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Technological Change in an Unstable Labor Market: A Dynamic System Approach

Timon Scheuer and Stella Zilian

Abstract: The rise of digital technologies, robots and computers has once again drawn attention to questions about the economic impact of technological progress. While process innovation is usually associated with productivity gains and a corresponding displacement of labor, product innovation is assumed to have rather positive effects on employment. We incorporate both channels of technological change by considering their different effects on productivity, needs, and expectations in a stock-flow consistent dynamic system approach. The highly simplified economic system presented in this article is based on standard assumptions, while with regard to technological progress and its effects the model allows for the emergence of off-equilibria paths and an unstable labor market. The chosen framework illustrates key dependencies in market economies, but simultaneously ties in with a fundamental level and thereby leaves space for shortcomings. Both may be seen as contribution to further developments as science, just like technological change, partly always will be a process of trial and error.

Keywords: labor market, product innovation, process innovation, system perspective, stock-flow consistency, path-dependence

JEL Classification Codes: P10, J01, O30

Technology is commonly seen as a main driver of economic growth (Romer 1994). Simultaneously, phases of major technological change have always been accompanied by anxieties and fears. Many of them are associated with the possible negative effects technology may have on employment. Throughout history people were worried that technology may render human work superfluous as machines were increasingly able to substitute for human labor. Thus far the predictions of high technological unemployment have never been fulfilled. On the contrary, innovation and new technologies have always given rise to the creation of new jobs and industries as labor productivity and productive capacities increased, living standards improved and new products were developed. While especially product innovations cause an increase in the demand for labor, the theoretical economic literature has identified

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several channels through which the substitution of labor by machines can be compensated (see also Vivarelli 1995; Vivarelli 2014; Piva and Vivarelli 2018; Mokyr, Vickers, and Ziebarth 2015; Spiezia, Polder, and Presidente 2016). Whether the compensating forces are able to offset the initial decrease of the labor demand depends on many factors such as the degree of market competition, elasticities of demand and preferences, substitutability between factors in production, labor intensity of the production of new goods and more (Spiezia, Polder, and Presidente 2016; Piva and Vivarelli 2018). Also the reduction of weekly working hours was instrumental to mitigate the problem of technological labor substitution (Leontief 1982). Since 1870, in Western Europe annual hours worked per capita shrank by about half (Maddison 2006). Empirical research assessing the employment effects of product and process innovation is manifold and the field can broadly be categorized as being conducted at the macroeconomic country-level (e.g., Vivarelli 1995), at the sectoral level and at the microeconomic firm-level (see also Piva and Vivarelli 2018). The overall microeconometric evidence covering different countries and time periods suggests that there is a positive relationship between innovation, especially product innovation, and employment (Van Reenen 1997; Harrison et al. 2014; Falk 2015; Piva and Vivarelli 2005; Lachenmaier and Rottmann 2011). For example, Daria Ciriaci, Pietro Moncada-Patern-Castello, and Peter Voigt (2016) find, using a sample of 3304 Spanish firms, that high employment growth from 2002 to 2009 was more likely to have happened in innovative firms, although the size and age of the firm also mattered. Results from sector-level empirical research highlights the differences of employment effects between different sectors, often due to the mix of product and process innovations (e.g.,Vivarelli, Evangelista, and Pianta 1996; Vivarelli 2014). Francisco Bogliacino, Mariacristina Piva, and Marco Vivarelli (2012) cover 677 European firms between 1990 and 2008 and show that business R&D is associated with positive employment effects in services as well as high-tech manufacturing, however, not in traditional sectors. Alex Coad and Rekha Rao (2011) study only high-tech manufacturing industries in the United States and find a positive relationship of innovation and employment over the period 1963–2002. Piva and Vivarelli (2018) find, covering eleven European countries over the period 1998–2008, positive employment effects of product innovation in high-tech and medium-tech sectors but no effects in low-tech sectors while capital formation, as a proxy for process innovation, is negatively linked to employment. Rinaldo Evangelista and Antonio Vezzani (2012) find that process innovations are only linked to labor displacement in the manufacturing industry and only when they are combined with organizational innovations.

So even though experiences of the past indicate that human labor seems to be quite robust to technological replacement, at least at the aggregate level and in the medium to long run (Mokyr, Vickers, and Ziebarth 2015), the economic impacts of the on-going phase of technological progress including artificial intelligence need to be reconsidered, nonetheless. For example, (Brynjolfsson and McAfee 2011; Brynjolfsson and McAfee 2014) raise the concern about the "great decoupling" of (technology-driven) productivity and employment growth. Indeed, for a long period of time, productivity and employment have risen together but over the last decades, this pattern changed. Even though productivity has been rising steadily, employment growth has lagged behind and Erik Brynjolfsson and Andrew McAfee (2011 and 2014) argue that technological change is at the core of modern unemployment.

We therefore incorporate technological change in a model which takes a system perspective. Acknowledging the complexity of the system we nevertheless follow the advice to keep the model as simple as possible by sticking to a closed economy consisting of representative agents for households and firms, trading only one type of good and one type of labor (Nikolic and Kasmire 2013, 52).[1] Our focus lies on the incorporation of process and product innovations in order to capture some of the ambiguous effects technological change may have on employment in case of an unstable labor market. An unstable labor market is characterized by the absence of a stable equilibrium where stability refers to the recurrence of such an equilibrium, induced by market mechanisms, after any deviation from it. The instability of labor markets is often explained by the existence of a (partially) downward sloping labor supply function meaning that labor supply decreases as the wage rate increases. In basic textbook microeconomics this is explained by an income effect that outweighs the negative substitution effect which tends to occur at higher wage segments. Critical economists admit the possibility for such an instability especially with regard to low wage segments (e.g., Keen 2004; Prasch 2008), which is also the segment of workers that is expected to be most heavily affected by the current wave of technological change (Frey and Osborne 2017; Wolter et al. 2015; Arntz, Gregory, and Zierahn 2016).[2]

In the proposed model we keep the translation mechanisms regarding the impact of technological change on employment simple: (i) the positive impact of labor-saving process innovations on productivity and (ii) the positive impact of product innovations on needs and expectations—approaching a common and validated point of view (cf. Piva and Vivarelli 2017). Economic behavior is described by sequentially executed routines represented by a set of equations. The chosen set of assumptions and simplifications are thus used to illustrate key dependencies in market economies and their development. While the perspective is far from complete, it still offers fruitful insights into the workings of an economic system and its high sensitivity with regard to the assumptions that are usually taken as given in mainstream economic modelling.

