AN ECOLOGICAL STOCK-FLOW-FUND MODELLING FRAMEWORK

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PKSG Annual Workshop, 29 May 2015

AIM OF THE PAPER

- An important limitation of **post-Keynesian macroeconomic** analyses is that they almost totally ignore the ecological constraints of macroeconomic activity.
- At the same time, **ecological economics** lacks the solid macroeconomic framework of post-Keynesian macroeconomics.
- Therefore, the **synthesis** of these two fields is essential for an integrated analysis of macroeconomic, financial and ecological issues.
- **Ecological macroeconomics** is a new interdisciplinary field that largely draws on the synthesis of ecological economics and post-Keynesian macroeconomics (Harris, 2009; Jackson, 2011; Rezai et al., 2013; Jackson et al., 2014; Fontana and Sawyer, 2013, 2015).

AIM OF THE PAPER

- Recent research has contributed to the development of the **building blocks** of **ecological macroeconomics**.
- Victor and Rosenbluth (2007), Victor (2012) and Barker et al. (2012) have presented **large-scale models** with Keynesian features that take into account the energy sector and various environmental issues.
- Jackson (2011), Fontana and Sawyer (2013), Rezai et al. (2013) and Taylor and Foley (2014) have put forward certain frameworks that combine **ecological with Keynesian (or post-Keynesian) insights**.
- Godin (2012), Jackson et al. (2014), Berg et al. (2015), Naqvi (2015) and Fontana and Sawyer (2015) have examined environmental problems within stock-flow consistent or monetary circuit models that include a **financial sector**.

AIM OF THE PAPER

- However, in the literature there is still a lack of an integrated framework that combines **physical stocks, flows and funds** with **monetary stocks and flows** in a consistent way.
- The development of such a consistent framework is important for the joint analysis of **ecological issues** (such as the degradation of ecosystem services and the depletion of natural resources), **financial issues** (such as financial fragility and the financing of green investment) and **macroeconomic issues** (such as growth and unemployment).
- This paper puts forward an **ecological stock-flow-fund (ESFF)** modelling framework that provides such an integrated analytical platform.

STRUCTURE OF THE PRESENTATION

1. Main features of the ESFF framework
2. Matrices
3. Stock-flow-fund channels
4. Conclusion

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1. **Main features of the ESFF framework**
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1. MAIN FEATURES OF THE ESFF FRAMEWORK

Feature 1: The ESFF framework takes explicitly into account the accounting principles and the laws of thermodynamics.

- Drawing on the recent stock-flow consistent post-Keynesian literature (Godley and Lavoie, 2007), the ESFF framework depicts the monetary flows (e.g. interest, profits, wages) via a **transactions flow matrix** and the monetary stocks (e.g. loans, deposits, equities) via a **balance sheet matrix.**
- The use of balance sheet and transactions matrices ensures that the accounting principles are explicitly considered: **monetary inflows=monetary outflows**, **financial assets=financial liabilities**.
- The integration of accounting into dynamic macro modelling permits the detailed exploration of the links between the **real and the financial spheres of the macroeconomy** and illuminates the non-neutral role of money and finance.

1. MAIN FEATURES OF THE ESFF FRAMEWORK

Feature 1: The ESFF framework takes explicitly into account the accounting principles and the laws of thermodynamics.

- Drawing on the tradition of Georgescu-Roegen (1971) and the literature on physical input-output tables (see e.g. Giljum and Hubacek, 2009), the physical flows (energy, matter, waste) are captured by a **physical input-output-fund matrix** and the physical stocks are presented via a **physical stock matrix**.
- These matrices ensure that the **First Law of Thermodynamics** is satisfied. According to this law, matter and energy cannot be created or destroyed.
- These matrices also allow us to consider the **Second Law of Thermodynamics** which implies that macroeconomic activity has a tendency to increase the entropy (i.e. disorder) in the ecosystem.
- Importantly, the energy and matter inflows and outflows are measured in **mass** (tonnes) or **energetic units** (tonnes of oil equivalent).

1. MAIN FEATURES OF THE ESFF FRAMEWORK

Feature 2: The ESFF framework pays particular attention to the distinction between stock-flow resources and fund-service resources.

