Diffusion Challenges of Circular Economic Products

Yoshitaka Miura
E-mail: miuray0sh@gmail.com

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Abstract

Today's technology already allows some of the commercial products to be fully recycled through a closed-loop supply chain. However, despite many technological and commercial effort, such products are often prone to low market penetration and fail to reach a critical mass before their business become self-sustaining. To investigate why and to gain insight for an effective policy strategy, a diffusion process of such "circular economic" product is modeled and analyzed. For model case, a textile product chemically recycled through a closed loop supply chain is considered. The simulation explains that a diffusion of such products are both enabled and constrained by reinforcing loops originating from the installed capacity for production and collection, as well as accumulated social recognition such as trust of the product. As conclusion, the path dependent nature of the process is identified as the main hurdle for the diffusion, and therefore a policy to reduce it by introducing a powerful balancing loop (budget allocation via taxation) is discussed.

Key Words:
Circular Economy, closed loop supply chain, recycle, Life Cycle Assessment

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Author Information: Yoshitaka Miura is a master's student in European Master in System Dynamics (EMSD) at University of Bergen (Norway), University of Palermo (Italy) and Radboud University (the Netherlands). He has a B.A. in Economics at Waseda University (2011) and 6 years' work experience of managerial/financial accounting at a Japanese electric manufacturer. His interest is application of system dynamics and accounting methods to the domains of circular economy, renewable energy, material flow analysis and regional currency, aiming to contribute for sustainable regional developments.

1. Introduction

1.1 Problem Identification

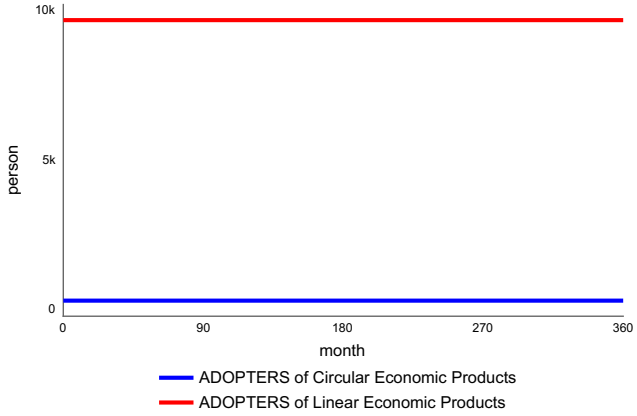
In order to satisfy increasing human needs in a conventional linear economy, where resources are extracted and consumed through a "take-make-waste" life cycle, non-renewable resources are consumed at ever growing speed while at the same time the environment is degraded by increasing waste output, faster than it can recover. The eventual consequence indicated by continuing this predominant lifestyle is clear – an overshoot and collapse – caused by an overconsumption of carrying capacity. Even though it is a relevant and significant issue for everyone and consumers' environmental consciousness has been growing gradually, a fundamental transition towards a circular economy still remains challenging due to technological, social and economic reasons.

Today's technology already allows however, some of the commercial products to be fully recycled through a closed loop supply chain. The problem is rather that, despite many technological and commercial effort, such products are often prone to low market penetration and fail to reach a critical mass before their business become self-sustaining. In order to investigate why and to gain an insight for policies aimed at a smoother diffusion, a hypothetical model case of polyester garment market is conceptualized by the author and analyzed, since textile industry is one of the most polluting industry, has several good real case examples and is largely affected by consumer choices.

1.2 Research Objective

The focus of the research is limited to investigate the hypothesis mentioned later which are thought to be important hurdles for diffusion of circular economic products in general. For simplicity, the model market is fixed in total size with 10,000 adopters and assumed to be consisting of 2 types of products; the conventional Linear Economic Product (LEP, polyester garment made from virgin resource such as crude oil and incinerated at the end of use) and the Circular Economic Product (CEP, polyester garment made from recycled polyester via closed loop supply chain). Fig. 1 shows the reference mode, the problematic behavior of stagnation of CEP adopters.

Fig. 1 Reference Mode



2. Hypothesis

(1) In purchasing decisions of polyester garments, consumers mainly focus on attributes such as price, compatibility, functionality and social acknowledgement of the products. Even though customer's environmental consciousness is growing, it is still not enough to override the main attributes of attractiveness mentioned above, as observed in the rapid development in the fast fashion industry.

(2) As with any product, the market growth of LEP and CEP are both enabled and constrained by reinforcing loops originating from economies of scale, learning curve and accumulation of social recognition such as trust in the product. Thus, the nature of the CEP diffusion process is path dependent, eliminating any accumulated effort below the tipping point.

(3) Compared to LEP, CEP bears a disadvantage of significantly higher fixed cost since it has to invest both in production and recycling capacity. This forces higher initial cost and unit price, higher risk and increased difficulty to adjust to changes of the demand.

(4) The current economy is functioning under bounded rationality. The standard accounting and economic system will be biased against investments to improve environmental performance because the costs of investment will be accounted for while its long term benefit will not be reflected to market prices. CEP has to invest heavily in reverse logistics, yet it is not for the improvement of the product itself, but for saving its natural resource consumption. As long as the current economic system treats such long term benefits as externality, the market will likely to fail to appreciate the full benefit of CEP. Since the consumption of natural resources can be physically measured, it indicates a need for a new indicator or means that capture material flow and resource effectiveness, in order to endogenize the origin of environmental impacts.

3. Model Description

In order to construct and analyze the behavior of the reference mode, a hypothetical market in a textile industry was conceptualized as a model case by the author. Fig. 3.1, Fig. 3.2 and Fig. 3.3 shows the Causal Loop Diagram and Stock Flow Diagram of the model case. The model was based on the assumptions and preconditions listed in points a) to f).

Fig. 3.1 Causal Loop Diagram of the model (base case)

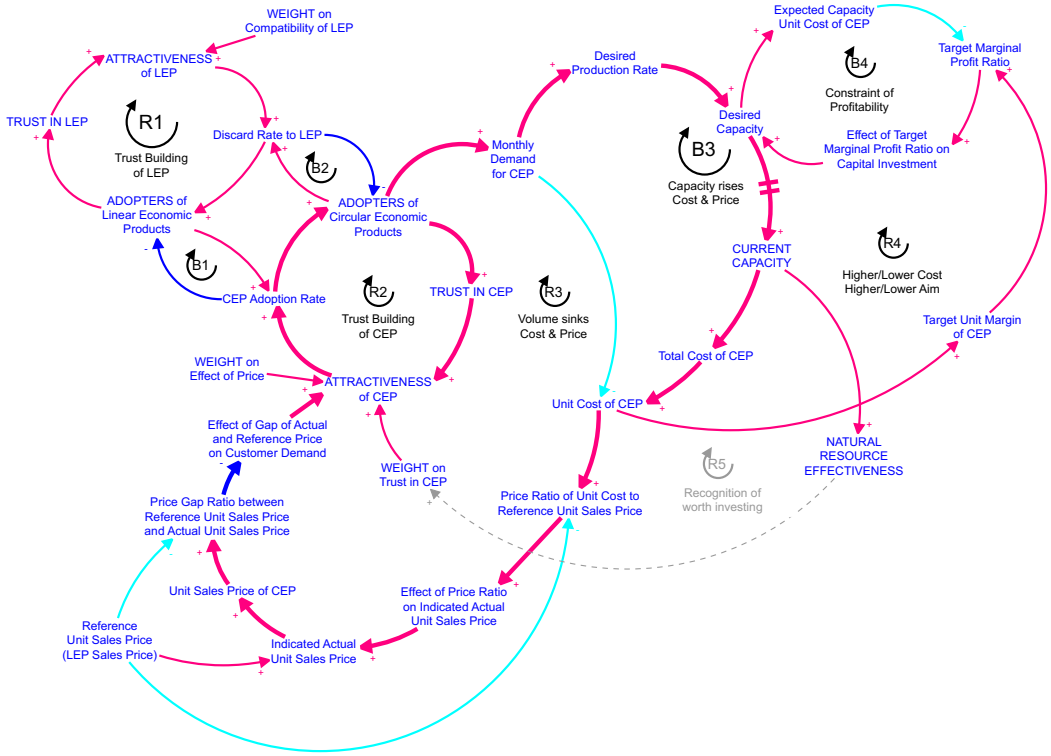


Fig. 3.2 Stock Flow Diagram (Consumer Sector)