The article contributes to the economic literature in two ways. First, upon the incorporation of needs and expectations and their dependency on technological change, our model integrates aspects that are usually not considered explicitly in standard economic models. These aspects are important in order to forsake Say's law and its self-fulfilling prophecy of equilibria. The explicit consideration of needs and expectations as drivers of decisions not only is more plausible, but also provides points of contacts beyond the disciplinary blinders. The second contribution of this article refers to the incorporation of technological change. In contrast to the mainstream economic literature where technological progress is assumed to be unambiguously good for the economy in the long run, we find that technological progress adds a potential source of instability to the economic system allowing for off-equilibrium growth paths. The fragility of the modelled economic system is a key finding of this article and it hints at the potential flaws of the assumptions underlying mainstream economic theory. The remainder of this article is structured as follows: the next section gives a short review of the literature on approaches to model technological progress and unstable labor markets. The section "Derivation of the Analytical Framework" introduces the aggregate model of a closed economy with technological change as the driving force of growth. The following section discusses the statics of the incorporated markets and

[1] This can also be seen to be in line with the famous quote attributed to Albert Einstein *everything should be made as simple as possible, but not simpler* which perfectly summarizes the principle of Occam's razor that finds application in the development of theoretical models across disciplines (Duignan n.d).

[2] A related approach puts forward that labor supply follows an inverted S-shape because poor people face an additional constraint related to the subsistence level of the family (Dessing 2002). Other authors go even further and dispute the existence of labor supply and demand curves altogether (e.g., Fleetwood 2014)

the determining assumptions, while the subsequent section presents the implied dynamics in a narrative way which is then illustrated by numerical simulations. The final section provides a critical outlook and conclusion.

Technological Change in Endogenous and Evolutionary Growth Models

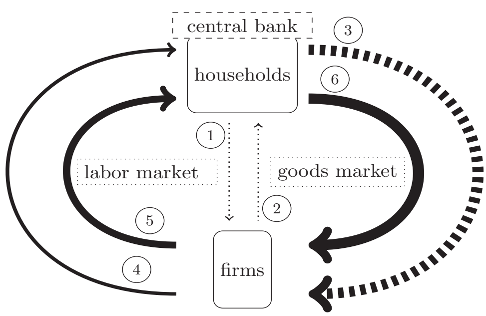
The conventional approach to incorporate technological progress in theoretical economic models, is to make assumptions on the ways in which it affects the aggregate production function and the utility-maximizing representative agent. Neoclassical growth models in the tradition of Robert Solow (1957) do not provide an explanation for technological progress—it is assumed to be exogenous. This shortcoming has been addressed by many economists, (e.g., Paul Romer (1994) who puts knowledge at the center of economic growth or Philippe Aghion and Peter Howitt (1992) and Gene Grossman and Elhanan Helpman (1991) with their focus on the role of innovation). Very generally speaking, in these models technological change is endogenized by incorporating (some sort of) knowledge in an aggregate production function with representative agents optimally deciding on the resource allocation to knowledge generation (e.g., R&D) which leads to technological progress and consequently economic growth (see Aghion and Howitt 2009). While these approaches and their distinctive conceptualization of technological change are useful for the description of long run developments of economies as well as processes of convergences, their main element, namely the process of knowledge generation, is explained with the standard ingredients of orthodox economic theory: a representative agent maximizes some objective function subject to certain constraints. Even though some endogenous growth models take into account elements such as the riskiness (and therefore the probability) of the success of innovations (e.g., Aghion and Howitt 1992), systematic errors as a result of misinterpretation do not occur. Thus, a crucial element of endogenous growth theory is the assumption that economic entities can be represented by one rational agent who correctly understands his decisions as well as the resulting consequences. Other strands in the economic literature, for example, in the tradition of evolutionary economics (see Nelson and Winter 1982; Dosi and Nelson 1994), focus explicitly on the microeconomic explanation of innovation and technological change and refrain from the rational-choice theory. For the evolutionary perspective, entrepreneurs and the microeconomic explanation of their behavior are of particular importance. It is usually assumed that all agents, and therefore also entrepreneurs, are subject to bounded rationality (Nelson and Winter 2002) and consequently they cannot understand all their actions and their environment in full detail. But they, nevertheless, need to make decisions which are led by routines "whose origin is shaped by the learning history of the agents, their pre-existing knowledge and, most likely, also their value systems and the prejudices" (Dosi and Nelson 1994, 33). Another distinctive feature of evolutionary approaches is the adaptability of behavior—while in neoclassical economics and in endogenous growth models the representative homo oeconomicus never changes his rules upon which he bases his decision, evolutionary theories allow for adaptive behavior (Dopfer 2007). Finally, while endogenous growth models analyze technology within the framework of the aggregate production function, in evolutionary economics, technology is understood as a system in which each technology is linked to other technologies, economic activities, routines of producers and consumers, and all kinds of institutions (Kemp, Mulder, and Reschke 2001). The system's view is very prominent in the literature on the economics of innovation (see Carlsson 2007 for a literature review): this strand of literature acknowledges that technological change is a path dependent and collective process that emerges within a dynamic and complex economic system (Antonelli 2009).

Within the remainder of this article we address some of the mentioned issues and develop a highly simplified theoretical model, using several standard economic assumptions within a stock-flow consistent framework and introduce technological change in terms of product and process innovations. In the model, we draw on some of the concepts of evolutionary and adaptive behavior of agents: our system entities are led by routines which are set up in pre-determined ways, but they are then allowed to develop endogenously driven by needs and expectations which are determined by technological change. Another distinctive feature of our model is the departure from the neoclassical presumption of stable equilibria: the markets in our model are not necessarily in equilibrium and an equilibrium in the labor market may even be unstable. Nonetheless we do not reject the concept of equilibria as itself, but we follow the view of Joseph A. Schumpeter (1912) with his conception of the economy as a circular flow which tends towards an equilibrium position.

Derivation of the Analytical Framework

In order to capture an economy in a very simplified model, it is useful to think of the economic system as mainly consisting of two system entities: firms and households (see Figure 1). Households consume the goods (2) firms produce by the means of labor (1) which is provided by the households in the first place. The main objective of households is to satisfy their needs for consumption goods by giving up as little leisure as necessary. Firms in turn are assumed to act in a competitive market setting. They try to produce the amount that is expected to be saleable at a given market price and hire the amount of labor necessary for this purpose.

Figure 1. The Circular Flow



To represent a rather developed economy, the exchange of goods and labor is assumed to be eased by money. Money is created by the central bank given to households against collateral they possess. Households then may lend this money to firms (3) and claim a fee called interest. In favor of a consistent and sustainable flow of money, firms have to pay the interest (4) out of the loan they have received. The rest regularly is expensed in terms of wages (5) in order to hire the labor necessary for production. The consumption goods produced are finally sold at the market and generate the inflow of sales revenue (6). Thus, in the modelled economy, households have two sources of income so far, namely interest income and wage income—both being paid by firms. Firms also receive monetary inflows from two sources, loans and sales revenue—both are coming from households. The consideration of money is therefore crucial in order to allow for the unilateral notion of a circular flow. Money provides liquidity to the economic system and it flows from one entity to another and back again in exchange for a representative consumption good and homogeneous labor.[3]

The Loop of Adaptation

In the following we describe the circular flow and its guiding institutions by equations. To imagine the dynamic component the reader may think of these equations as a sequentially executed bunch of routines applied in discrete time steps. This is also what happens in favor of later on discussed simulations, in which after a first exogenous set-up, the development of the economy is endogenously determined by a fixed order of procedures.