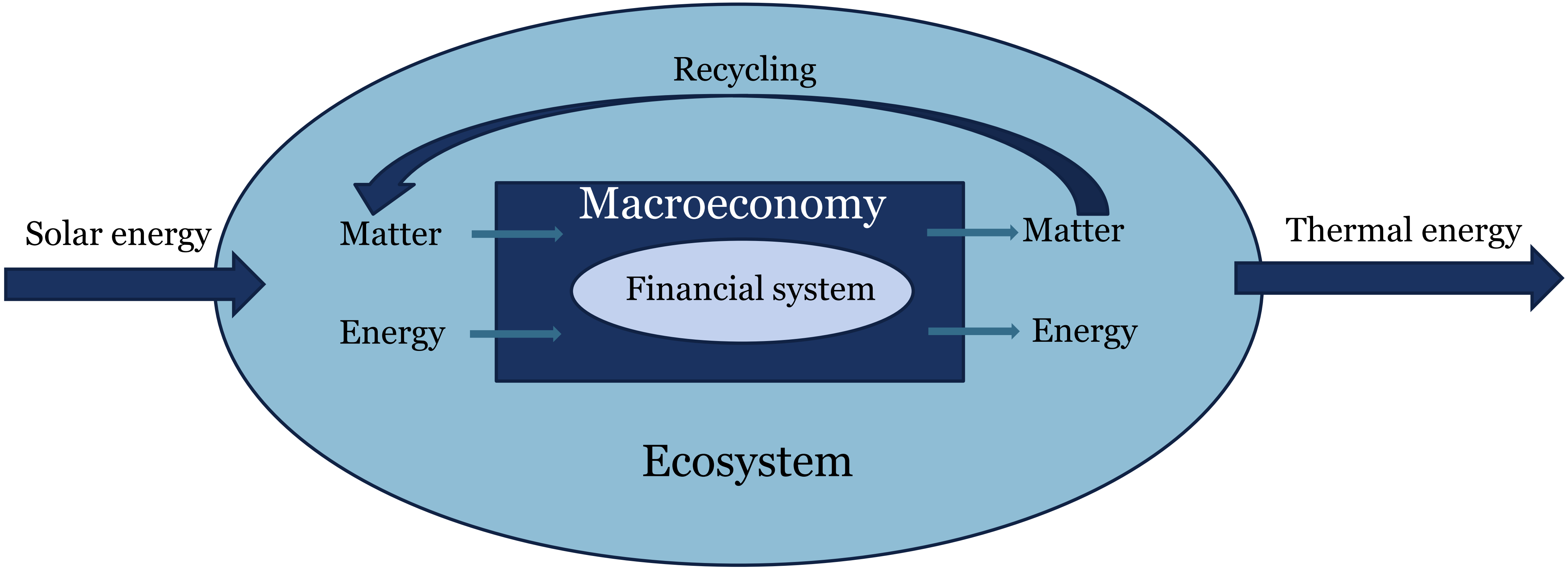
- Georgescu-Roegen (1971) makes a crucial distinction between the stock-flow resources and the fund-service resources (see also Mayumi, 2001 and Daly and Farley, 2011).
- **Stock-flow resources** (e.g. fossil fuels, minerals) refer to the energy and matter which are the necessary inflows in the production process and are transformed into the desired products or waste. These resources are not taken into account in the traditional production functions.
- **Fund-service resources** (e.g. labour, capital) refer to the services provided during the production process. These resources are not transformed during the production process.

1. MAIN FEATURES OF THE ESFF FRAMEWORK

Feature 3: The ESFF framework allows an explicit analysis of the various stock-flow-fund channels through which the stability of the ecosystem, the financial system and the macroeconomy are interconnected.

- The stock-flow-fund channels are analysed by formulating the macroeconomy as an open subsystem of the closed ecosystem.
- The financial system is part of the macroeconomy.

1. MAIN FEATURES OF THE ESFF FRAMEWORK



STRUCTURE OF THE PRESENTATION

1. Main features of the ESFF framework
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2. MATRICES

- The ESFF modelling framework relies on four matrices:
  1) The physical input-output-fund matrix (it presents the physical flows)
  2) The physical stock matrix (it presents the physical stocks)
  3) The transactions flow matrix (it presents the monetary flows)
  4) The balance sheet matrix (it presents the monetary stocks)

2. MATRICES

- The ESFF modelling framework will be presented by postulating **a highly simplified structure of the economic processes**.
- Firms make **conventional** and **green investment** by using retained profits, loans and equities.
- Firms produce goods by using **useful matter and useful (renewable and non-renewable) energy** from the ecosystem, which have been previously transformed into a controlled form.
- Firms **recycle** a part of their waste which is then used as an additional inflow in the production of goods.

2. MATRICES

- In line with the post-Keynesian tradition, the **production of goods is equal to their demand** (consumption plus investment). However, this happens only when there are no supply constraints due to the unavailability of **useful matter, useful energy, labour and capital**.
- If these constraints arise, the production is supply-constrained. We have explicitly considered this by postulating a **Leontief-type production function**.

2. MATRICES

- We consider the following physical processes:

(1) **Production of controlled matter**: This is the process through which the useful matter that is in the ground (this could be, for example, silver, manganese or iron ore) is extracted and transformed in order to be used as an inflow in the production of goods.

(2) **Production of controlled energy**: This process creates energy that can be used as an inflow in all economic processes. The energy is supplied either from renewable resources (e.g. solar, wind) or non-renewable resources (e.g. oil, gas, coal).

(3) **Production of goods**: This process produces goods for consumption and investment purposes using controlled energy, controlled matter and recycled matter.

(4) **Recycling**: This process produces recycled matter using recyclable matter, controlled energy and controlled matter.