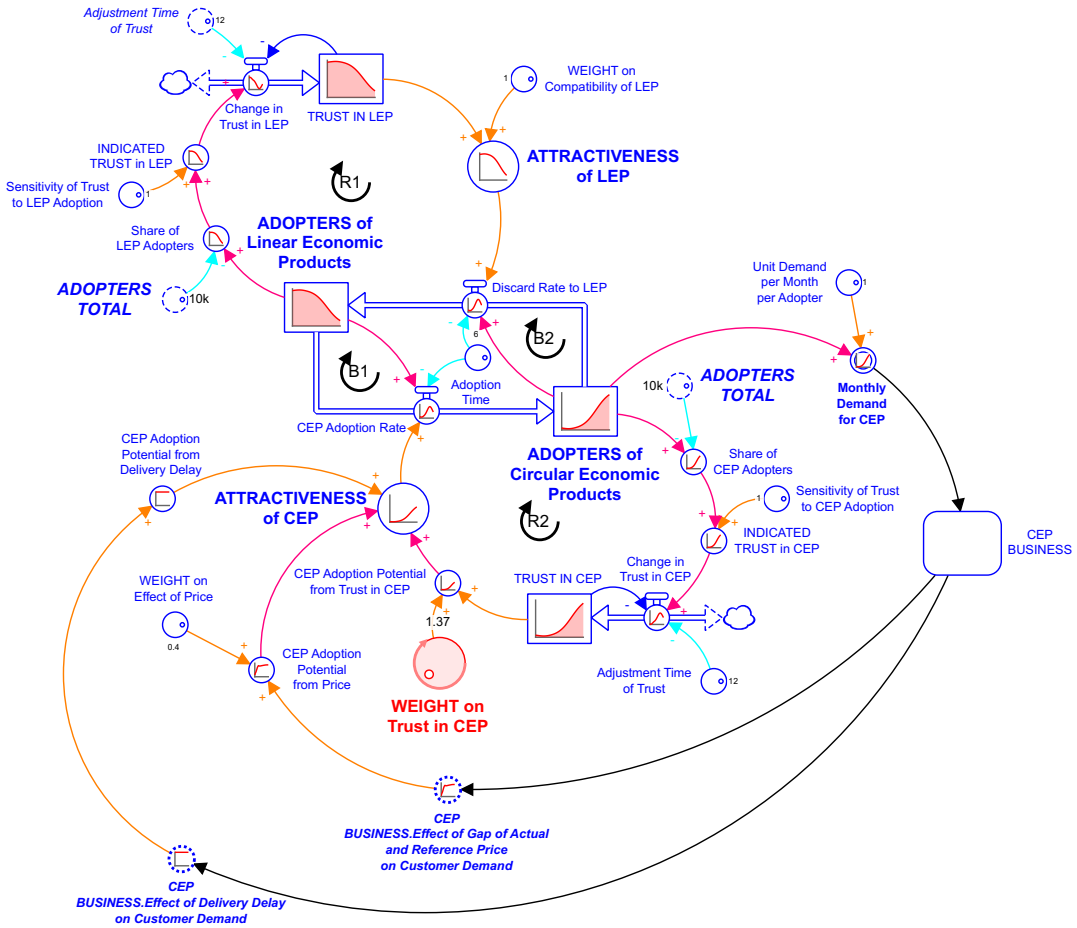
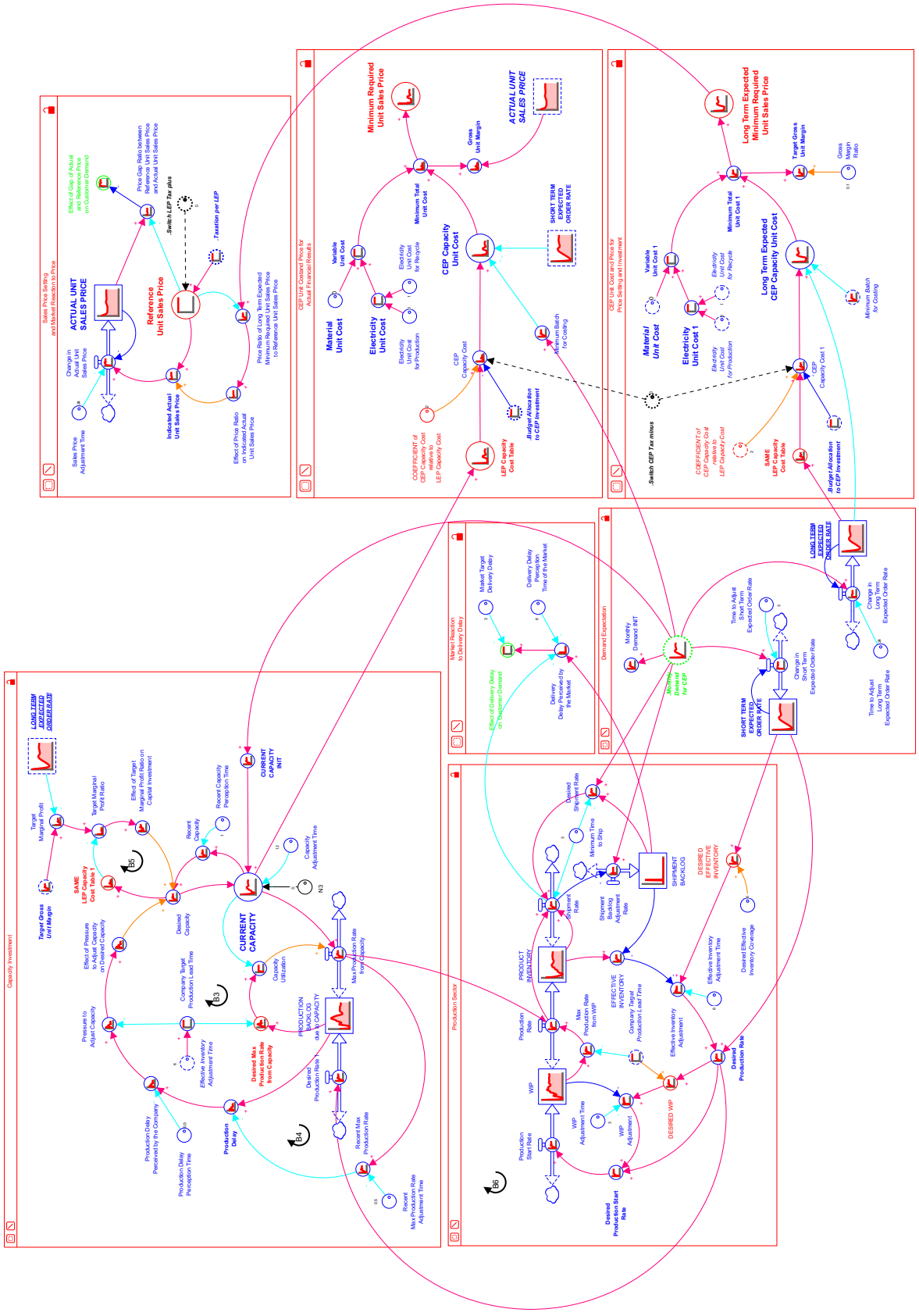


Fig. 3.3 Stock Flow Diagram (CEP BUSINESS Sector)



Assumptions and precondition used for the model case development are listed as below.

a) Market size and time horizon

A closed market with a fixed total size, consisting of polyester garment of two types of products, the Circular Economic Product (CEP) and the Linear Economic Product (LEP) is considered. There are 10000 adopters in total who purchase, use and repurchase the product. The average lifetime of the product is set to 12 month, and each adopter buys 1 garment every month. The time horizon is set to 360 months (30years).

b) Initial state of the system

At the initial stage, the market is dominated by LEP, holding the share of 95% of the total adopters. Therefore, there is already a large amount of capital installed in the conventional LEP industry, and therefore LEP has a strongest cost advantage with the sales price of €30/unit, which is used as a reference sales price in the model for the entire period of time. This state of the system is a result of path dependent development of the market growth. On the contrary, CEP industry is an emerging phenomena and has only very limited customer base and installed capacity. The scarcity of demand keeps the unit cost of CEP higher than LEP, hence also the sales price.