- productivity may increase due to technological change (eq. 3)
- money supply and demand are determined (eqs. 7, 11)
- interest rate adapts (eq. 12)
- loans are granted and debt adapts (eqs. 13, 14, 15)
- interest payments are determined (eq. 16)
- labor demand and supply are determined (eqs. 4, 5)
- wage rate adapts (eq. 17)
- employment and wage payments are determined (eqs. 18, 19)
- income flows from firms to households (eq. 20)
- ideas for technological change find consideration
- expectations for the upcoming period are formed (eq. 2)
- newly created money flows to vouching households (eqs. 21, 22)
- goods supply is determined (eq. 23)
- needs may grow due to the embodied technological change (eq. 1)
- goods demand is determined (eq. 6)
- price of consumption good adapts (eq. 24)
- consumption is determined (eq. 25)
- sales revenue flows from households to firms (eq. 26)
- eventual profits are determined (eq. 27)

For the dynamics of the model, the timing of any adaptation is crucial. Applied analytic, which is not explicitly discussed within the next sections, can be found in the Appendix. The next sections focus on just those characteristics that seem to distinguish our approach from others.[4] One of them is the starting point.

The Pleasure of Stagnation

The story of the modelled economy starts in a stationary state. To be in a stationary state means that all stocks and flows in the economic system remain constant over time. A

[3] Note that the introduction of a fee that households would have to pay for the provision of money would not affect the concept of a circular flow. Parts of the liquidity would just make a detour from households to the central bank. Any costs of the central bank covered by the fee would be, by assumption, some form of income to the same extent and thereby generate a corresponding flow back to households again.

[4] We were advised to keep the discussion on basic assumptions about the circular flow rather short and selective as well as to spare references to underlying basic economic textbooks like Blanchard and Illing 2009, 127, 473, 575; Boeri and van Ours 2008, 109–111; Burda and Wyplosz 2009, 210–213; Keen 2004, 119–121; Klump 2011, 62, Pindyck and Rubinfeld 2009, 108, 113, 123, 161–165, 177–178, 308–309, 360–373, 684, 691–693, 695–702, 750; Snyder and Nicholson 2008, 575–577.

constant amount of a good is produced by a constant amount of labor and is consumed by a constant number of people. The system entity of firms represents a constant number of producers, the system entity of households represents a constant number of consumers.

The assumption of a stationary state requires some further details regarding the circular flow of money. First, the price of the consumption good is set in such a way that the income of the households exactly suffices to buy all consumption goods produced. Second, the whole flow of income composed by wage payments as well as interest payments is used to buy consumption goods and therefore finds its way back to firms via sales. Third, period for period firms can decide whether to repay the whole loan or keep it for another period in order to pay interest and wages out of it. With its markets in equilibrium, the economy therefore finds itself on a stable path of stagnation.

While a stable path seems to be favored by economists, stagnation and thus the stationary state usually are not. In order to meaningfully discuss the incentive to deviate from a stationary state towards economic growth, one has to consider the incentive to engage in any economic activity in the first place. According to the definition of economic science, economic activities are those that serve the satisfaction of human needs (Wöhe and Döring 2008, 1). Needs, therefore, lie at the heart of (economic) decisions and the most fundamental decision that has to be made is: what is needed?

In terms of the storyline of the model, some individuals of the system entity of households may have an idea about what is needed and what can thus be expected to be sold and consumed if produced. Within the stationary state this may be given by what has been consumed so far. In order to produce this portfolio of products represented by the consumption good, these individuals found firms and borrow money created by the central bank. This money forms the initial firm funds and determines the liquidity describing the circular flow of the stationary state.

From Stationary to Steady

What holds the state stationary is that there is no change at all—not even expected. The story of a dynamic model cannot end at such a point, but instead considers the dimension of time to combine both: undeniable ongoing change on the one hand, and its once theoretically reached limits on the other hand. The combining element lies in a deviation from mainstream microeconomics: temporary satiation. Considering the dimension of time, the nonsatiation principle is ultimately no longer tenable. The abandonment of the nonsatiation principle in turn is not hard to argue: given any period of time, there is a limit for the amount of a certain good an individual is willing or even able to consume to its own benefit. This is a fact rather than an assumption. The abandonment of the nonsatiation principle is therefore just the abandonment of a simplification commonly applied in mainstream microeconomics.[5]

To acknowledge the fact that needs are indeed satiable because of (more or less) natural time constraints, implies the abandonment of another principle commonly applied in mainstream economics: Say's law. Supply does not necessarily create its own demand. Whether it does so, depends on whether or not it meets the previously unsaturated needs.

In order to illustrate the point about the temporary satiation of needs, the story of the model at hand begins in a world where the only good produced is bread. There is clearly a

[5] One of the critics of the nonsatiation principle was John Maynard Keynes (1930), who argues: one has to distinguish between absolute needs, the satisfaction of which is at the heart of the economic problem, and relative needs, which he describes as the "desire for superiority."

limited amount of bread that households are willing or even able to consume in a certain period of time. Once reached, this limit for the periodical need for bread, as the only product represented by the representative good, also constantly defines demand and supply within the stationary state. What could cause a change is another newly invented product expanding the portfolio of products represented by the representative good. If it expands it in a complementary way—instead of substituting for bread—it would trigger a corresponding so far unsaturated need. Expecting this increase in needs means expecting a corresponding increase in demand for the representative good. This is, simply put, the foundation of a business idea as it is incorporated in the model: an idea for a product that both triggers and satisfies needs thereby increasing the quantity of representative goods that are expected to be saleable. Based on these expectations, entrepreneurs in terms of firms raise loans, hire labor, and start (enlarging) their production—just like they did when bread was invented. In this way the story of the model may be expanded product by product, letting needs, expectations, and thereby the economy grow over time. This is the concept of product innovation (τ^x) as it is incorporated in the model.

