is therefore a fundamental aspect.

This paper focuses on the role of SOI by proposing the IN4.0-SD model to capture the interplay of industrial innovation with fundamental economic variables such as inequality, unemployment and inflation change.

The model can be considered as an early-stage theoretical model of a closed system economy, but at the same time can provide great insights in the functioning of innovation, its side effects, and impact economic development.

Next steps in the modelling work can include integration of the model with data emerging from public and private sources, likely to involve case-studies and business partners. Additionally, in the future authors plan to extend the model by taking into account not only economic and social considerations but also environmental ones, either including it as part of larger frameworks (e.g. the ERRE) or extending the current structure.

Acknowledgements

The Authors would like to thank Ventana Systems Inc. for providing the Ventity software free of charge to produce the paper and run the analysis.

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