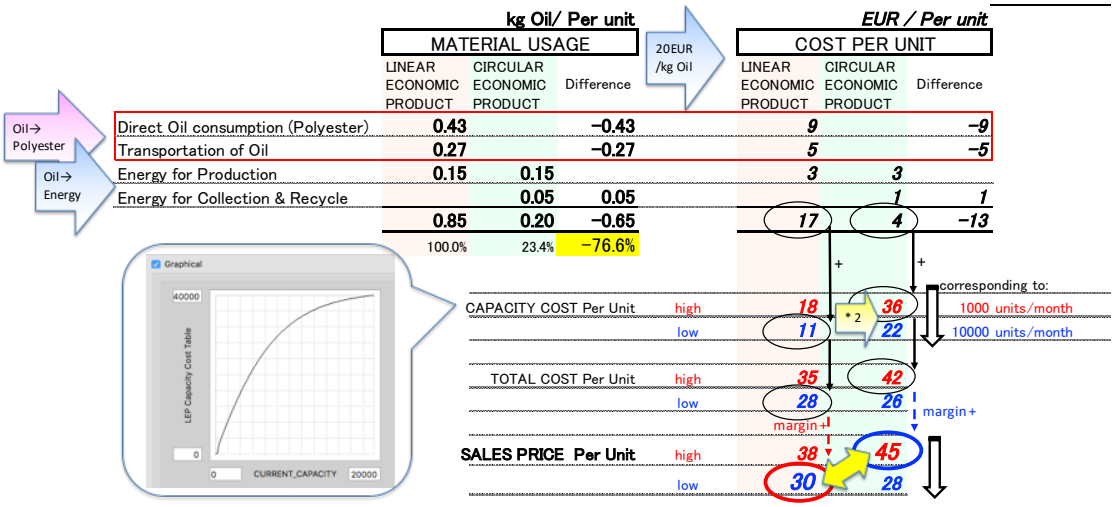
c) Reference Sales Price

The sales price of LEP is set to be constant at €30/unit. In the model, both customer and companies are assumed to anchor their decision making to that price. The supply and demand dynamics of LEP sales price is not included for simplicity. Such assumption can be justified by hypothesizing a second market where LEP can be easily replaced with another LEP garment product, e.g. by imports.

d) Cost Setting of LEP an CEP

The case of Patagonia's Common Threads Garment Recycling Program (Reference-1) was referred to in order to replicate a close-to-reality scenario. Reference-1 shows a Life Cycle Assessment (LCA) Data of CO2 emission (i.e. almost equivalent to Oil usage) of a standard LEP and CEP, highlighting that CEP is 77% more resource effective than LEP. This data was converted to data of material usage/unit. Adding an assumption that each kg of Oil consumption (material or energy) costs €20, the data for variable unit cost is derived. Variable unit cost is assumed to be constant, as it increases or decreases proportionally to the amount of units. On the other hand, fixed cost such as capacity cost is assumed to changes nonlinearly according to the production capacity, because of effect of economies of scale and learning curve. Since capacity cost cannot be derived from the LCA data, it is added with an assumed table function. Also, production capacity cost of CEP is assumed to be exactly twice as much as that of LEP, since CEP has to invest in the capital for collecting system through reverse logistics, in order to function as a closed loop supply chain. The overall data is summarized as Fig. 3.4.

Fig. 3.4 The Overview of Cost Setting



e) Key behaviors of Companies (CEP BUSINESS SECTOR)

Demand Estimation:

The company perceives demand from CEP adaptors purchasing and forms short term and long term expectation of demand. The former is utilized to initiate production, inventory adjustment process and calculation of financial results. The latter is utilized for price setting and investment decisions. This is due to the assumption of sales price which adjusts slowly, in order to avoid fluctuation and thereby affecting customer's choice negatively, and due to the nature of investment that it is made in projection of long term cost and benefit.

Production:

Production is constrained both by material supply and max production capacity. The company aims to keep 6 months of inventory coverage, assuming relative conservative attitude because of complexity of closed loop sully chain. However due to simplification, this material flow is not considered in the model and it is assumed that the company can obtain material for WIP as desired. The unfulfilled shipment order accumulates in the backlog, and will be shipped as soon as possible.

Investment:

First, the company bases the investment decision rule based on its production lead time, and it is initiated by the desired production rate. Second, the desired capacity is compared with the financial profitability and reduced when financially less profitable. The actual capacity develops with a significant delay of 12 months with a 3rd order delay, as often assumed in many business SD models. Near the range of maximum production rate, the capacity can be flexibly adjusted though capacity utilization.

Sales Price setting:

First, the company bases the pricing rule on the Long term Minimum Total Unit Cost, in order to secure the minimum cost. However, just as customers, the company recognizes the Reference Sales Price of €30/unit to be the standard acceptable price by the market and therefore anchors and adjusts gradually to that price, in order not to lose the customers.

f) Key behaviors of adopters

Purchasing decision:

It is assumed that the customer choose product by comparing the overall attractiveness of the product of LEP and CEP respectively. The attractiveness consists of trust in LEP and CEP (Intangible Stocks of social recognition that accumulate over time), price advantage and delivery delay. The sensitivity for each attribute is determined by the weight of the customer, which is assumed as follows in Fig. 3.5.

Fig. 3.5 The default state of the weight of attributes for product attractiveness:

Attributes	Weight on Attributes	assigned weight	weighted average (relative weight)	explanation
TRUST in LEP (Stock)	WEIGHT on Compatibility of LEP	1	29.4%	Same meaning as "TRUST in", since compatibility is one of the major factor of trustuing the conventional product.
TRUST in CEP (Stock)	WEIGHT on Trust in CEP	1	29.4%	Represents overall favorable social recognition, contributing to overriding of other attributes such as economical benefits.
Effect of Gap of Actual and Reference Price on Consumer Demand	WEIGHT on Effect of Price	0.4	11.8%	Normal value is 0, corresponding to Actual Sales Price of CEP = Reference Sales Price. It takes effect in summation with Attractiveness from Trust in CEP
Effect of Delivery Delay on Consumer Demand	WEIGHT on Delivery Delay	1	29.4%	Takes effect, only when thre is a delivery delay over 3 months, overriding instantaneously, therefore the weight is omitted in SFD.
		3.4	100.0%	

It is assumed that both weight on trust in LEP and CEP have same values, therefore representing that the customers potentially react to accumulated trust in each products equally, keeping the system in equilibrium. It is only the effect of price and delivery delay which kicks the system out of equilibrium. In the model, it is assumed that the effect of price takes effect independently, where as other attributes take effect simultaneously in multiplication. This is due to the assumption that the social trust building process and economic decision process develops independently, for example high price does not by itself diminish the trust built in CEP instantaneously.