In concrete terms, product innovation is incorporated into the model in two ways. First, it determines the evolution of temporary needs for consumption (η_t) in terms of the absolute quantity of the representative good needed (see eq. 1). Second, it determines expectations (ξ_t) in terms of an economic growth rate (see eq. 2). It is the percentage by which the portfolio of goods can grow, based on the ideas already realized and quantified as consumption. The extent to which ideas for product innovation contribute to expectations about future consumption, depends on the rigidity (Ξ) of expectations. The more rigid expectations are, the more they are formed adaptively, based on the short-term growth of aggregate consumption in the past (φ_τ). The less rigid they are, the more they are influenced by the belief in the ideas for new products. Whatever the final expectations are, they are applied as an aggregated variable collectively shared by both firms and the central bank. This is important in order to generate the loans (υ_t) necessary to initiate and expand production.[6] Only the implementation of ideas for product innovations in the sense of successful production leads households to regard them as consumer goods. In the absence of product innovation, temporary needs remain unchanged. To which extent a product innovation may increase the households' needs for consumption, depends on the time left for its consumption in the first place.[7] Households take into account that consumption takes time and the latter is limited by nature. Time left for consumption is just the residual not dedicated to labor (σ^l). If there is not enough time to consume new products, there is limited need to buy them. Temporary satiation therefore becomes harder and harder to overcome.

$$\eta_t = \left(1 + \tau_t^x \frac{1-\sigma_t^l}{\eta_{t-1}}\right)\eta_{t-1} \mid \upsilon_t > 0 \tag{1}$$

$$\xi_t = (1-\Xi)\tau_t^x + \Xi\frac{\varphi_{t-1}-\varphi_{t-2}}{\varphi_{t-2}} \tag{2}$$

[6] Already, Schumpeter (1934, 102) emphasized that the access to money is crucial for innovators in order to realize their ideas.

[7] It was the fathers of marginalism themselves who discussed time as a natural constraint for consumption (cf. Kurz 2008, 207). While the mainstream theories based on the ideas of the marginalists failed to fully integrate the notion of time as a constraint for consumption, they consistently assume a diminishing marginal rate of substitution—for goods and services as well as for leisure.

While it is the concept of product innovation that allows to overcome the constraint given by limited needs and expectations, process innovation (ψ_t) overcomes the constraint given by a temporarily limited productive capacity (see eq. 3). In the story of the model, productive capacity is determined by the labor force only. Process innovation as it is incorporated in the model therefore has to increase productivity of labor (τ_t^l). Hence, process innovation as it is interpreted here may also represent the invention and application of new intermediate goods and capital—both neglected in the explicit framework of the model.

$$\psi_t = (1+\tau_t^l)\psi_{t-1} \mid \delta_{t-1}^l > \sigma_{t-1}^l \qquad (3)$$

Technological change of this sort may be triggered by restrictions faced in the past, especially by the scarcity of labor and a corresponding increase in the wage rate.[8] Change and corresponding adaptation therefore is induced and absorbed via markets.

Discussion on Implied Statics

Markets are modelled in a very rudimentary way. Balancing effects amongst supply and demand are incorporated via a simple price mechanism. Prices act as signals of scarcity—they increase in case of excess demand and decrease in case of excess supply. However, equilibria are neither presumed nor self-evident.

The Labor Market

The most prominent example is the title-giving labor market. Taking temporary limited needs for consumption as given, the quantity of the representative good (ρ^x) determines the income level aspired by households. In the short run they have no benefit from earning more than that. Consequently, they also have no incentive to supply more labor than is necessary to earn the residual not earned elsewhere—by interest payments (ι) or extra profits (π).[9] Given this residual, the quantity of time supplied for labor decreases as the wage rate (ρ^l) increases (see eq. 4). While here, the model obviously deviates from common practice in mainstream microeconomics, it is just the logical consequence of temporary limited needs. The wage rate defines the amount of money which may be earned by providing all time available for labor. The actual quantity of labor supplied in terms of time is therefore a proportion of the total amount of time available—from all to nothing [0,1].

$$\sigma_t^l = max\left[min\left(\frac{\eta_{t-1}^x \rho_{t-1}^x - \iota_t - \pi_{t-1}}{\rho_{t-1}^l}, 1\right), 0\right] \qquad (4)$$

Labor demand (δ^l) is also determined by the minimum of two arguments (see eq. 5). On the one hand, firms aspire to hire the amount of labor necessary to produce what they expect themselves to be able to sell. This amount represents the upper limit and is determined by growth expectations (ξ), past consumption (φ), and labor productivity (ψ). On the other hand, they are not able to hire more than the amount of labor they can afford at the actual wage rate. Their budget for hiring is determined as a residual of periodical funds (κ). It is what is left to dispose after paying interest and extra profits.

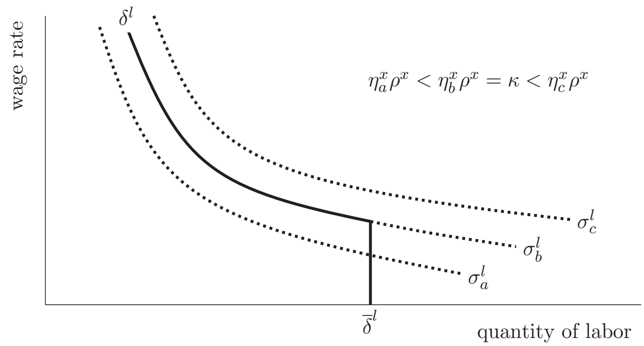
[8] The assumption that process innovation is only a consequence of excess demand is highly critical. However, it prevents the system from further exacerbating technological unemployment.

[9] In many countries, weekly working hours are regulated. The model does not consider such regulation as it does not truly consider individuals in the first place. It is up to the representative household to decide how much of its personal resources it provides to the labor market.

$$\delta_t^l = max\left\{min\left[\frac{\chi_t - \iota_t - \pi_{t-1}}{\rho_{t-1}^l}, (1+\xi_{t-1})\frac{\varphi_{t-1}}{\psi_t}\right], 0\right\} \quad (5)$$

The form of the budget constraint of firms strongly resembles the form of the function that describes the part of household income that has to be earned by labor. This parallelism of shapes reduces the potential for the occurrence of an equilibrium in general, and for stable ones in particular, to those cases where the parts with an elasticity of unity fully coincide. The instability of labor markets is regularly discussed with regard to a, at least partially, downward sloping labor supply function (see Figure 2) where labor supply decreases with an increasing wage rate. In terms of basic microeconomics, this is implied by an income effect associated with an increase in the wage rate greater than the oppositely directed substitution effect. In our model, a downward sloping labor supply function is just the logical consequence of assuming temporarily limited needs for consumption goods and a zero marginal utility for consumption above this limit.