2. MATRICES

Physical input-output-fund matrix

1st Law of Thermodynamics: inputs=outputs

Output / Input	Intermediate output: Controlled matter	Intermediate output: Controlled energy	Intermediate output: Goods	Intermediate output: Recycled matter	Final output	**Total output**
Controlled matter			x_{13}	x_{14}		TO_1
Controlled energy	x_{21}	x_{22}	x_{23}	x_{24}		TO_2
Material goods					x_f	TO_3
Recycled matter			x_{43}			TO_4
Natural resources						
Useful matter	m_1					
Useful energy		e_2				
Renewable energy		er_2				
Non-renewable energy		en_2				
Use of residuals						
Recyclable matter				r_4		
Supply of residuals						
Recyclable matter	$-w_1$		$-w_3$			
Emissions to nature						
Dissipated matter	$-s_1$	$-s_2$	$-s_3$	$-s_4$		
Harmful matter	$-sh_1$	$-sh_2$	$-sh_3$	$-sh_4$		
Non-harmful matter	$-sn_1$	$-sn_2$	$-sn_3$	$-sn_4$		
Dissipated energy	$-d_1$	$-d_2$	$-d_3$	$-d_4$		
Total input	TI_1	TI_2	TI_3	TI_4		
Funds:						
Labour	L_1	L_2	L_3	L_4		
Capital	UK_1	UK_2	UK_3	UK_4		

2nd Law of Thermodynamics: Economic processes transform a part of useful energy and matter into dissipated energy and matter that are characterised by high entropy

2. MATRICES

- The processes in the matrix are characterised by **technical coefficients** that capture efficiency. We have **three types of efficiency**:

  1) Resource efficiency: It captures the relationship between inputs and outputs. The lower the inputs relative to outputs the higher the efficiency.

  2) Recycling efficiency: It captures the relationship between recyclable matter and total output. The higher the recyclable matter relative to total output the higher the efficiency.

  3) Pollution efficiency: It captures the relationship between harmful matter (e.g. greenhouse gas emissions) and total output. The lower the harmful matter relative to total output the higher the efficiency.

- **Green investment** affects all these types of efficiency.

2. MATRICES

Physical stock matrix

	Useful matter	Non-renewable energy	Harmful matter	Material goods
Opening stock	M_{U-1}	E_{N-1}	M_{H-1}	M_{G-1}
Additions to stock				
Discoveries of new stock	$+DISC_M$	$+DISC_E$		
Emissions to nature			$+sh$	
Production of goods				$+x_f$
Reductions to stock				
Extraction	$-m_1$	$-e_2$		
Natural dissipation			$-ND$	
Destructions due to natural disasters				$-DES$
Closing stock	M_U	E_N	M_H	M_G

$\Delta M_U = DISC_M - m_1$ $\Delta E_N = DISC_E - e_2$ $\Delta M_H = sh - ND$ $\Delta M_G = x_f - DES$

2. MATRICES

Transactions flow matrix

Inflows=outflows

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	$-C$	$+C$				0
Conventional investment		$+I_C$	$-I_C$			0
Green investment		$+I_G$	$-I_G$			0
Wages	$+wL_{-1}$	$-wL_{-1}$				0
Firms' profits	$+DP$	$-TP$	$+RP$			0
Commercial banks' profits	$+BP$			$-BP$		0
Interest on deposits	$+i_D D_{-1}$			$-i_D D_{-1}$		0
Desctruction of conventional capital		$-DES_C$	$+DES_C$			0
Desctruction of green capital		$-DES_G$	$+DES_G$			0
Interest on conventional loans		$-i_C LC_{-1}$		$+i_C LC_{-1}$		0
Interest on green loans		$-i_G LG_{-1}$		$+i_G LG_{-1}$		0
Δdeposits	$-\Delta D$				$+\Delta D$	0
Δequities	$-p_e \Delta e$		$+p_e \Delta e$			0
Δconventional loans			$+\Delta LC$		$-\Delta LC$	0
Δgreen loans			$+\Delta LG$		$-\Delta LG$	0
Total	0	0	0	0	0	0

Banks provide green loans after imposing credit rationing

Budget constraint

2. MATRICES

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Conventional capital		$+K_C$		$+K_C$
Green capital		$+K_G$		$+K_G$
Durable consumption goods	$+DC$			$+DC$
Deposits	$+D$		$-D$	0
Equities	$+p_e e$	$-p_e e$		0
Conventional loans		$-LC$	$+LC$	0
Green loans		$-LG$	$+LG$	0
Total (net worth)	$+V_H$	$+V_F$	0	$K_C + K_G + DC$

2. MATRICES

How do the matrices interact? Some examples

Physical input-output fund matrix

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Total input	TI_1	TI_2	TI_3	TI_4		
Funds:						
Labour	L_1	L_2	L_3	L_4		
Capital	UK_1	UK_2	UK_3	UK_4		