Disposal or Returning:

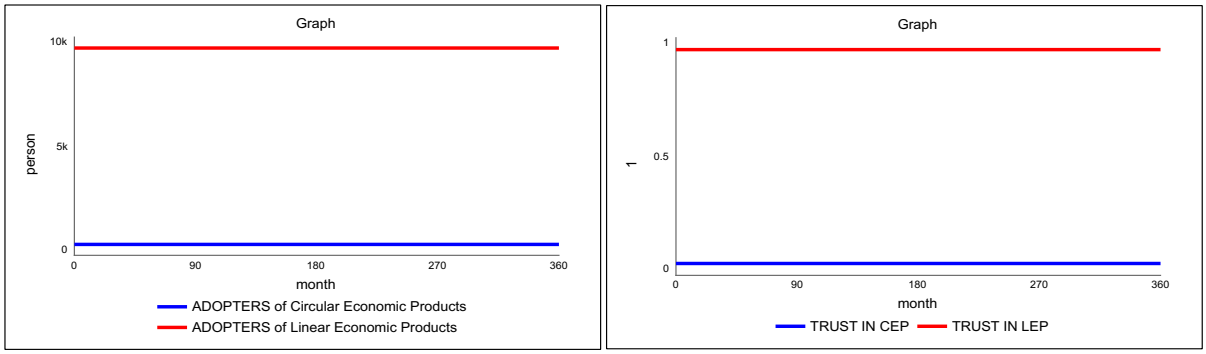
As if both LEP and CEP were rented products, customer are assumed to dispose of and repurchase products exactly 12 month after original purchase. This assumption is made to simplify the material flow and to focus on the analysis of diffusion of adopters and their trust.

4. Analysis

a) Tests of basic behavior

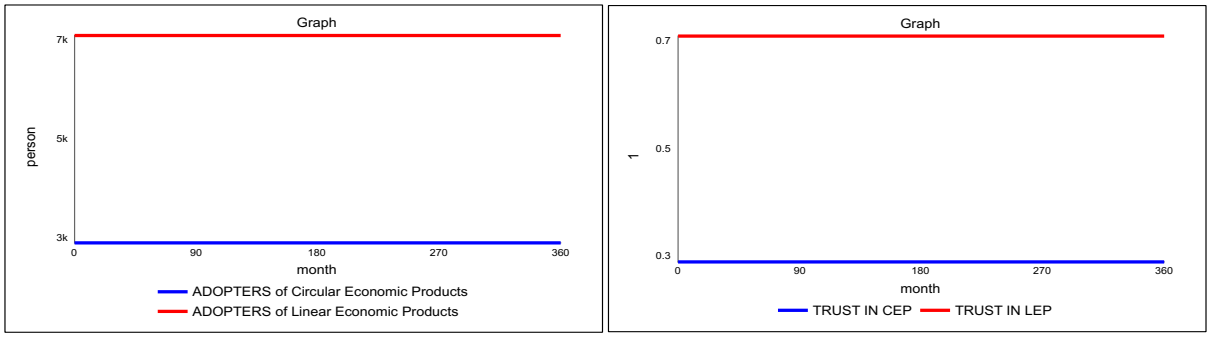
In order to test the basic behavior of the model, some tests are conducted.

Fig. 4.1 Test 1



- Equilibrium (weight variable as Figure 3.5)
- Activated switch: Switch Equilibrium, Initial CEP Adopters 500

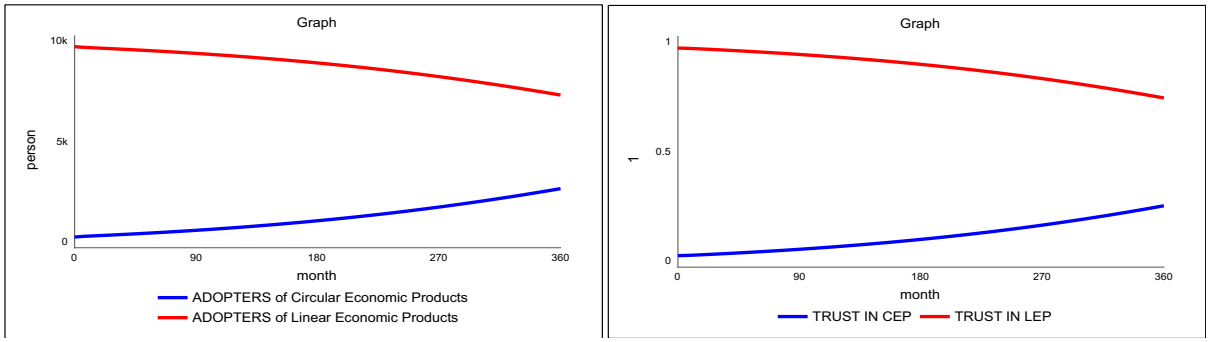
Fig. 4.2 Test 2



- Activated switch: Switch Equilibrium, Initial CEP Adopters 3000

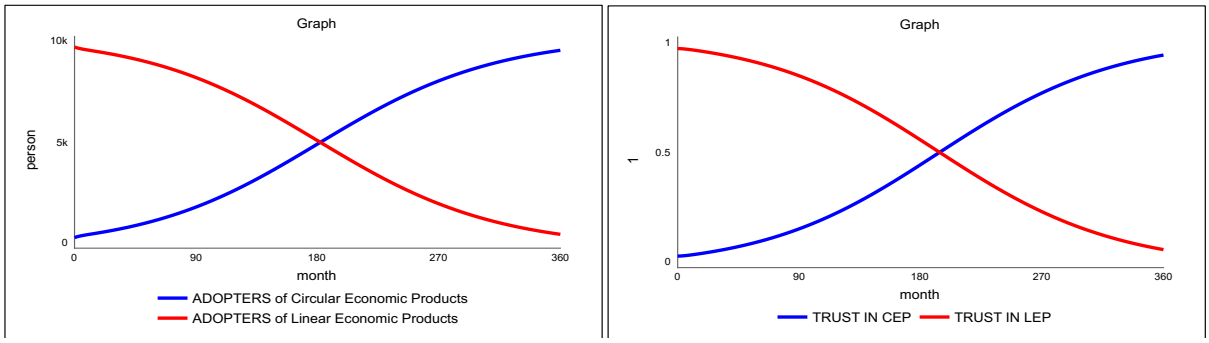
As the switch of effect of price and delivery delay are turned off, the model operate fully in equilibrium, since all weight variables are set to equal. The system keeps steady at the initial level of adopters and accumulated trust in customers. (Dominance of loop B1, B2 in CLD)

Fig. 4.3 Test 3



- Changing weight on Trust in CEP (weight variable as Figure 3.5 except Weight on Trust in CEP=1.1)
- Activated switch: none, Initial CEP Adopters 500

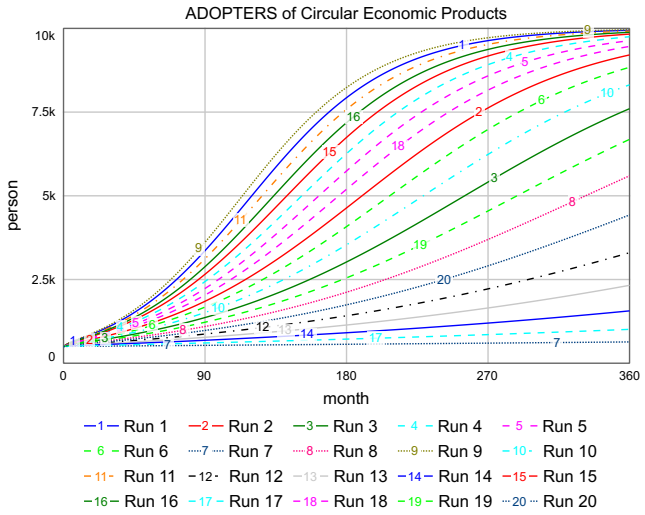
Fig. 4.4 Test 4



- Changing weight on Trust in CEP (weight variable as Figure 3.5 except Weight on Trust in CEP=1.3)
- Activated switch: none, Initial CEP Adopters 500

Now only the weight on Trust in CEP is increased by 10% to 30%. This leads to a steady S-shaped growth. As the sensitivity graph shows, without any effect of price and delivery delay, the system develops in a steady growth smoothly, which does not show a path dependent behavior. However, if we think about today's customers, the environmental concerns are growing. Which corresponds to this model setting. If so, the share of CEP adopters can be easily increased, with a steady behavior. Since this does not reflect the struggle of CEP Businesses to expand, this setting is rejected to replicate the reference mode.