Figure 2. Different Constellations in the Labor Market



The term "instability" refers to the fact that the price mechanism does not imply a tendency towards an equilibrium where supply equals demand, which would be graphically marked by an intersection of the supply and demand functions. In order to obtain such a unique intersection in the modelled labor market, firm funds would have to exceed nominal needs. If that is the case, the labor supply function (σ_a^l) lies to the left of the labor demand function. The two curves then intersect where the quantity of labor demanded is maximized and equals the quantity desired according to production plans at a wage rate where firm funds as a budget constraint l are not binding ($\bar{\delta}^l$). If, on the other hand, nominal needs exactly equal firm funds, both functions for labor demand and labor supply (σ_b^l) coincide as long as the budget constraint given by firm funds is binding. In the case of nominal needs exceeding firm funds, the labor supply function (σ_c^l) lies to the right of the labor demand function and an equilibrium is ruled out.

In the last case, (*c*) labor supply always exceeds labor demand. Without an institutionally defined minimum wage, the wage rate is condemned to fall indefinitely. In fact, any decrease of the wage rate caused by the price mechanism would even lead to an increase in excess supply. The same is true in the second case (*b*) if the wage rate reaches a level low enough so that the constraint given by firm funds is not binding. It is also true in the first case (*a*) if the wage rate reaches a level beneath the equilibrium level. Furthermore, instability is also found to the left of the intersection in case (*a*): labor demand exceeds labor supply for all wage rates higher than the one in the unique equilibrium. An increase in the wage rate may be able to reduce excess demand, but it would not be able to bring about a new equilibrium. Ceteris paribus, as comparative statics generally assume, the wage rate would be condemned to increase.

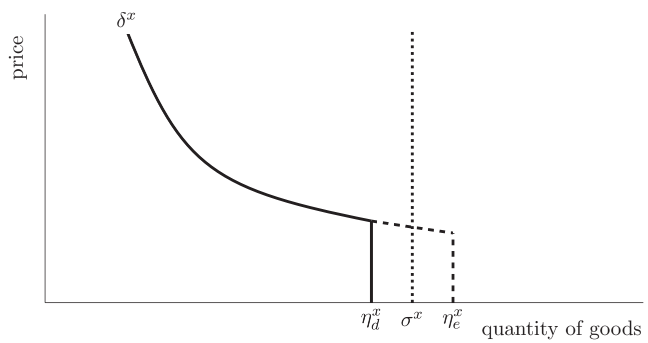
The Goods Market

In the market for the representative good, the price mechanism works more reliably as there is not much parallelism between supply and demand functions (see Figure 3). In contrast, goods supply is fixed by periodical planning depending on the level of employment determined at the labor market (see Appendix, eq. 23). It exhibits an elasticity of zero which is illustrated by a vertical line. With regard to demand, the situation is different: households do not try to spend all the money at their disposal (β), but just as much as necessary to satisfy their needs according to current prices (see eq. 6).[10] As supply is already fixed at the time households decide about periodical demand for consumption goods (δ^x), the goods market marks another deviation from Say's law.

$$\delta_t^x = min\left(\frac{\beta_t}{\rho_{t-1}^x}, \eta_t^x\right) \tag{6}$$

Figure 3. Different Constellations in the Goods Market

The demand for goods is described by a function that decreases in prices at an elasticity



of unity up to the point where the maximum is reached which is given by real needs. Whether there is a unique intersection of the supply and demand function depends on whether needs exceed periodical supply (as in the case denoted by the index *d*) or not (denoted by the index *e*). If the attainment of an equilibrium is possible, the price mechanism helps to approach it. Therefore, in case of an intersection, the goods market can be described as stable.

The Money Market

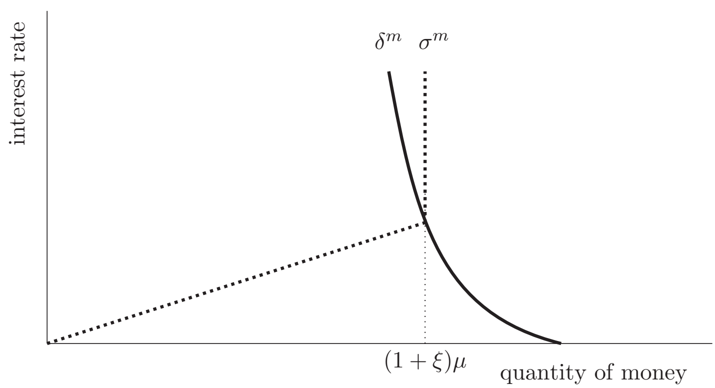
Stability is what the money market provides like no other. The money supply (see Appendix, eq. 11) depends on money creation (see Appendix, eq. 21), while the willingness

[10] In terms of a utility function, the marginal utility of consumption is assumed to be zero once the determined need in absolute terms is satisfied. Since money has to be earned before it can be spent, rational consumers have an incentive to consume only as long as marginal utility is positive.

to invest in money and thus make loans possible as an asset, increases with rising interest rates. However, the central bank does not deliver more than growth expectations would suggest anyway. In the relevant area, the money demand function is downward-sloping (see Figure 4). Assuming that production plans are already formed according to expectations (ξ) about consumption (φ), the demand for money is mainly determined by the cash flow that has to be financed (see eq. 7). The latter is not only given by wage (ρ^l) payments for labor necessary according to productivity (ψ) and extra profits (π) to be distributed, but also by the amount of money necessary in order to serve interest (ρ^m) payments. Although a higher interest rate leads to a higher demand for money to pay for it, it is assumed that the comparison with the reference rate balances this effect so that a low interest rate encourages borrowing, a high interest rate discourage it.

$$\delta_t^m = max\left[\frac{(1+\xi_{t-1})}{(1-\rho_{t-1}^m)}\frac{\varphi_{t-1}\rho_{t-1}^l}{\psi_t}\frac{\tilde{\rho}^m}{\rho_{t-1}^m}+\pi_{t-1},0\right] \tag{7}$$

Figure 4. Different Constellations in the Money Market



Because of this implied balancing, the reference interest rate works as an attractor. The intersection of money demand and supply lies at this rate, even when other variables like expectations and productivity cause shifts in both functions.

Amendment on Selected Sensitivities

How sensitive markets are to outcomes on other markets may be seen in the case of the money market where demand not only depends on prices in the real economy, but also on the expectations formed there. The interaction of expectations shared by firms, households, and the central bank decisively determines the existence and the nature of an equilibrium in the money market. Within the framework of the model, it can be shown that not only a negative development of expectations, but also a comparably large increase in productivity due to technological change may result in a lower demand for money. Shifting the money demand function to the left would then provoke a drop in the interest rate. As obvious as these insights may be, as important seems their emphasis with regard to empirical observations of stagnation and liquidity traps.

Another empirical observation that deserves some attention is inflation. In the goods market of our model one explanation for inflation is excess demand. Obviously excess demand needs to be financed and the question is, by what means is it primarily financed? Considering that household funds are regularly refreshed by income, that income in turn is regularly determined by the costs, and that costs are regularly financed by sales revenue, it becomes evident that demand-driven inflation would have been financed mainly by consumer credits. These are also the main source for extra profits. Consumer credits have to play a minor role in stable settings of the model since they are granted according to expectations and are thus mainly related to usage in terms of investment.