Production increases harmful matter

Higher aggregate demand leads to higher use of useful energy and matter

More green loans improve technical coefficients

Transactions flow matrix

	Households	Firms: Current	Firms: Capital	Commercial banks: Current	Commercial banks: Capital	Total
Consumption	$-C$	$+C$				0
Conventional investment		$+I_C$	$-I_C$			0
Green investment		$+I_G$	$-I_G$			0
Wages	$+wL_{-1}$	$-wL_{-1}$				0
Firms' profits	$+DP$	$-TP$	$+RP$			0
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Interest on green loans		$-i_G LG_{-1}$		$+i_G LG_{-1}$		0
Δdeposits	$-\Delta D$				$+\Delta D$	0
Δequities	$-p_e \Delta e$		$+p_e \Delta e$			0
Δconventional loans			$+\Delta LC$		$-\Delta LC$	0
Δgreen loans			$+\Delta LG$		$-\Delta LG$	0
Total	0	0	0	0	0	0

Physical stock matrix

	Useful matter	Non-renewable energy	Harmful matter	Material goods
Opening stock	M_{U-1}	E_{N-1}	M_{H-1}	M_{G-1}
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Reductions to stock				
Extraction	$-m_1$	$-e_2$		
Natural dissipation			$-ND$	
Destructions due to natural disasters				$-DES$
Closing stock	M_U	E_N	M_H	M_G

The reduction in the stock of useful energy and matter may impose supply-side constraints on consumption and investment

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Conventional capital		$+K_C$		$+K_C$
Green capital		$+K_G$		$+K_G$
Durable consumption goods	$+DC$			$+DC$
Deposits	$+D$		$-D$	0
Equities	$+p_e e$	$-p_e e$		0
Conventional loans		$-LC$	$+LC$	0
Green loans		$-LG$	$+LG$	0
Total (net worth)	$+V_H$	$+V_F$	0	$K_C + K_G + DC$

More green loans increase the stock of loans

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3. STOCK-FLOW-FUND CHANNELS

- In order to capture environmental problems we have defined three flow-stock/stock-stock ratios:

1. **Energy depletion ratio**: $dep_E = e_2 / E_N$

   where e_2 is the extraction useful energy flow and E_N is the remaining stock.

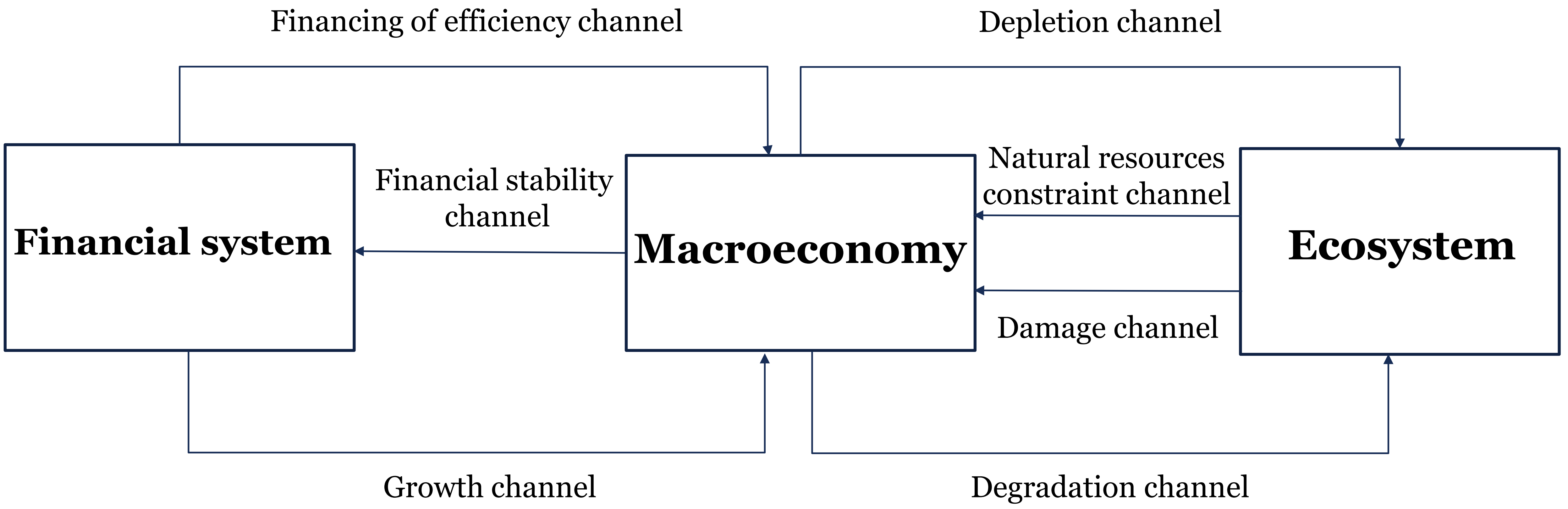
2. **Matter depletion ratio**: $dep_M = m_1 / M_U$

   where m_1 is the extraction flow of useful matter and M_U is the remaining stock.