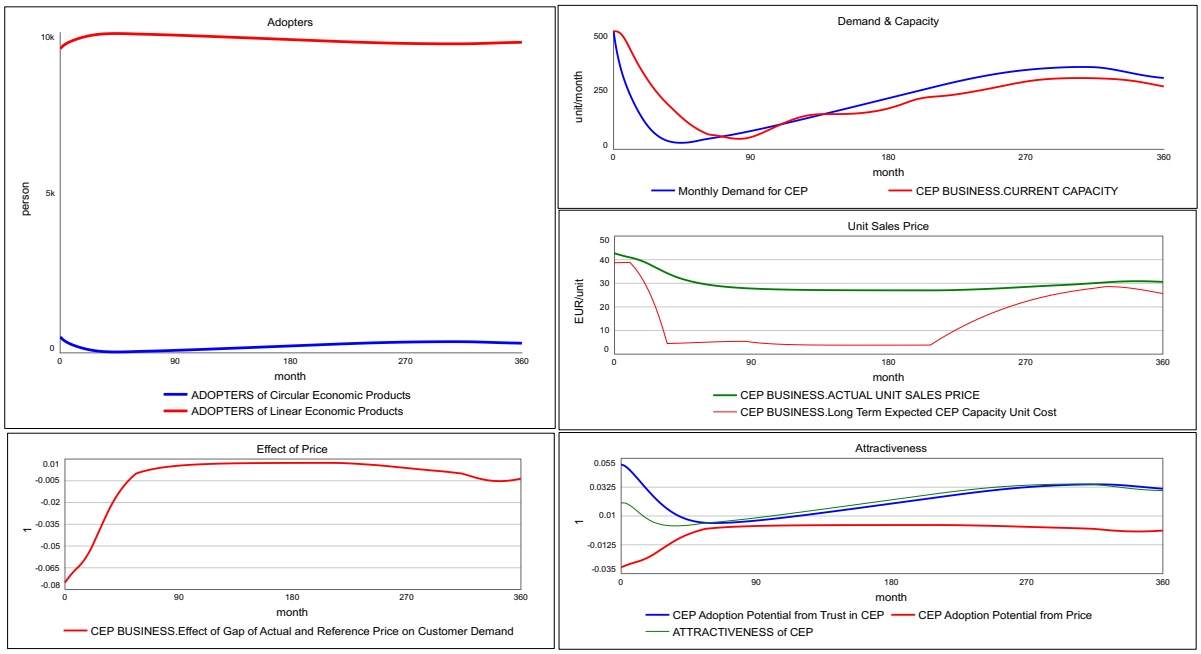
Fig. 4.5 Sensitivity Test by changing Weight on Trust in CEP between (1.0 to 1.5)



b) Base run (weight variable as Figure 3.5)

- Activated switch: Switch Effect of Delivery Delay on Consumer Demand
  Switch Effect of Gap of Actual and Reference Price on Customer Demand

Fig. 4.6 Behavior of key variables of Base Run



The upper left side of the graph(Adopters) shows a similar problematic behavior as reference mode, however, a slight oscillation is observed. This can be reasonably explained by the graph Attractiveness, Demand & Capacity and Unit Sales Price.

First, the initial demand of CEP starts from as the initial CEP adopters are set to be 500. The production capacity is initialized to that monthly demand, hence the high unit capacity cost, and unit sales price (€42.7/unit) is higher than the reference sales price (€30/unit). This price gap leads to a negative reaction by the customer, since they anchor their acceptable price to the reference price, therefore demand decreases until month 43. As the demand decreases, the company loses its reason to hold production capacity, so they adjust to the decreasing demand, with a large delay. (Loop B3 in CLD)

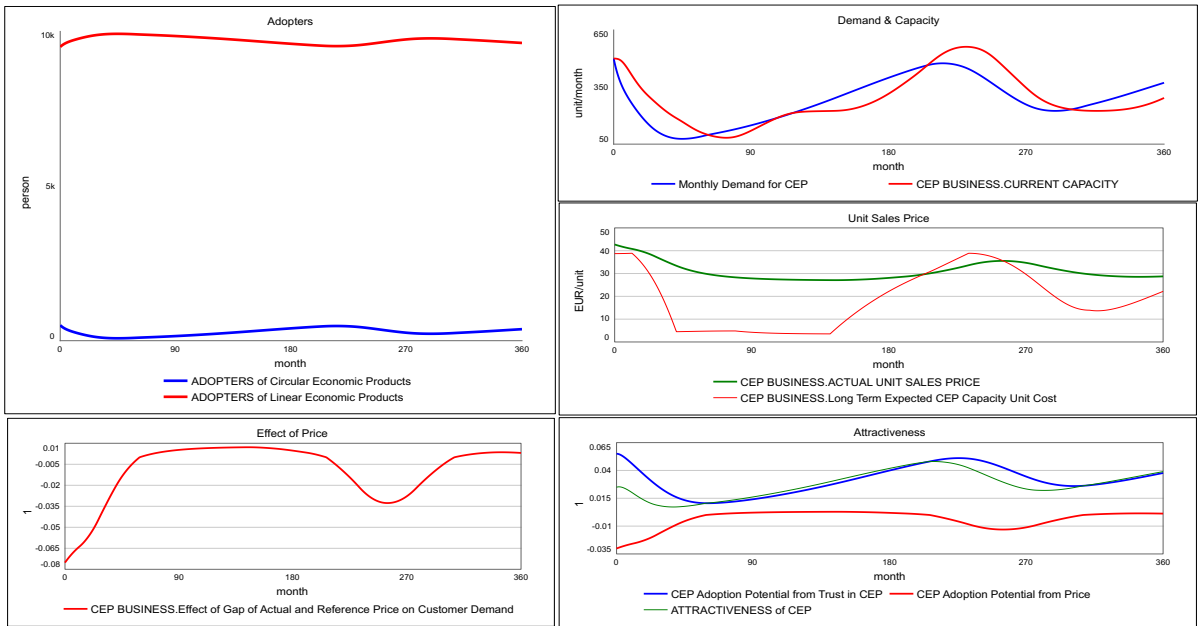
As the capacity decreases, so does the unit capacity cost and the sales price gradually adjusts to the reference sales price (€30/unit) by month 51. However at that point, since there is almost no demand and capacity, the cost of sales is so low that the company can set their price lower than €30/unit, so the sales price gradually undershoots that line and stabilizes at around €27/unit. A slight negative gap to the reference sales price brings some customers back from the LEP adopters pool, thereby gradually accumulating the Trust in CEP and thus the Attractiveness of CEP.