Inflation does not necessarily have to be driven by excess demand for goods. It can also occur if there is excess supply of goods as long as the wage rate and the interest rate cause an increase of average costs which would translate to increasing price levels. A convenient reason for continuously increasing costs can be derived from the interplay of supply and demand at the labor market: steadily rising costs require that the labor supply function lies to the left of the labor demand function with a wage rate that lies above the market-clearing wage rate of the unique unstable equilibrium. High inflation at the goods market tends to shift the labor supply function to the right and thus reduces the scope for rising wage rates or may even trigger the opposite: a steadily increasing excess supply of labor and a corresponding fall in the wage rate. For a similar directed effect imagine incidental wage costs in terms of a mark-up on the wage rate that has to be paid by firms. In our model this would directly affect the intercept of the labor demand function and shift it to the left.

It is the interdependency of all these markets that underline that the modelled economy could not even allow itself to withdraw once created and circularly flowed money. It would have to be accompanied with recession and deflation. To avoid both, it therefore has to be assumed that on aggregate debt does not get repaid—even if redistributed. Thus, static analysis already offers gainful insights in incorporated interdependencies, their implications and shortcomings. For a more thorough understanding of the workings of the economic system, however, a dynamic perspective is needed.

Discussion on Sketched Dynamics

The dynamic story of the modelled economy starts in a state of stagnation but from there on enters a growth path triggered by ideas and their realization in terms of technological change. Which ideas—product or process innovations—are realized is crucial. We sketch this issue in the next sections dealing with the different directions the economic path can take.[11]

A Promising Long Run

The first exemplary path is a fruitful one approaching stylized facts of the past. Although some of stylized facts do not match current empirical observations, they still provide an interesting benchmark which allows us to reproduce (past) real world developments with this simplified model. With regards to the modelled economy and its three selected markets, the following stylized facts are incorporated:

- exponential growth, accompanied by

[11] We initially refrained from excessive use of numerical simulations in order to avoid the correspondingly comprehensive quantitative discussions on scenarios and sensitivities. However, during the review process it was suggested to at least illustrate the different incorporated effects of product and process innovation—which we gladly did, but we nevertheless kept the focus on the qualitative aspects of the model.

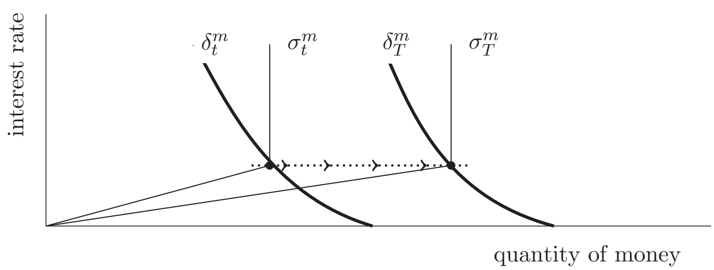
- increasing nominal as well as real wage rates, despite
- inflation, and a rather
- constant labor income share, with
- an ongoing reduction in working time.

The labor income share is mainly determined by the interest rate, at least as long as extra profits play a minor role—and they do in stable settings, as the price setting mechanism implicitly assumes a highly competitive market structure. Constancy of the interest rate requires a cleared money market (see eq. 8) so that there is no reason for noteworthy adaptation.

$$\sigma_t^m \approx \delta_t^m \tag{8}$$

The determination of money creation does not only favor constancy. Rather, the exact level of the interest rate and thus the labor income share is exogenously fostered by the fixed reference rate as sort of attractor. Consequently, as long as the money market remains stable, the labor income share exhibits a constant tendency towards its initial value.

Figure 5. Shifts and Exemplary Outcome Path at the Money Market



Inflation does not require stability in the goods market in its ordinary sense as inflation may also be cost-driven. However, as supply continuously exceeds consumption, sales revenue at unit cost prices would not cover costs and parts of the regular income would not be returned to firms. To avoid this and the possibly implied distortions in other markets, it is also not preferred to spend much more than the regular income on consumption. The most convenient steady state is therefore described by the one where cost-driven and demand-driven inflation coincide. While demand for goods could therefore potentially exceed goods supply, demand must at least equal goods supply (see eq. 9). With regard to the determination of consumption, supply has to be the binding constraint in this case.

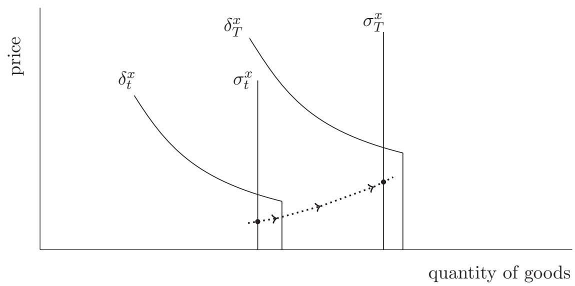
$$\varphi_t \approx \sigma_t^x \leq \delta_t^x \approx \eta_t \leq \frac{\beta_t}{\rho_{t-1}^x} \tag{9}$$

Also in order to prevent distortions, the binding constraint on the demand side is better given by needs. If needs are not the binding constraint, they obviously outgrow expectations determining money creation. This would provoke a rightwards shift of the labor supply function and trigger downwards instability of the market.

For the unstable labor market the preferred constellation is even more obvious. In order to induce an increase in wage rates, labor demand has to exceed labor supply (see eq.

10). Because of the instability a deviation from excess demand also bears a lot of risk, namely an economic downturn.

Figure 6. Shifts and Exemplary Outcome Path at the Goods Market



$$\sigma^l_t < \delta^l_t \tag{10}$$

In a very flexible labor market it might even be possible that labor demand adapts in a way that underbids labor supply. Due to simplification, the implied underemployment is equally shared among a homogeneous group of households and therefore does not hurt as long as the increase in wage rates ensures a sufficient passing-on of money from firms to households.

In order to capture this promising long run one detailed setting is applied (see Figure 8 as well as Tables 3, 2). The setting is an arbitrary and in its scales rather standardized one, selected in favor of the graphical illustration of choice and corresponds to the conditions derived before. The sketched story not only captures all the stylized facts mentioned before, but also deals with a constantly shrinking labor demand and supply—the latter always underbidding the first. The thereby implicitly incorporated decrease in working time per head is not only a further empirical fact, but also captures a main issue of our model. a little more leisure helps to overcome limits set by ongoing (temporary) satiation.

