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Think Again: Higher Elasticity of Substitution Increases Economic Resilience

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Summary
This paper shows that, counter-intuitively, a higher elasticity of substitution in model production function can lead to reduced economic resilience and larger vulnerability to shocks in production factor prices. This result is due to the fact that assuming a higher elasticity of substitution requires a recalibration of the production function parameters to keep the model initial state unchanged. This result has consequences for economic analysis, e.g., on the economic vulnerability to climate change.

Keywords: Substitution, Calibration, Constant Elasticity of Substitution, Shock

JEL Classification: D24, E17, E23

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Think again: higher elasticity of substitution increases economic resilience*

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1 Introduction

To cope with exogenous shocks, it seems obvious that flexibility, often measured by the elasticity of substitution, is crucial. Indeed, when facing an increase in commodity price or a decrease in a sector productivity, a more flexible economy with a higher elasticity of substitution will be more able to substitute alternative productions or supplies, thereby mitigating the consequence of the shock.

This paper questions this intuition, when different sets of elasticity values are used in the same model to compute the effect of a shock. In the simple model presented in this paper, using an illustrative production structure, calculations even lead to opposite results: a higher elasticity of substitution can cause a higher reduction in production in response to a price or productivity shock. The reason behind this result is that all function parameters have to be calibrated to fit with observed economic conditions. When one assumes a higher elasticity of substitution, *ceteris paribus*, it is necessary to change the parameters of production functions to keep the equilibrium situation unchanged (Klump and Saam, 2008). The point is that, while the direct effect of the elasticity increase is to enhance resilience and reduce the total cost of a shock, the indirect effect through parameter changes is to decrease

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resilience and increase the total cost. Over all, the latter effect often exceeds the former, and the total effect of an increase in elasticity of substitution is to reduce resilience and increase the vulnerability to supply-side shocks.

2 Model

We consider an economy with two sectors. The first sector produces an intermediate goods that is used by the second sector, which produces a final consumption goods. For instance, the first sector can be the infrastructure sector that produces the services used by the rest of the economy (e.g., electricity, water, transportation services).

The first sector uses a borrowed amount capital K, with constant return to scale to produce the intermediate good M that is sold at price p. The price of the capita K is supposed to be fixed and equal to r. The intermediate good market is supposed to be competitive.

The production function of the first sector is:

$$M = \beta K. \tag{1}$$

The condition of null profit and market clearing leads to the equality:

$$pM = rK, \tag{2}$$

and the equilibrium price is given by:

$$p = \frac{r}{\beta}. \tag{3}$$

The second sector is composed of n identical firms, producing an output Y considered as the numeraire, which is sold at a fixed price set to 1. Production is assumed to be made with two inputs: the intermediate good M that is bought at the price p; and labor L that is provided with inelastic supply $\bar{L}$ at the equilibrium price w.

At symmetric equilibrium on the labor market, all firms use $\hat{L} = \bar{L}/n$ units of goods L. The firms are price takers on all the markets. The production of final goods is integrally useed by the workers and the capital owners.

The production function of the second sector is a Constant Elasticity of Substitution (CES) function (Arrow et al., 1961), with an elasticity of substitution $\sigma = \frac{1}{1-\rho}$:

$$Y(M, L) = (\lambda M^\rho + \mu L^\rho)^{1/\rho}. \tag{4}$$

If $\rho = 1$, we have $\sigma = +\infty$ and the production function is linear with perfect substitution; if $\rho \to -\infty$, we have $\sigma = 0$, and the production function is given by a Leontieff production function, with fixed factors and no substitution. If $\rho \to 0$, we have $\sigma = 1$ and the function is a Cobb-Douglas:

$$Y(M, L) = \gamma M^{\lambda} L^{1-\lambda}. \tag{5}$$

Firm profits are given by:

$$\Pi = Y(M, L) - wL - pM. \tag{6}$$

Firm profit maximization, with equilibrium on the market of L gives the first order condition:

$$\frac{\partial Y}{\partial M}(M, \hat{L}) = p. \tag{7}$$

This determines the value M^*, the total consumption of goods M by all firms:

$$M^* = \bar{L} \left(\frac{\mu}{\left(\frac{p}{\lambda}\right)^{\frac{\rho}{1-\rho}} - \lambda} \right)^{1/\rho}. \tag{8}$$

