CHAPTER 25

Macroeconomics of the Energy Transition

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1 Introduction

Two conflicting narratives are frequently heard in connection with the economic impact of energy transitions. The first maintains that energy transitions are a great opportunity to revitalize economic growth and increase employment. The second, in contrast, estimates that objectives like reaching carbon neutrality by 2050, as pledged by the European Union, would be "too expensive." Which is right?

In the following pages, we attempt at disentangling the multiple contrasting interactions between economic conditions and energy transitions. It goes without saying that the net effect, resulting from the balance of such multiple contrasting interactions, is extremely difficult, or even impossible to predict. It will surely very much depend on the specific characteristics of the economy facing the need to decarbonize, notably its current energy system, rate of growth of energy demand, available energy resources, and opportunities for decarbonization. All of these parameters are extremely variable country by country. It will also greatly depend on the specific transition path pursued, and especially the intended speed of the transformation.

This chapter expands and modifies an earlier similar essay of mine entitled "The Impacts of the Energy Transition on Economic Growth and Income Distribution" (Luciani 2020); some passages are reproduced, but the thrust of the argument is completely different.

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2 Energy: In Transition

Energy, its qualitative characteristics and relative cost, is very closely interrelated with the economy:

- Energy availability is a condition for economic growth (quantitative expansion) and development (qualitative evolution).
- Technological progress opens up new sources or opportunities to harness energy; and the availability of energy in new forms allows for further new technology development and uptake.
- Economic growth and development, in turn, are the main determinants of the volume and quality of energy demand.

The energy industry entered in a phase of constant evolution and permanent transition already at the beginning of the nineteenth century, in parallel with the industrial revolution; we have witnessed an "energy permanent revolution" ever since.

Until recently, this permanent revolution has been driven mainly by market forces. New sources/forms of energy grew in importance because they were cheaper or more convenient or both. Yet, older sources of energy, while accounting for a progressively diminishing share of a rapidly growing total primary energy demand, were not abandoned—indeed they hardly declined in absolute terms at all.

Major changes in relative prices, and/or in the composition of final demand, did impact the total demand for energy as well as the demand from specific energy sources (e.g., mobility drove the demand for oil; appliances and electronics drove the demand for electricity). The increase of oil prices in the 1970s did create a discontinuity in the trend of oil demand, which slowed down markedly thereafter (e.g., losing the power generation market almost completely).

Demand for immaterial services has gradually gained importance in the composition of gross national product (GNP) over material goods from agriculture or industry. It is often assumed that services are less energy intensive than material products, although this is not necessarily the case (e.g., financial or information services and/or international travel and tourism can be highly energy intensive). In addition, technological progress has to some extent also allowed for more energy-efficient production of material goods. In consequence, the elasticity of energy demand relative to GDP growth has been declining and is below 1 (meaning that for a given percentage increase in GDP, energy demand will register a smaller increase). Yet, in a crucially important list of energy-intensive industries (chemicals, metals, glass, paper, cement, etc.) energy efficiency has not improved very much. In some industries/services, energy intensity has even tended to increase, for example, in agriculture and in the retail trade of food products (chilling, packaging, etc.). It is therefore not possible to conclude with certainty that the elasticity of energy demand relative to GDP is bound to decline further: it depends on the nature of future technology and composition of future demand.

In discussing the economic impact of the energy transition, we need to keep the other side of the coin, that is, the impact of economic "transitions" on energy, in mind. Demographic, health, financial, political, and security developments can massively impact the demand for energy, either directly or indirectly through economic growth (or lack of it). The COVID-19 crisis has been a very clear illustration of how exogenous shocks (in this case health-related) can impact the economy and the energy industry very profoundly.

Vice-versa, since the invention of the steam engine, energy developments never were the cause of a major economic crisis. Rather, it is arguably the case that historically the abundant availability of cheap energy greatly facilitated the extended period of rapid growth that began after the Second World War—and may have ended in the first decade of the current century. The impact of other factors on economic growth has been much more important and in turn has conditioned the evolution of the energy landscape. If we conceive of economic growth as a bounded optimization exercise, energy very rarely was an active boundary responsible for limiting growth. It did so only occasionally and for very short periods of time.