At month 207, the demand reaches a certain threshold that the company initiates to build up production capacity in order to meet demand. As it does, the capacity increases with a large delay, therefore the unit capacity cost increases, eventually leading to the sales price to over shoot €30/unit. Again this leads to a negative reaction by the customer, and the process is repeated.

c) Scenario 1 (weight variable as Figure 3.5 except Weight on Trust in CEP=1.1)

- Activated switch: Switch Effect of Delivery Delay on Consumer Demand
  Switch Effect of Gap of Actual and Reference Price on Customer Demand

Fig. 4.7 Behavior of key variables of Scenario 1

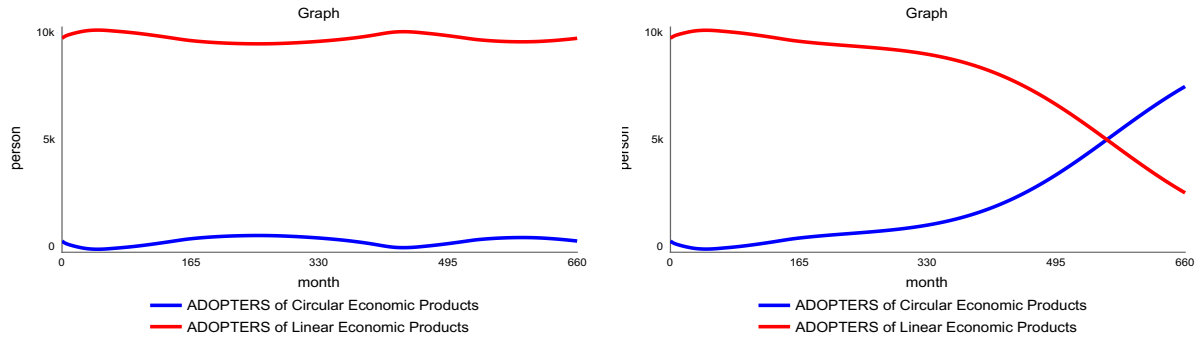


Now the weight on Trust in CEP is increased by 10%. This reflects the hypothesized situation where customer's environmental consciousness is rising, therefore possessing higher weight on Trust in CEP, than weight on Trust in LEP or weight on compatibility. Even so, the adopter's share struggles to grow. In comparison with the base run, the oscillatory behavior is more evident.

d) Scenario 2(weight variable as Figure 3.5 except Weight on Trust in CEP=1.19 and 1.2)

- Activated switch: Switch Effect of Delivery Delay on Consumer Demand
  Switch Effect of Gap of Actual and Reference Price on Customer Demand

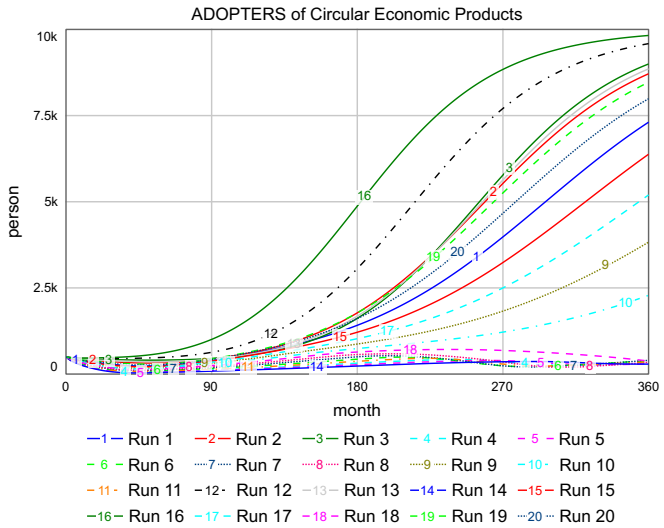
Fig. 4.8 Behavior of adopters of Scenario 2



Increasing the weight on Trust in CEP by 19% and by 20%, and extending the time horizon reveals the path dependent nature of the structure. The graph below shows that the system resists CEP to diffuse in the market until the threshold where the weight on Trust in CEP is increased by 20%, and even so the diffusion takes place extremely slowly. If we for example aim to create a circular economy within 2050, this will be too slow for hedging the resource depletion risk.

A sensitivity analysis by changing the weight on trust in CEP shows an uneven distribution of CEP demand, suggesting a strong dominance of reinforcing loops over the system, strictly separating scenarios below or above the tipping point.

Fig. 4.9 Sensitivity Test of Base Run by changing Weight on Trust in CEP between (1.0 to 1.5)



As briefly discussed, the system resists the diffusion of CEP until the weight on Trust in CEP increases by 19%(Run18). In order to achieve 90% diffusion within the 30 years, the weight on Trust in CEP must increase by 44%(Run3). Although Trust building is a highly important process since it has the power to override the effect of price and tips the market by changing the regime of the system, by shifting the loop dominance (B3 to R2, R3), it is a challenging task and there has to be a supplementary policy to increase the odds of success. Moreover, if CEP had the same cost requirements as LEP (higher material cost, much lower capacity cost), the diffusion above the tipping point would be quicker and the oscillation below the tipping point would be less amplified. A comparison between Fig. 4.9 and 4.10 shows that CEP is destined to bear a disadvantage of cost structure from the beginning, as hypothesized.

Fig. 4.10 Sensitivity Test under the precondition that CEP with same cost requirements as LEP

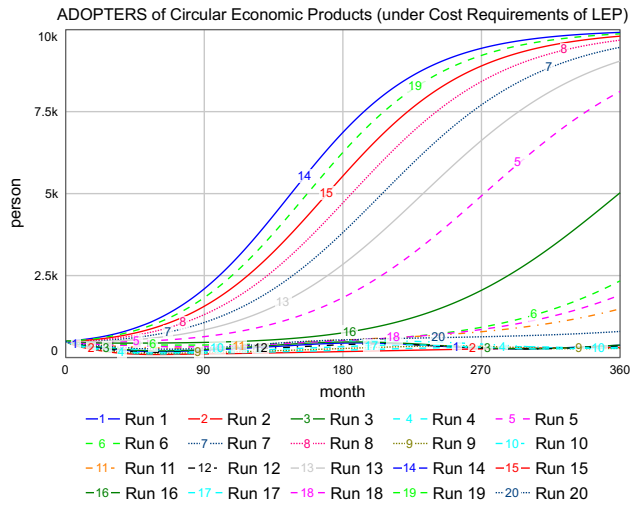


Fig. 4.9 shows that, below the tipping point, the system is locked in a certain threshold of limit cycle where customer reacts instantaneously to high sales price, and the company reacts to the increasing demand by building up the capacity with a significant delay. The capacity building cannot stop at the right point where the sales price can meet the reference price, but rather overshoots, since the capacity building decision had been already initiated too much in the past. Hence the price overshoots the reference price, and again leads to too high price to the customers. This can be summarized as a combination of bounded rationality caused by 2 signals, price and demand, where customer reacts to price variation in short term and the company reacts to demand with delay. Even this is a result of a rational decision by each actor in the system, it creates a fluctuation in the system, absorbing the effort and chance for CEP Businesses to grow. Since this underlying structure explains the hypothesized resistance of diffusion and bounded rationality caused by the interaction of customers and companies, in alignment to higher weight on Trust in CEP, Scenario 2 is adopted as the reference case replicating the problematic behavior.

This leads to 2 key important insights for policy strategy.

(1) Need to increase the weight on Trust in CEP within the customers
However, only increasing the weight does not reduce the path dependence, as analyzed above. The customer could have possibly higher weight on Trust in CEP, however it is not enough to change the loop dominance from B3 to R2 and R3. It can be assumed that the link between increased circularity by CEP and its effect to customer's weight on CEP is cut or extremely week.(CLD Loop R5). In other words, if that link could be strengthened, the possibility to increase weight on Trust in CEP can grow steadily over time.