The quantity of borrowed capital is K^*:

$$K^* = \frac{M^*}{\beta}. \tag{9}$$

Total production at equilibrium is Y^*:

$$Y^* \;=\; \bar{L} \left(\frac{\lambda\mu}{\left(\frac{p}{\lambda}\right)^{\frac{\rho}{1-\rho}} - \lambda} + \mu \right)^{1/\rho}. \tag{10}$$

In the Cobb-Douglas case, one gets:

$$M^* \;=\; \bar{L} \left(\frac{p}{\lambda\gamma} \right)^{\frac{1}{\lambda-1}} \tag{11}$$

$$Y^* \;=\; \bar{L} \left(\frac{p}{\lambda\gamma} \right)^{\frac{\lambda}{\lambda-1}}. \tag{12}$$

The value added created by this economy, i.e., the Gross Domestic Product (GDP), is the sum of the two sector values added:

$$\mathsf{GDP} = Y^* - pM^* + pM^* = Y^*. \tag{13}$$

3 Calibration

We assume that initial equilibrium conditions are fixed: production is equal to Y_0, total supply of labor L is $\bar{L}$, initial consumption of goods M is M_0, and initial price of the goods M is p_0.

Such a calibration makes sense from a practical point of view: considering any economic sector, national accounts can provide an assessment of how much input M is consumed by this sector (M_0) at what price (p_0), how much labor ($\bar{L}$) is consumed, and how much is produced (Y_0). The elasticity of substitution and the parameters of the production function, on the other hand, are difficult to measure and often have to be calibrated (Magnus, 1979). Also, the elasticity is sometimes modified to account for various mechanisms. For example, Rose et al. (2007) divide the elasticity of substitution by 10 to take into account short-term rigidities in the economic system in the aftermath of a disaster.

Here we assume that the elasticity of substitution is chosen first (in an *ad hoc* manner or from econometric analyses), and the other parameters are then calibrated from economic data.

When the elasticity of substitution has been chosen (through the choice of ρ), the values of parameters λ and μ (or, equivalently, λ and γ), are chosen as a function of $X_0 = (Y_0, M_0, \bar{L}, p_0)$ and of ρ. First order conditions (7) gives, after reintroducing Y_0:

$$\lambda = \left(\frac{Y_0}{M_0}\right)^{\rho-1} p_0. \tag{14}$$

Substituting λ back in the production function leads to:

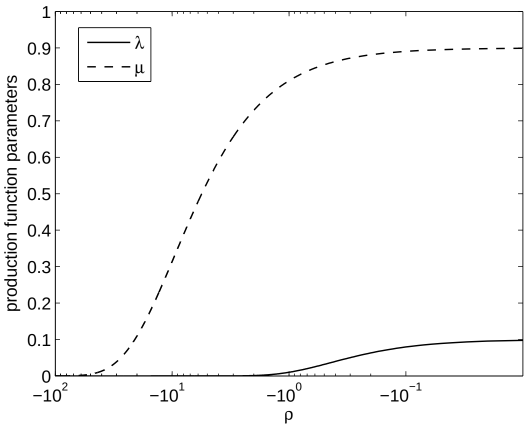
$$\mu = \left(\frac{Y_0}{\bar{L}}\right)^{\rho} - \left(\frac{M_0}{\bar{L}}\right)^{\rho} \left(\frac{Y_0}{M_0}\right)^{\rho-1} p_0. \tag{15}$$

With a Cobb-Douglas function, one gets in a similar way:

$$\lambda = \frac{M_0}{Y_0} p_0 \tag{16}$$

$$\gamma = \frac{Y_0}{M_0^{\lambda} \bar{L}^{1-\lambda}}. \tag{17}$$

As shown in Fig. 1, λ and μ increases when ρ increases and the elasticity of substitution is larger. For instance, if ρ tends to $-\infty$, i.e., if the production function is a Leontieff function, then λ and μ tend to zero. If ρ is close to zero, i.e., if the production function is close to a Cobb-Douglas with an elasticity of substitution tending to one, then $\lambda = p_0 M_0 / Y_0$ and $\mu = (Y_0 - M_0)/\bar{L}$.