The need for a new, different phase in the process of continuous energy evolution is directly related to the impact that the use of fossil fuels has had on the concentration of greenhouse gases (GHGs) in the atmosphere, and the consequent warming of global climate. The assertion that there must be an energy transition is, per se, nothing more than an extrapolation of existing trends, because energy has been in a transition for the past two hundred years. What is new is the belief that we face a market failure: the market does not take into account the cost of global warming, therefore a continuing energy transition based purely on spontaneous market forces would be heading in the wrong direction. We must intervene to change this course, and somehow interfere with market forces to drive down emissions, and at a rapid pace. The pace is important, because there is considerable inertia in energy structures: most installations are expected to have economic lives of several decades, and turnover is slow.

What is new is not the fact that we are in an energy transition. What is new is the conviction that the transition must now be guided by policies aimed at remedying a market failure.

3 Imposing a Price on Carbon

Global warming is a market failure due to the fact that the cost of emitting CO_2 and other greenhouse gases (GHGs) into the atmosphere is not borne by the emitter (Nordhaus 2013). No one has to pay for using the atmosphere, and rules for preventing corporations and individuals from emitting pollutants are mostly concerned with local or, at most, national atmospheric conditions.

Until very recently, the emission of GHGs has not involved a cost for the emitter, thus creating a negative externality.

This interpretation assumes that in the absence of a cost for emissions, carbon-intensive technologies will be more attractive than clean alternatives. According to a point of view which is more and more frequently expressed, some clean alternatives—notably non dispatchable renewables—are becoming cheaper and cheaper, and soon will be, or are already, competitive with, or even absolutely preferable to carbon-intensive technologies, even in the absence of the imposition of a cost for emissions. These expectations mostly do not account for systemic costs arising from growing penetration of non-dispatchable renewables beyond a certain threshold (variously estimated at 35–50%). But even ignoring the issue of systemic costs, if it is verified that clean sources become cheaper than fossil ones, the market would be vindicated, and policies to promote clean technologies would not be needed, because the latter would prevail out of their own greater competitiveness. At most, the energy transition might be a matter of speeding up (at a cost) a process that is taking place anyhow.

Internalizing the cost of emissions requires that a price be imposed on them, subjecting emitters to a carbon tax or the obligation to buy emission allowances from an emission trading system (ETS). By definition, the emergence of a new cost associated with the production of goods reduces the value added which the economy generates. Other things being equal, the new cost increases the total cost of production. As energy enters in the production of all goods, this means that all productive activities will be faced with an increase in production costs—the energy-intensive ones more so.

What happens next depends on the market power of producers: if they have market power and can pass on the increased cost, they will be able to defend their value added. Given the wage bill, passing on the increased cost to sale prices may allow to defend the revenue accruing to capital. However, the subsequent increase in the general level of prices (inflation) erodes the purchasing power of salaries; in constant prices, salaries will be reduced. Therefore, even if producers have market power, some reduction of value added in constant prices seems inevitable.

If, on the other hand, producers have no market power and cannot pass the increased cost on to sale prices, the revenue accruing to capital is reduced. So, we cannot say for sure whether the decrease in value added will manifest itself through lower real wages or lower enterprise revenue, but in either case value added is decreased. As the definition of GDP is the sum total of value added generated in all activities in an economy, imposing a price on carbon decreases GDP.

Furthermore, imposing a price on carbon emissions will affect different industries differently, depending on their respective carbon intensity. The result will be a realignment of relative prices, with carbon-intensive goods becoming relatively more expensive. Value added will be more significantly reduced in carbon-intensive industries. If these lack market power (which might well be the case if they are exposed to international competition) then enterprise revenue may be significantly eroded and the very viability of the industry may be challenged. If the affected productive activities are closed down, GDP will be further negatively affected. At the same time, it is of course possible that other productive activities specifically functional to the reduction of carbon emissions may be able to increase their revenue and be encouraged to expand by growing demand for their products; but this is a successive development, requiring additional investment.