3. **Degradation ratio**: $\deg = M_H / M_T$

   where M_H is the closing stock of harmful matter and M_T is a threshold beyond which extreme environmental events can happen.

3. STOCK-FLOW-FUND CHANNELS



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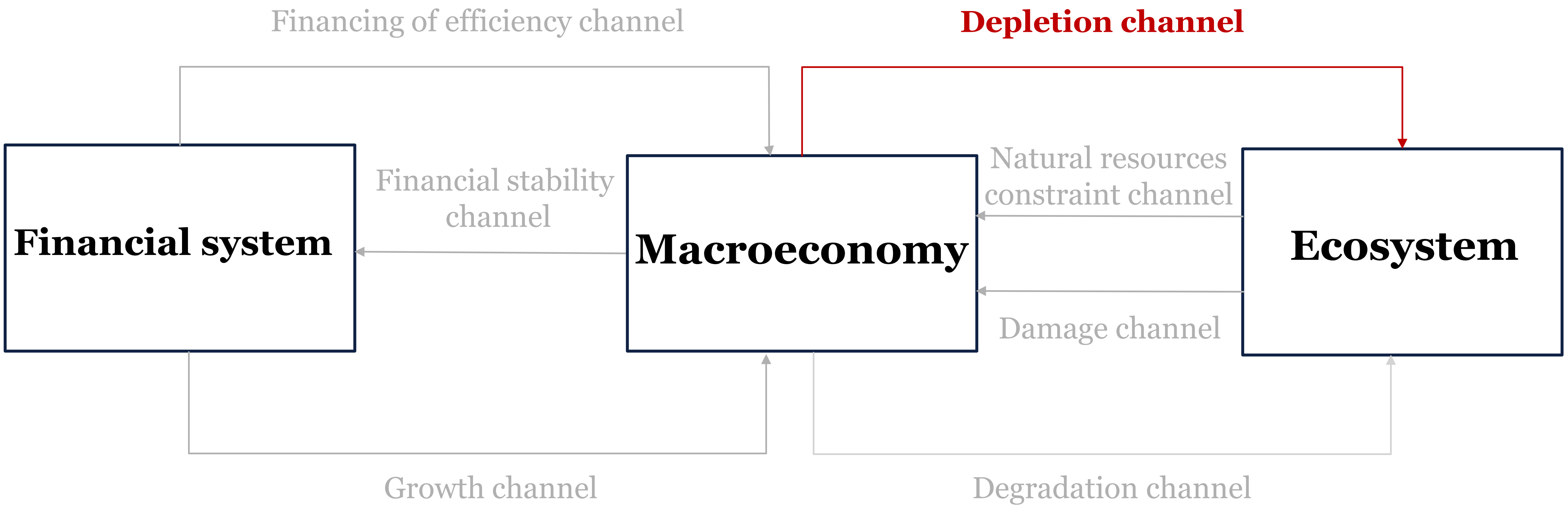

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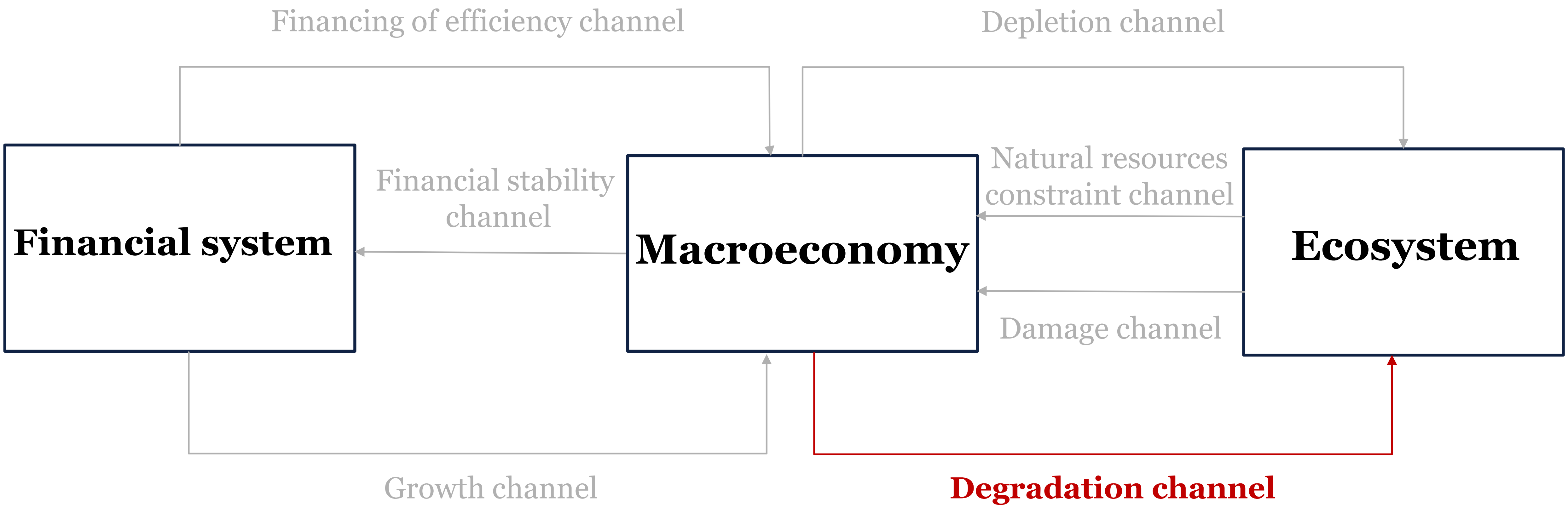