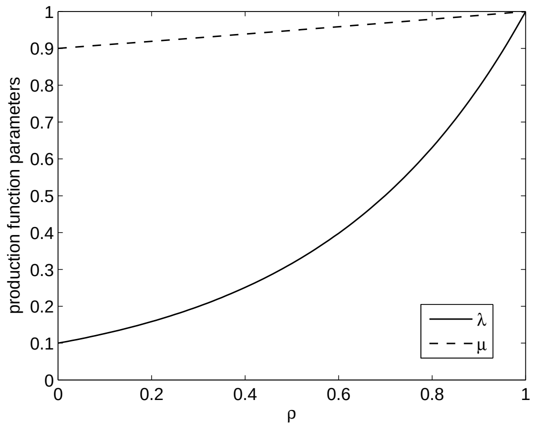


Figure 1: Values of the production function parameters, as a function of the elasticity of substitution ρ, for $\rho < 0$ on the left, and $\rho > 0$ on the right. These values are calculated with $Y_0 = 1$, $M_0 = 0.1$, $p_0 = 1$, and $\bar{L} = 0.9$.

In this case, λ is the ratio of intermediate consumption of goods M to total production, i.e., the cost share of goods M. If ρ tends toward 1, i.e., if the production function is close to the linear case, then λ is equal to p_0 and μ is equal to w.

These relationships are also apparent using cost shares, which are often used for calibration of the elasticity of substitution (Frondel and Schmidt, 2002):

$$\ln\left(\frac{p_0 M_0}{Y_0}\right) = (1-\sigma)\ln(p_0) + \sigma\ln(\lambda). \tag{18}$$

This equation shows that the parameter λ has to be adjusted if σ changes while $p_0 M_0 / Y_0$ and p_0 are unchanged.

More generally, this dependency shows that, when one wants to investigate the influence of the elasticity of substitution using a sensitivity analysis (Rose et al., 2007), it is necessary to take into account the direct effect of an increase in elasticity of substitution (through the production function shape) and the indirect effect of this increase (through the impact on the other parameters of the production function). The combined impact of these two effects is investigated in the next section.

4 Impact of a supply-side shock

We assess the consequence on production Y (i.e., on GDP) of an increase in the price of goods M, for various values of ρ (between $-\infty$ and 1). We assume that the new price of the goods M is $p = \alpha p_0$. This increase in the price of goods M could come from a reduction of the productivity in this sector, for example, one could have $\beta = \beta_0/\alpha$. This is for instance what can be expected if climate change reduces the productivity of infrastructure capital. The amount of borrowed capital changes, and we assume that there is enough unused capacity to respond to this demand, at an unchanged price r.

Since the production Y is used as a numeraire, the price p is measured with respect to the price of final production. Replacing the price in the expression of Y^* leads to:

$$Y^* = Y_0 \left(\frac{1 - \frac{p_0 M_0}{Y_0}}{1 - \frac{p_0 M_0}{Y_0} \alpha^{\frac{\rho}{\rho-1}}} \right)^{1/\rho} . \tag{19}$$

The denominator in (19) cancels out when the cost of intermediate consumption is larger than the value of production. In this case, producing does not make sense, and production reaches zero.

The ratio Y^*/Y_0 is also the ratio of GDP after and before the shock and is therefore a measure of the economic resilience to the price shock. The derivative d_σ of Y^*/Y_0 with respect to σ describes how resilience depends on the elasticity of substitution. This derivative d_σ has the same sign than d_ρ, the derivative of Y^*/Y_0 with respect to ρ.