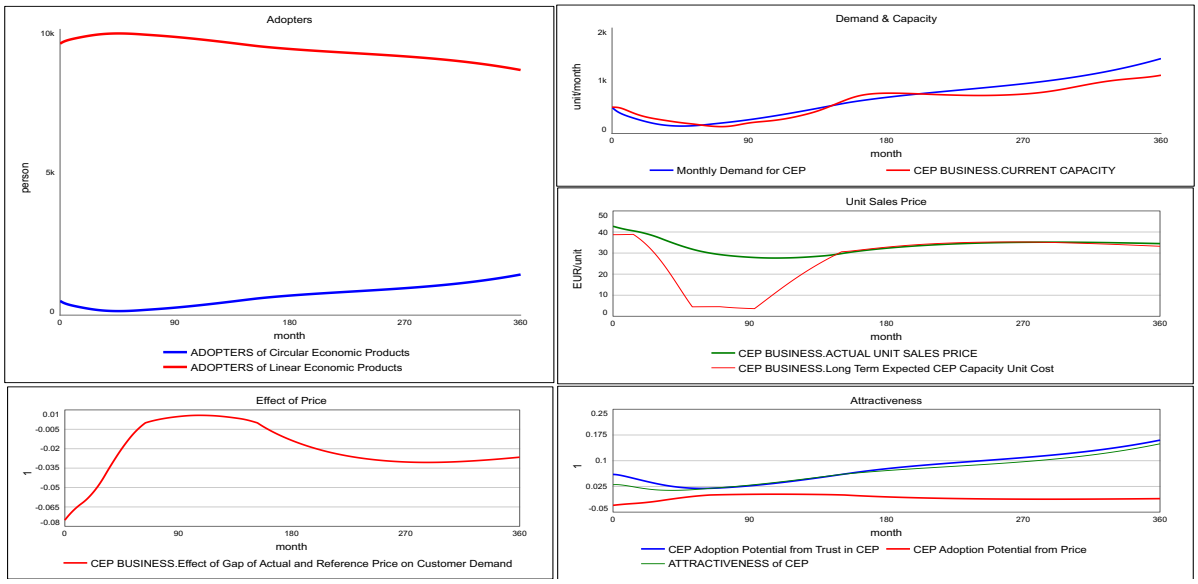
(2) Need to alleviate the path dependent nature of the economic market system
The system is locked in a situation where any effort of increasing the weight on Trust in CEP by below +20% does not count at all. This "Either Or" situation significantly reduces the chance of diffusion, since little effort and results cannot accumulate in the system. There should be some measure to cancel out or alleviating the path dependence, so that the above effort can steadily accumulate over time.

5. Policy Options Analysis

5.1 Policy 1: Trust Building

Education, increase of information transparency by disclosing resource effectiveness of the product on the price tag and data disclosure from the producers and municipality is suggested, in order to raise customers' weight on Trust in CEP. Fig. 5.1 shows a case of an increased weight by 20%.

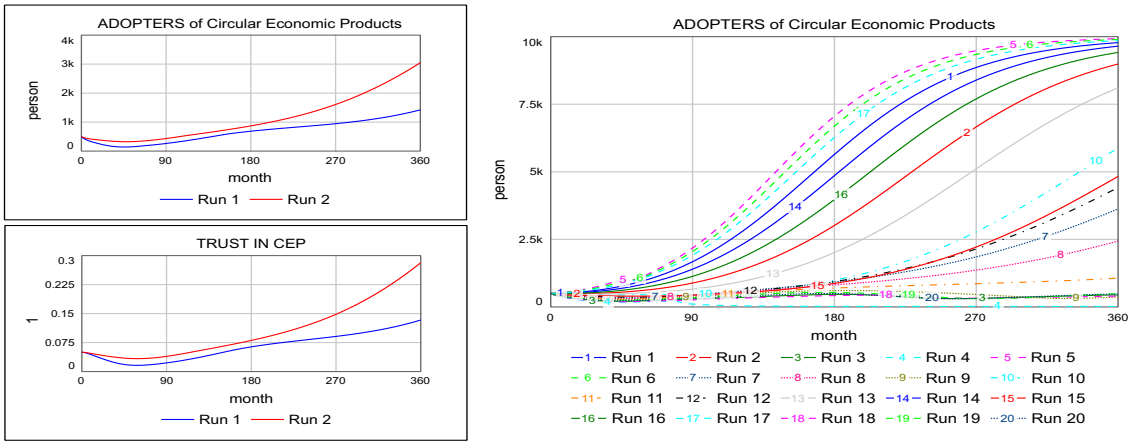
Fig. 5.1 Behavior of key variables of Policy 1



5.2 Policy 2: Constant subsidy for CEP

One of the reason for high cost of CEP was the high initial capacity cost. If so, one could consider to assist the investment of CEP companies by allocating budget by municipality. The below policy shows a simulation result of municipality allocation €20000/month for CEP companies, in comparison with above trust building policy. Such policy does increase the odds of diffusion, however, as the sensitivity test shows, the path dependence remains. Furthermore, the fairness issue remains. What is the rational that the municipality pays, for how much, to which specific investment of CEP companies?

Fig. 5.2 Behavior of key variables of Policy 2



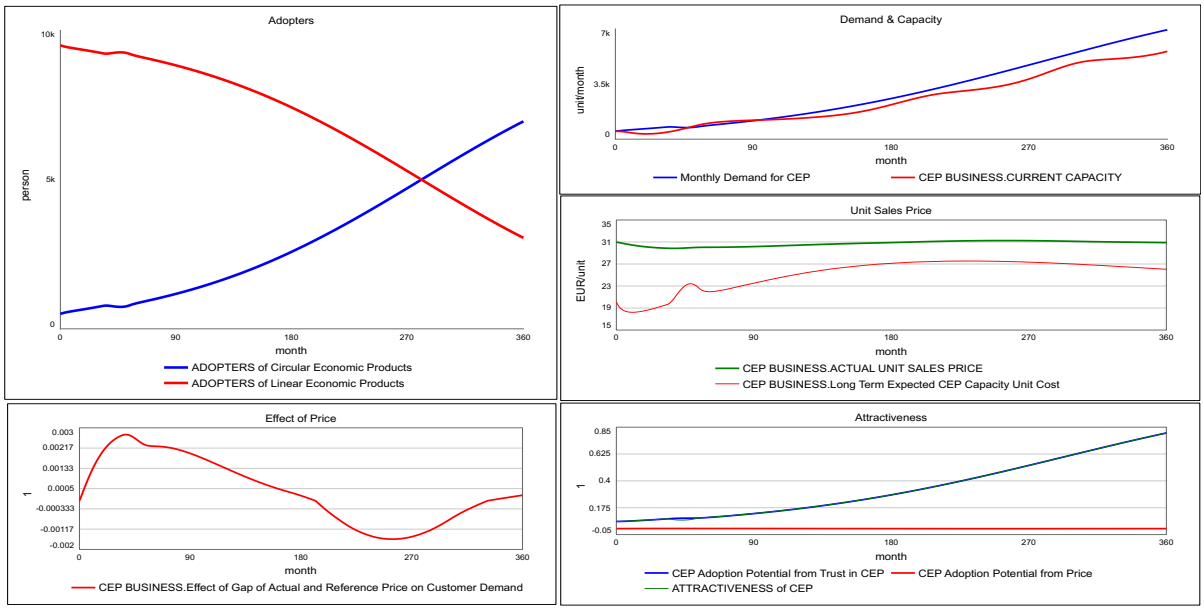
5.3 Policy 3: Pinpoint taxation to LEP

Next, a direct taxation to LEP is considered. If they are the less resource efficient than CEP, it is rational that the products as LEP should be taxed, in order to help shift towards a circular economy. A direct taxation to LEP also increases the reference price, which customers and CEP business sector both anchor their decision on. Although it reduces the effect of price on CEP demand slightly, although a major impact was not observed.