We conclude that a first, static effect of imposing a price on carbon is some decline of GDP.

It may be argued that the downsizing of GDP when the cost of carbon emissions is made explicit is the consequence of the failure of acknowledging this cost in earlier years, since the beginning of the industrial era. In this view, past estimates of GDP, that do not include externalities, are exaggerated, and the introduction of an explicit cost for carbon emissions is just a remedy to past miscalculation. Following this line of thinking, the World Bank has proposed a concept of adjusted national income, which estimates environmental depletion associated with value added generation, and not included as production cost; and corrects national income accordingly (Lange 2018). The weakness in this approach is the difficulty in estimating the negative value of environmental depletion, and the suggested approach has remained of specialist interest only.

The matter is further complicated by the time lag between damage to the environment and the emergence of the economic cost of such damage. We suffer today from emissions released by past generations over longer than a century; and future generations will suffer because of our emissions. The economic damage that emitting a ton of CO_2 today entails will only be visible in the future, and depends on how much CO_2 has been emitted in the past. Therefore, in fact we cannot internalize the externality by imputing as cost the present value of the future economic damage caused by an additional unit of emissions, because we have no precise idea of what this cost might be. We are, rather, imposing a price on carbon emissions in order to solicit a market response and achieve a reduction or elimination of emissions. This price then represents the opportunity value to the potential emitter of emitting one additional unit (ton of CO_2 or other): he will stop emitting only if the price is higher or equal to the benefit that he may derive from emitting one additional GHG unit.

An alternative way to look at a price for carbon is to consider the cost of abating or eliminating a given weight of CO_2 emissions. In other words, CO_2 emissions may still happen but may be captured and sequestered, or compensated by CO_2-absorbing activities at a cost. The target price for carbon should then be that which incentivizes enough CO_2-absorbing activities so that overall net emissions are zero.

The explicit addition of a previously hidden cost is the reason that most governments are reluctant to introduce carbon pricing, whether under the form of a carbon tax or of a price generated by an emission trading system. Governments frequently prefer to resort to regulation and administrative measures, whose cost is non transparent and not immediately predictable by those on whose shoulders it will fall. But some additional cost is created anyhow: it may manifest itself as a shift from a preferred technology to a less commercially attractive one, or as accelerated obsolescence of the existing capital stock, and will lead to a decline in value added, hence of GDP.

4 Carbon Prices Are a Tax

But how is a price imposed on carbon? It is out of acts of government introducing an emission trading system or a carbon tax (or a combination of the two). In one way or another, the imposition of a price for carbon emissions translates into revenue for the government, that is, higher taxation.

As any tax, a carbon price has an immediate recessionary effect. For this reason, it is rarely proposed without some form of compensatory measure, which can be either a parallel reduction of other taxes, or a parallel increase in expenditure. Historically, energy products have been taxed in many jurisdictions, at relative levels that mostly do not reflect the carbon content, but rather various social or policy considerations. Thus, for example, gasoline may be taxed more heavily than diesel, and the latter may be taxed more when used for road vehicles than when it is used in agriculture or fishing, or for heating homes. In contrast, in numerous countries energy products have been subsidized more or less indiscriminately, with negative consequences on the fiscal equilibrium of the respective states. Attempts at eliminating such subsidies have frequently led to protests and political instability, indicating how politically difficult it might be to impose a price on carbon.

If expenditure is increased in parallel with imposing a price on carbon, the recessionary effect can be compensated. In this case, we should note that not all expenditure is the same: investment expenditure has a higher multiplier effect than expenditure on consumption; and support to low-income households more likely translates into consumption rather than savings, thus again a higher multiplier effect than other forms of redistribution. Thus, if the imposition of a carbon price is fully compensated by an increase in expenditure focused specifically on supporting investment, the net result may be expansionary, especially if the volume of investment set in motion exceeds the government expenditure itself. If the revenue from the carbon price is destined to supporting the income of the poorer segments of the population the net effect may also be expansionary, because low-income households are less inclined to save. In contrast, if the revenue from imposing a price on carbon is not entirely spent, then some recessionary effect may be inevitable.