Elementary calculation gives the expression of d_ρ, with $B = p_0 M_0 / Y_0$:

$$\begin{aligned} d_\rho \quad = \quad & \left((1-B) \left(1 - B\alpha^{\frac{\rho}{\rho-1}} \right)^{-1} \right)^{\rho^{-1}} \times \\ & \Bigg[-\ln \left((1-B) \left(1 - B\alpha^{\frac{\rho}{\rho-1}} \right)^{-1} \right) \rho^{-2} + \\ & B\alpha^{\frac{\rho}{\rho-1}} \left((\rho-1)^{-1} - \frac{\rho}{(\rho-1)^2} \right) \ln(\alpha)\, \rho^{-1} \\ & \left(1 - B\alpha^{\frac{\rho}{\rho-1}} \right)^{-1} \Bigg]. \end{aligned} \tag{20}$$

A numerical analysis with $\alpha = 2$, see Fig. 2, shows that the derivative of production with respect to the elasticity of substitution can be either positive

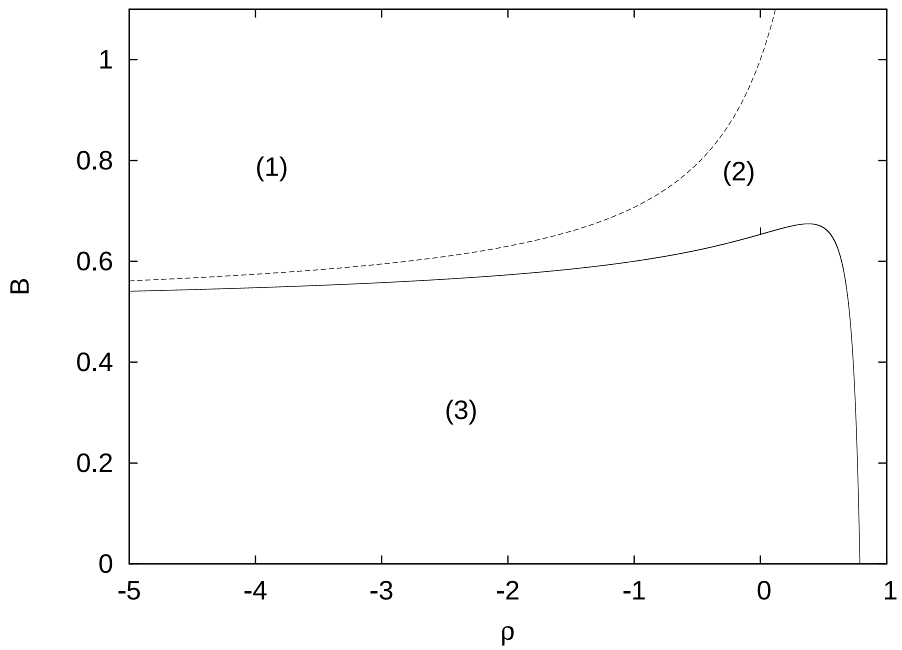


Figure 2: Sign of d_ρ, the output ratio derivative with respect to the parameter ρ, with $\alpha = 2$. Parameter ρ is varied on the x-axis, while the y-axis is the initial share of M in output, i.e., $B = p_0 M_0 / Y_0$. In region (1) production is impossible, in region (2) the derivative is positive, and in region (3) the derivative is negative.

or negative[1]. The figure shows three regions:

- In region (1), the denominator in (19) is negative, and Y^* is not defined (i.e., production becomes impossible after the shock). It is the case when $(p_0 M_0/Y_0)\alpha^{\frac{\rho}{\rho-1}} \geq 1$. In that case, the price of intermediate consumption is too large with respect to the price of production, production is not possible and the economy collapses.