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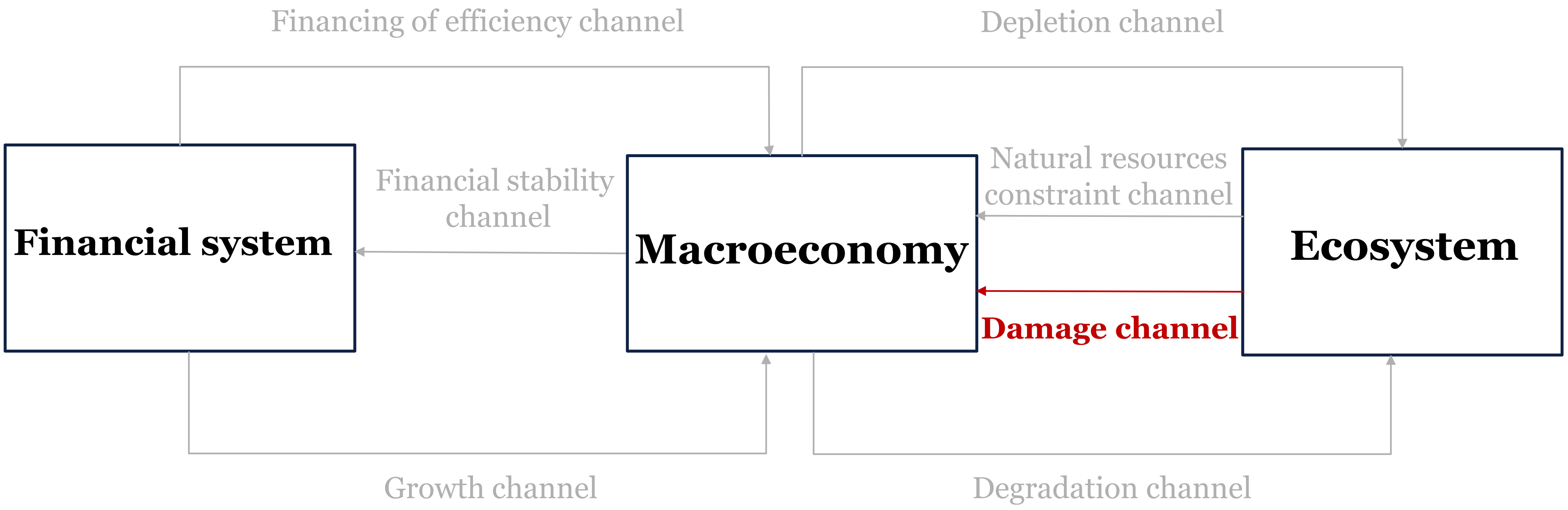

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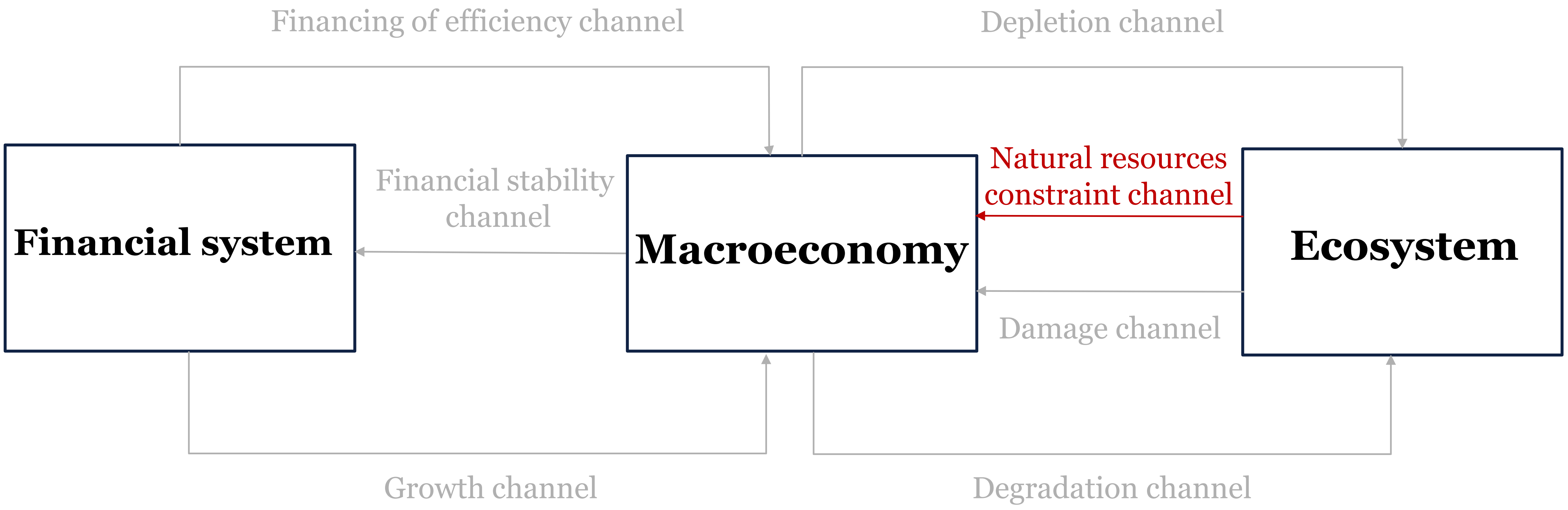