More broadly, the effect of the imposition of a price on carbon should be discussed in the context of the overall fiscal balance of the country in question. It may not be appropriate to tie specific expenditure to a specific source of revenue, although this is frequently done in the political debate. In the end what matters is the total fiscal position of the government, which may be expansionary or contractionary depending on circumstances and considerations that may be totally unrelated to the objective of imposing an explicit price on carbon.

It is therefore not a very sensible approach to discuss the *net* effect of imposing a price of carbon, because in the end whatever may be the net effect of this disposition narrowly defined, it will be compensated or exacerbated by the overall context of the country's fiscal policy.

5 Effects on the Destination of Income

Policies for decarbonization will also affect the allocation of income to investment as opposed to consumption. From this point of view, the needed outcome is a decline in consumption, and increase in investment.

All consumption of goods and services entails some demand for energy. Energy saving is unanimously identified as a key component of the necessary decarbonization process: we need to drive less, fly less, heat or air condition less, and so on. We may shift to more efficient machines (requiring additional investment) in order to maintain the same level of net service while reducing energy consumption (increasing energy efficiency), but very likely reduced net service is part of the deal.

At the same time, there is no progress possible toward decarbonization that does not require some form of investment. True, the energy sector always stood out as relatively capital intensive, meaning that investment would in any case be necessary to satisfy growing demand or improve efficiency, even if we were to continue with emitting GHGs into the atmosphere; however, the decarbonization agenda entails even higher investment.

If an economy is operating below full employment of its resources of labor and/or capital, measures aiming at supporting investment, in general or specifically targeted to clean energy and reduced emissions, may be expected to result in improved economic conditions. Any increase in expenditure, be it for consumption or investment, will generate an increase in income higher than the initial expenditure (Keynes's multiplier), but investment expenditure will have a higher multiplier than consumption because it helps bridging the gap between propensity to save and propensity to invest. The less than full employment equilibrium is caused by an excess of savings over investment: increasing investment will tend to eliminate this excess and fully absorb available savings. Energy transitions require large increases in investment, thus are commonly presented as being favorable to economic expansion.

However, this preliminary conclusion must be mitigated by consideration of the effect on the economy's average capital-output ratio as well as rate of capital obsolescence. Energy in general is a sector characterized by high capital intensity and capital/output ratios, but clean energy tends to be even more capital intensive (see text box). In all forms of clean energy—hydro, solar wind, and even nuclear—the bulk of the production cost is in the initial investment, direct costs are small, and marginal cost close to zero. Hence if investment in energy, and specifically in clean energy, increases as a share of total investment, the overall capital-output ratio of the economy may be expected to increase. The productivity of capital, which is the inverse of the capital-output ratio, will decrease.

The capital-output ratio governs the speed at which an economy can grow. Given the propensities to save and invest, a higher capital-output ratio means that the economy can only grow more slowly. This is simply because the total investment will generate a smaller increase in income in successive periods, hence also less growth in further investment. Of course, one can hypothesize that the propensities to save and invest will both increase, that is, that consumption will decrease, and more resources will be made available for investment. This assumption highlights how energy transitions are much more problematic in poorer countries, where the level of consumption is hardly compressible, than in richer ones—a point that will be further explored.

At the same time, the goal of abating GHG emissions will also accelerate the obsolescence of capital. Most energy-related capital equipment is characterized by long economic lives. Power plants, refineries, pipelines, transmission networks: these are all installations expected to last several decades. If we had the time to let an energy transition take place at a pace that does not force early retirement of existing productive capacities, accelerated obsolescence would not be a problem. But this is not the case: we know that existing installations, if allowed to continue in production without any remedial action, would exhaust the remaining carbon budget that we have if we want to achieve the objective of the Paris agreement (IEA 2020). Therefore, we need to speed up the process, and retire some productive capacity ahead of the end of its economic life, or engage in further investment to reduce the emissions that it generates.