Figure 7. Shifts and Exemplary Outcome Path at the Labor Market

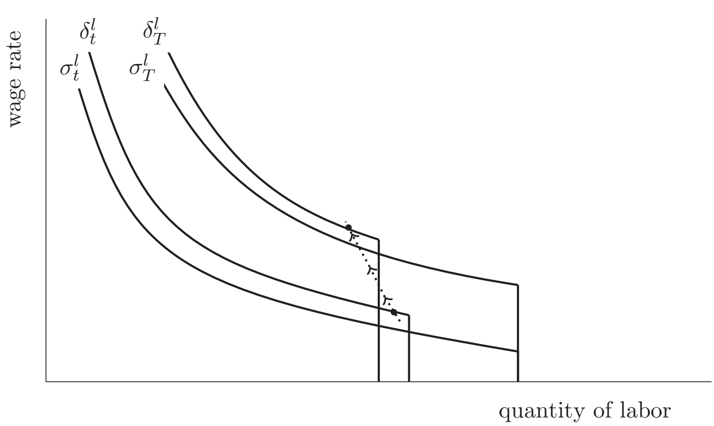
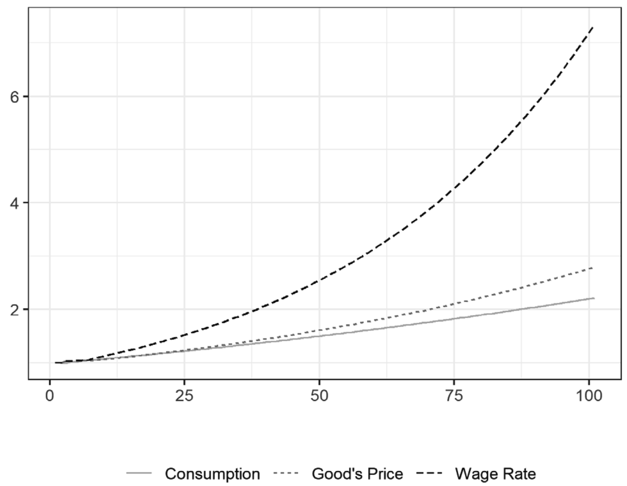


Figure 8. Promising Long Run (see Appendix, Tables 2, 3)



Causing and Solving Economic Crisis

It is product innovation that revives the economy as it may have an increasing effect on investment and consumption. In another exemplary simulation, we present this type of technological change in isolation, as we assume that after a certain period of stagnation, only product innovations kicks in (see Figures 9a and 9b). The result is a slight economic growth while labor supply asymptotically approaches its theoretical maximum (*t*. 10 to 50). The real wage rate remains constant because the exponential growth of nominal wage rate and goods price coincides. Consumption growth is positive but continuously declining.

Figure 9a. Varying Combinations of Technological Change (see Appendix, Tables 2, 3)

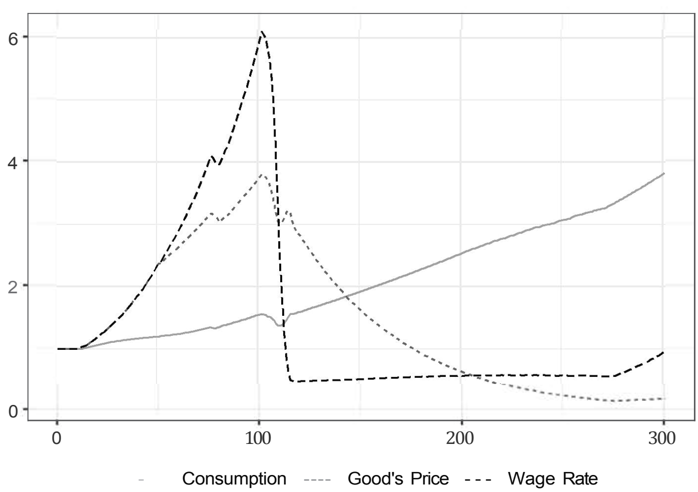
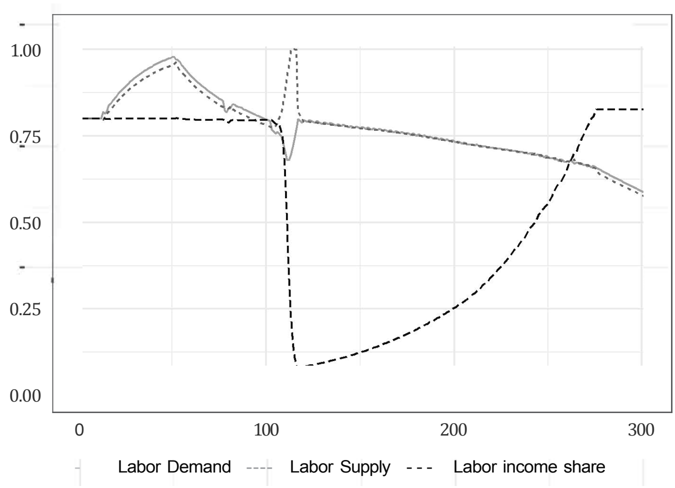


Figure 9b. Varying Combinations of Technological Change (see Appendix, Tables 2, 3)



It is process innovation that helps the economy to overcome the obvious constraint given by limited productive resources. Once it kicks in, the economy takes the fruitful path of the promising long run discussed earlier (*t*: 50 to 75). Inflation falls behind wage rate growth, which means that the real wage rate increases.

If the economy now for once lacks product innovation, expectations drop and labor demand with it (*t*: 75, 2 period downtime). Only if product innovation keeps the time without product innovation short enough, the modelled economy may avoid a huge crisis.

If product innovation returns only a little later and prices are not rigid at all, the path the economy takes is rather different: while it still is a growth path, it is accompanied by deflation for goods and labor (*t*: 100, 3 period downtime). Also the labor income share correspondingly declines sharply before it slowly recovers. When it has recovered to a newly stable height slightly above the original one, the economy is back on an exponential growth path in wage rate, goods price and consumption—just like in the promising long run.

Amendment on Selected Sensitivities

The previous simulation already shows how fragile the setting and thereby the modelled economy is and how strong the fruitfulness of the path taken depends on the exact combination of product and process innovations. Even the return to the stationary state does not seem possible without diving into crisis. A deviation from high expectations to rather low, although not negative ones, also lowers the growth in money supply and thereby loans. If they are not able to keep up with ever increasing wage rates, labor demand has to drop, and the rather unstable labor market may enter a vicious circle.

Besides the sensitivity with regard to product and process innovation, rigidities also play an important role. Flexible prices not only allow for higher growth rates in the wage rate and the goods price, but also for a tremendous drop in case of a downturn. Legislative measures observable in reality would be capable to avoid that. For example, a minimum wage rate would prevent the labor income share from falling and together with unemployment benefits may even stabilize the demand for consumption goods.