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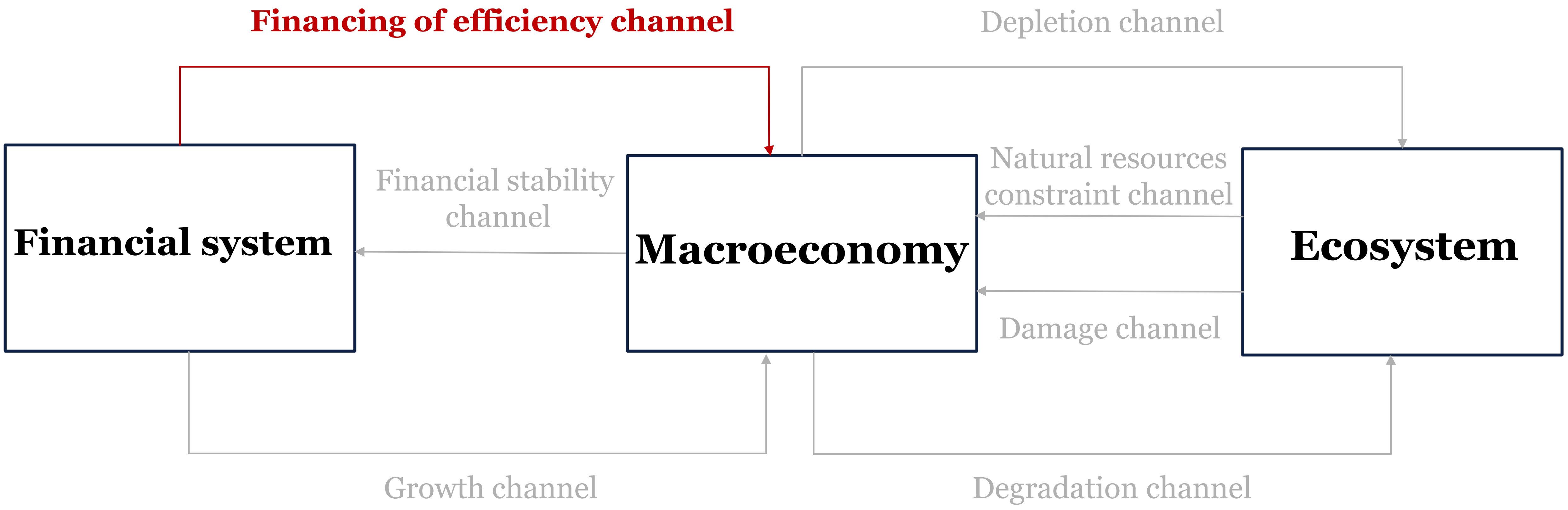