5.4 Policy 4: Budget allocation from LEP to CEP

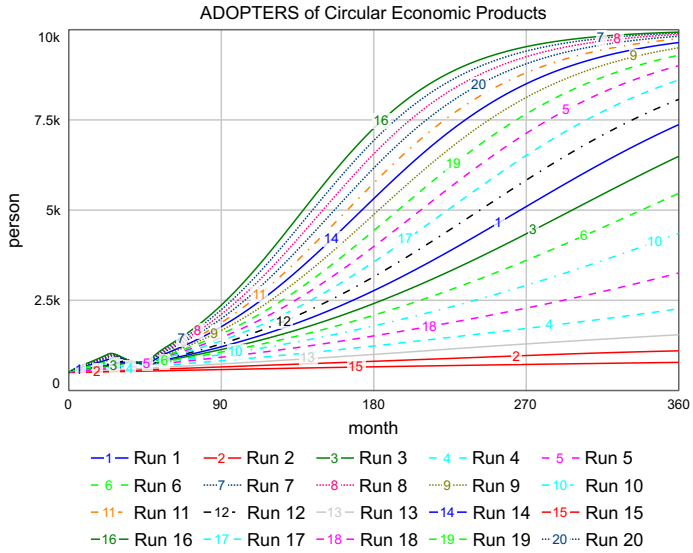
Finally, allocation for CEP's investment, in such a way that aligns with CEP's diffusion is considered. Path dependence arise from dominance of reinforce feedback loops. In order to increase stability, there is a need to install a balancing loop which exactly counteracts the development of the system. Therefore, as the combination policies of mentioned above, it is considered to introduce a direct taxation to LEP, and at the same time allocating the budget earned to CEP investments. The rational is backed by the LCA data, with the basic idea of taxing the consumption of natural resources. Since it is a pure allocation, no extra budget at municipalities are needed.

Fig. 5.3 Behavior of key variables of Policy 4



It is observed to be effective, especially stabilizing the unit sales price over time. The sensitivity test in Fig. 5.4 also shows that this policy is effective to reduce the path dependence. It makes originally sense that introducing a factor to counteract the development of path dependent system helps to slow down the development of reinforcing loops, and therefore helps for smoother transition. This increases the odds of success of diffusion, by making the system able to reflect the effort of transition directly.

Fig. 5.4 Sensitivity Test of Policy 4 by changing Weight on Trust in CEP between (1.0 to 1.5)

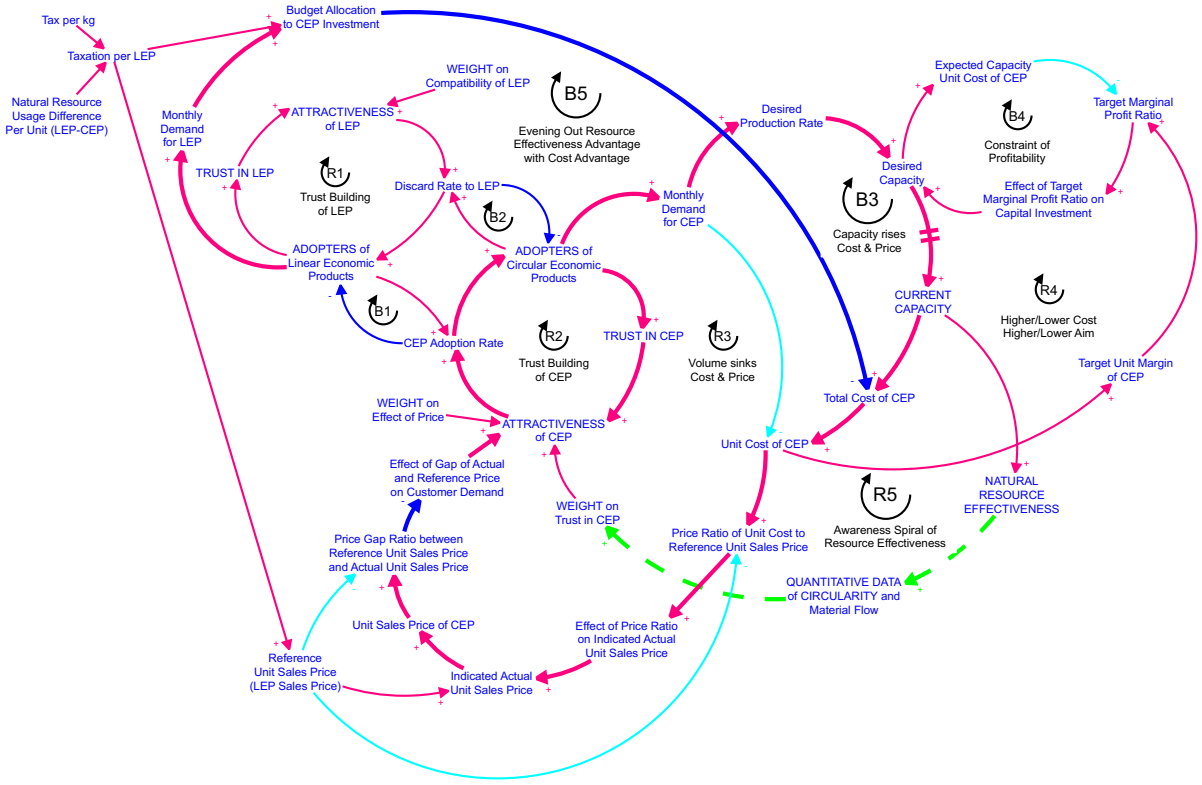


5.5 Discussion of Implications of Policy Options Analysis

H. Lehmann et al. (Factor X, 2018) points out that market prices are wrong due to discounted externalities, and economic instruments should be deployed to facilitate a shift away from overheads on labor and towards taxing raw materials. Nevertheless, it is physically possible to measure resource consumption of LEP and CEP quantitatively. Fig. 5.4 demonstrates a policy where per kg crude oil consumption is taxed and redistributed to the less consuming product (balancing loop B5 in Fig. 5.5). It shows that such policies based on so called “material added tax” could function as a powerful balancing loop that allows to address a fundamental problem of path dependence of the market. This is due to a simple reason that – the more LEP remains, the more budget for CEP remains – in such a way that the budget for CEP automatically adjusts with the degree of diffusion of CEP through the market. This taxation and allocation is a simple, yet a dynamic policy, that essentially offsets the environmental advantage of CEP with the economic advantage of LEP. If in place, compared to a static subsidy policy, it is more robust since the balancing effect reduces path dependence. The challenge might be rather in a process where different stakeholders have to agree to that policy. It can be reasonably assumed that a substantial number of LEP businesses will oppose to the implementation of that policy, in an attempt to diminish any risk for their financial performance.

Even though in that case, the simulation model provides a clear explanation why a dynamic policy to endogenize the environmental advantage of CEP is needed. It provides an effective way to communicate and thus help the understanding among different stakeholders, how the hurdle of the diffusion process lies within its path dependence, and how introducing a balancing loop plays an important role to reduce path dependence. Furthermore, by improving the overall information system, material flows could be used as a dynamic monitoring process, and if it succeeds to rise the awareness of trust in CEP, a positive loop could also reinforce the trust building process (Loop R5).

Fig. 5.5 Causal Loop Diagram of suggested policy case



6. Limitation

In this model, the physical stock and flow structure of the closed loop supply chain, the dynamics of LEP price and adopters disaggregation were intentionally omitted for simplicity. Further, this simulation model is based on several strong assumptions. Customers are assumed to give their product back, exactly one year after purchasing CEP. Production is only constrained by production capacity, never from materials. In other words, one of the most important factor of the closed loop supply chain where material input can be constrained by the customer's reverse flow, is not included in the feedback structure. Therefore the model almost functions as same as that of a linear economic product.

One of the crucial problem in closed loop supply chain lies within the interrelationships of several suppliers as well as uncertainties of the timing of product returns from customers. A random reverse material flow from the customers could cause instabilities to the system and is therefore challenging to manage. These aspects are omitted in the model in order to focus on the bounded rationalities based on price. For further research, it can be suggested to expand the material flow sector in order to reflect the main findings in this project, and identify whether the policy recommendation can be still valid under the closed loop supply chain material flow.

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