- In region (2), Y^* is positive, production remains possible, and the derivative of production with respect to the elasticity of substitution is positive. In this parameter domain, easier substitution smoothes the shock, as the intuition suggests. For high ρ, i.e., near perfect substitution, this region spans the entire range. But for lower ρ, this region is included in the domain where $(p_0 M_0/Y_0)\alpha \geq 1$ and $(p_0 M_0/Y_0)\alpha^{\frac{\rho}{\rho-1}} < 1$, i.e., in the domain where the shock would make production impossible in absence of substitution but where substitution makes production possible.

- In region (3), Y^* is positive, production remains possible, and the derivative of production with respect to the elasticity of substitution is negative. In this parameter domain, increasing ρ or σ, i.e., increasing substitution, reduces resilience. Contrary to the intuition, an easier substitution makes worse the consequences of the shock. Importantly, this is the case for all values of $\rho < 0$, provided that $(p_0 M_0/Y_0)\alpha < 1$, i.e., provided that production would remain possible even in absence of substitution.

In the extreme case of no substitution (the Leontieff case), the price shock has simply no impact on production level. For any value of α, indeed, when $\rho \to -\infty$ (i.e., $\sigma = 0$) and $(p_0 M_0/Y_0)\alpha^{\frac{\rho}{\rho-1}} \leq 1$, the production limit is Y_0. In fact, the additional cost of goods M is fully compensated by a decrease in the cost of labor L, i.e., on w, because this goods is inelastically provided.

Most of the cases that are analogous to our illustrative production structure are to be found in region (3). Assuming that $\rho < 0$ ($\sigma < 1$), i.e., that substitution is not too large, as found by most analyses (Kemfert and Welsch, 2000), and considering a large increase in the price of goods M by 100% ($\alpha = 2$), the model parameters would be in region (3) if $(p_0 M_0/Y_0) < 1/2$, i.e., if the initial consumption of goods M represents less than half of the value of production (i.e., if the cost share of goods M is lower than 50%).

As a comparison, according to the Bureau of Economic Analysis data, the manufacturing sector in the US (in the 15-sector level of aggregation)

[1] Other values give the same result.

consumes intermediate goods from the utilities sector for a value equal to 1.1% of its total production. Its largest client is itself (i.e., the manufacturing sector), for a value of only 33% of its total production. In France, according to INSEE, the industrial sector consumes energy for a value equal to 3.4% of its own production in 2006 (it was only 1.6% in 2004).

It seems, therefore, that in this simple general equilibrium setting, consistent with the US manufacturing sector or the French industrial sector and their infrastructure-service supply, the larger the elasticity of substitution between energy and labor, the larger are the consequences of an increase in infrastructure-service prices (or, equivalently, of a reduction in infrastructure-service production productivity). This counter-intuitive result is not due to the direct effect of substitution, which tends to smooth the shock when the elasticity is larger, but to the indirect effect of substitution, which makes the two other parameters of the CES production function change.

In this setting, however, the hypothesis of perfect wages adjustment is certainly exaggerated, at least in the short term. With less flexible wages, this mechanism should be reduced but remains present. Similarly, an unchanged capital price after the shock is a special case, as is the existence of unused capital. If there is no available capital, some investment (i.e., reduction in consumption) would have to be spent in order to reach the capital stock level that corresponds to the after-shock situation. In many cases, and in absence of rapid depreciation, this amount of transient investment should however be very low compared with the change in production.

5 Conclusion

This paper shows that, counter-intuitively, a higher elasticity of substitution in production function can lead to a reduced economic resilience and a larger vulnerability to shocks in production factor prices. This result is due to the fact that assuming a higher elasticity of substitution requires a recalibration of the production function parameters to keep the model initial state unchanged.

Even though the analysis presented in this paper uses restrictive hypotheses, this analysis is sufficient to show that the relationship between elasticity of substitution and resilience is not automatically positive.

This result has consequences that are important for economic analysis. For instance, it is likely that climate change will affect primarily the infrastructure sector, which has a long capital lifetime and will reveal at least partly ill-adapted to new climate conditions, reducing its productivity. In such a situation, a larger elasticity of substitution in the production function of the rest of economy that relies on infrastructure services may lead to a higher vulnerability.

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