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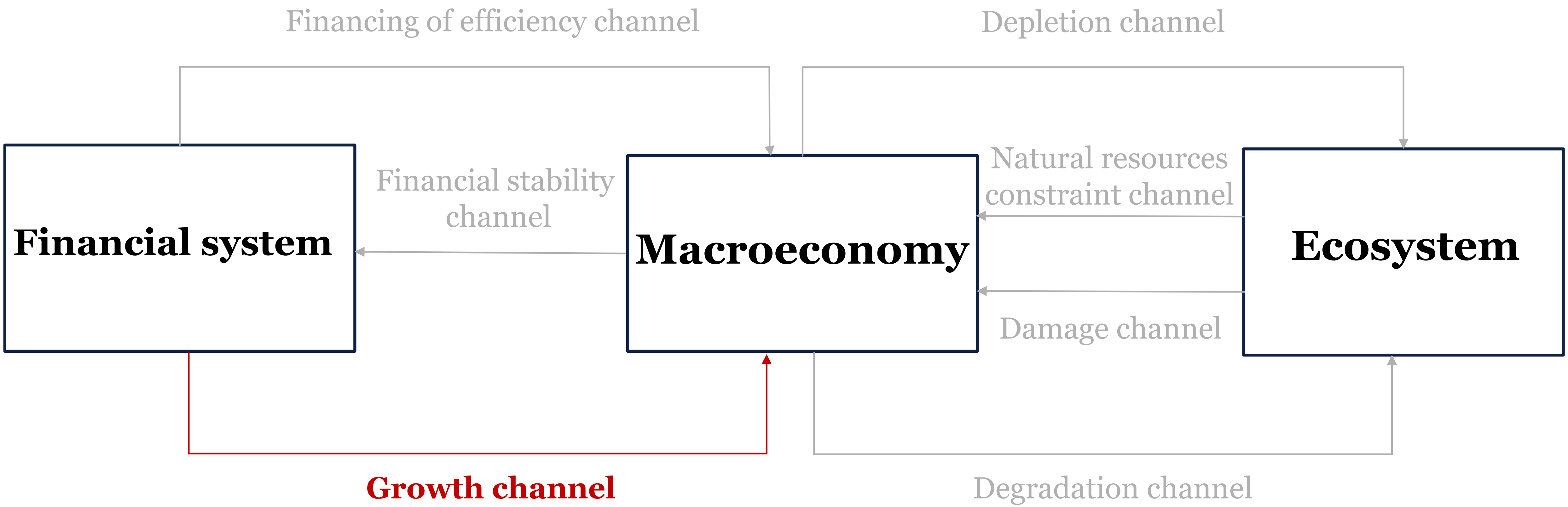

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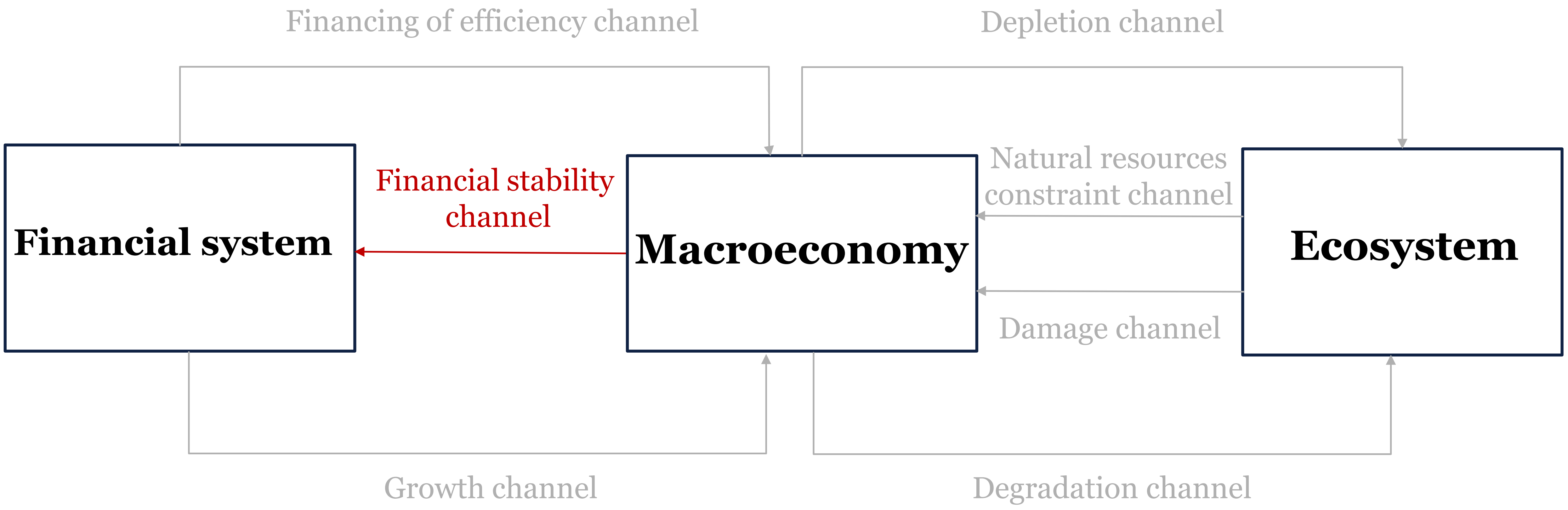

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4. CONCLUSION

- The paper puts forward an ESFF modelling framework that integrates the post-Keynesian **SFC modelling approach** with the **physical input-output** accounting framework.
- The modelling framework provides a coherent analysis of the monetary and physical stocks and flows using the **accounting principles** and the **laws of thermodynamics**.
- Moreover, it pays particular attention to the distinction between **stock-flow resources** and **fund-service resources**, it combines the post-Keynesian emphasis on the role of aggregate demand with ecosystem supply-side constraints and incorporates the non-neutral role of finance in the analysis of macroeconomic and ecological issues.
- The high flexibility of the ESFF framework allows it to be used for various types of academic and policy analyses in the field of **ecological macroeconomics**