Critical Outlook and Conclusion

What can be taken away so far is, that alternative perspectives on economic systems and their dependency on technological change may at least hint on potential flaws in mainstream assumptions. It thereby also reveals that economic theory was, is and remains—just like this approach—a process of trials and errors, where from both should be learned. Admitting the explanatory power of the approach, a first conclusion has to be that the economic system is much more fragile to technological change than especially empirical analysis presumes—particularly in the case of unstable labor markets. The path such an economic system takes, crucially depends on the exact mix of the effects implied by product and process innovation. The variety of paths reaches from virtuous circles of growth to vicious circles of crises towards the system's crash. It therefore can be assumed, that a sufficiently challenging mix of effects implied by product and process innovation may disrupt the system in a way that cannot be dealt with by markets alone—even, if they deviate from the form they are modelled here. Some tendencies observable in the simulation of the model simply need counteracting institutions in order to stabilize the path of the economy.

Despite the interesting insights gained from the analysis of the proposed model, future work will have to deal with some of its weaknesses. For instance, the way technological change is incorporated can be criticized on several grounds. Firstly, its assumed regularity does not take into account the possibility of disruptive inventions. The flow of feasible ideas may not be constant but might rather trigger cyclical patterns of the emergence of new ideas. Secondly, the nature of the take-off depends crucially on the assumption that ideas for process innovations are only considered in the case of an excess demand for labor. However, this assumption implies that expectations grow, which, in turn, has a positive effect on labor demand before any negative effects on labor demand due to productivity gains arise. The incentive to improve productivity, though, might not only be reinforced by the scarcity of production factors, but there is probably an incentive to innovate simply because of competitiveness and entrepreneurship. Nonetheless, the main message remains the same: if the mix of effects assigned to product and process innovations changes in favor of the latter, the modelled economic system faces corresponding defiances.

Finally, proceedings may not only incorporate some more real world institutions, but discuss some of the already applied assumptions in more detail—e.g., the issue of lending and borrowing in general and the associated process of money creation. This is then the time for testing and analyzing different scenarios and thus also the sensitivities of the model.[12]

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[12] We skip this in this article because we consider it presumptuous to quantitatively analyze scenarios and sensitivities of a model whose basic assumptions and contributions have not yet been discussed by a sufficiently large scientific audience.

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Appendix

$$\sigma_t^m = \sum_{t'=0}^{t-1} \Theta_{t'} \tag{11}$$

$$\rho_t^m = max\left[\Xi^m \rho_{t-1}^m + (1 - \Xi^m)\rho_{t-1}^m \frac{\delta_t^m}{\sigma_t^m}, 0 \right] \mid \sigma_t^m > 0 \tag{12}$$

$$\upsilon_t = max[min(\sigma_t^m, \delta_t^m), 0] - [\varkappa_{t-1} - \mu_{t-1} + \zeta_{t-1}] \tag{13}$$

$$\vartheta_t = \sum_t \upsilon_t \tag{14}$$

$$\varkappa_t = \varkappa_{t-1} + \zeta_{t-1} + \upsilon_t - \gamma_{t-1} - \iota_{t-1} - \pi_{t-2} \tag{15}$$

$$\iota_t = min(\rho_t^m \vartheta_t, \varkappa_t) \tag{16}$$

$$\rho_t^l = max\left[\Xi^l \rho_{t-1}^l + (1 - \Xi^l)\rho_{t-1}^l \frac{\delta_t^l}{\sigma_t^l}, 0 \right] \mid \sigma_t^l > 0 \tag{17}$$

$$\varepsilon_t = min\left(\frac{\varkappa_t - \iota_t - \pi_{t-1}}{\rho_t^l}, \delta_t^l, \sigma_t^l\right) \tag{18}$$

$$\gamma_t = \rho_t^l \varepsilon_t \tag{19}$$

$$\mu_t = max(\iota_t + \gamma_t + \pi_{t-1}, \varkappa_t) \tag{20}$$

$$\Theta_t = max\left\langle min\left\{\xi_t \mu_t, \left[(1+\xi_t)\frac{\rho_t^m}{\tilde{\rho}^m}\right]\sigma_t^m\right\}, 0\right\rangle \tag{21}$$

$$\beta_t = \beta_{t-1} + \mu_t + \Theta_t - \zeta_{t-1} - \upsilon_t \tag{22}$$

$$\sigma_t^x = \varepsilon_t \psi_t \tag{23}$$

$$\rho_t^x = max\left[\Xi^x \rho_{t-1}^x + (1-\Xi^x)\rho_{t-1}^x \frac{\delta_t^x}{\sigma_t^x}, \frac{\iota_t + \gamma_t}{\sigma_t^x}, 0\right] | \sigma_t^x > 0 \tag{24}$$

$$\varphi_t = min\left(\frac{\beta_t}{\rho_t^x}, \delta_t^x, \sigma_t^x\right) \tag{25}$$

$$\zeta_t = \rho_t^x \varphi_t \tag{26}$$

$$\pi_t = max(\zeta_t - \iota_t - \gamma_t, 0) \tag{27}$$

Appendix Table 1. Variables and Parameters used in the Model

$\varkappa$	firms' funds	ζ	sales revenue
υ	loans	γ	wage payments
ι	interest payments	π	extra profits
ρ^m	interest rate	ϑ	firm debt
δ^l	labor demand	ρ^l	wage rate
ξ	growth expectations	ϕ	consumption
ψ	productivity	σ^l	labour supply
η	consumptive needs	ρ^x	goods price
Ξ^l	rigidity labour market	ε	employment
μ	income	Θ	money creation
$\tilde{\rho}^m$	reference interest rate	θ	households debt
β	households' funds	δ^x	goods demand
σ^x	goods supply	Ξ^x	rigidity goods market
σ^m	money supply	δ^m	money demand
Ξ^m	rigidity money market	Ξ	rigidity in optimism
τ^x	growth potential implied by ideas for product innovation		
τ^l	growth potential implied by ideas for process innovation		

Appendix Table 2. Starting Values for Exemplary Path

ξ_0	0	Θ_0	1	ϑ_0	1	σ_0^m	1
δ_0^m	1	ζ_0	1	γ_0	0.8	ι_0	0.2
π_0	0	κ_0	1	δ_0^l	0.8	σ_0^l	0.8
ε_0	0.8	σ_0^x	1	δ_0^x	1	φ_0	1
π_{-1}	0	φ_{-1}	1	η_0	1	μ_0	1
ρ_0^l	1	ρ_0^x	1	β_0	1	υ_0	0
ψ_0	1.25	τ_0^x	0	τ_0^l	0	$\varphi - 2$	1

Appendix Table 3. Parameter Setting for Exemplary Path

Ξ^m	0.00	Ξ^l	0.00
Ξ^x	0.00	Ξ	0.50
τ^x	0.05	τ^l	0.01
$\tilde{\rho}^m$	0.20	$\Rightarrow \rho_0^m, \ldots$	