In the first case, early retirement of "stranded" assets, new investment will largely simply substitute for retired capacity, and the net effect might be little or no capacity addition. In this case, marginal capital productivity would be zero. Another way to look at this is to refer to the distinction between gross and net fixed capital formation, of which only the latter is proper net investment. Accelerated obsolescence widens the gap between these two measures, reducing the importance of net over total investment.

Are Low-Carbon Sectors Less Capital and More Labor Intensive?

Some sources assert that low-carbon sectors are less capital and more labor intensive than high-carbon sectors. Thus, for example the IMF (2020) writes:

High-carbon sectors (such as fossil fuel energy and heavy manufacturing) are typically more capital intensive, whereas low-carbon sectors (such as renewable energy and many services) are more labor intensive. (page 92)

The expanding low-carbon sectors (renewables, services) are also less capital intensive than the contracting sectors (fossil fuel energy, manufacturing), further reducing demand for capital investment. (page 99)

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A graph shows a very high "job multiplier" especially for solar photovoltaic, and a note explains "Each bar shows the total number of job-years generated per gigawatt-hour of capacity. This includes both direct and indirect jobs…." This is puzzling because capacity is measured in gigawatt rather than gigawatt-hour (which measures energy produced). It seems that jobs generated by the creation of capacity (the investment process) are conflated with jobs in production proper (the process of generating electricity from existing capacity). The latter are minimal, as demonstrated by the fact that renewables are normally characterized by zero marginal cost of production, the latter involving no added labor at all.

When this chapter asserts that renewable sources are highly capital intensive and have low capital-output ratios, reference is made to production proper. In other words, most of the cost is in the investment phase (the creation of capacity) and direct costs are minimal. That the investment phase may be labor intensive is another matter, unless we want to abolish the distinction between the creation of capital (i.e. capacity) and the output from it (electricity generated). This would be a very unusual approach.

All energy production is highly capital intensive relative to other sectors, but within the energy sector production of electricity from renewables is comparatively more capital intensive than its production from other sources, as well as of production of other forms of energy, such as fossil fuels.

In the second case—investment aiming at abating emissions from existing power plants—we may even encounter examples of investment projects that reduce net output, rather than increasing it. For example, retrofitting an existing coal power plant with carbon capture and sequestration may reduce the net output of electricity from the plant by 30-35%. If a high enough price for carbon is imposed, a project of this kind may earn a net positive return for the plant owners, but in material terms it would still be a destructive project—if we look at the primary goal of the plant itself, that is, making electricity available.

Or consider the expected transformation of the mobility industry from internal combustion to electric engines (whether alimented by batteries or fuel cells) or alternative fuels such as clean hydrogen: this requires huge investment on the part of the vehicle manufacturers for the introduction of new models; on the part of distributors or municipalities for the installation of recharging stations; and on the part of final consumers for buying new vehicles—and the end result is a mobility service which is somewhat more limited (because of range limitations or recharging times) or at most equivalent to what they enjoyed previously. Thus, statistically GDP may increase because changes in relative prices, taxes and subsidies, or regulation may create an economic incentive to achieve this transition, but the utility of the final consumer is not improved.

We conclude that in case of an economy that finds itself in an equilibrium of less than full employment of available resources an increase in investment driven by the objective of decarbonization may have an expansionary effect, but this is potentially less important than if investment were directed to sectors with a lower capital-output ratio, or if it were geared to add capacity rather than just replace existing capacity whose obsolescence is accelerated.

This takes us back to the difference between rich and poor countries. In the latter, investment is frequently limited by the lack of an investable surplus, that is, insufficient rather than redundant savings. In fact, these countries normally depend on finance from abroad to support their investment requirements. These are also frequently countries where energy supply falls short of demand: the lack of access to modern energy, especially electricity, is a potent obstacle to their economic growth; meaning that additional energy availability may have a much larger impact on productivity and growth, well beyond the increased output of energy itself. Furthermore, demand for energy is normally rapidly increasing, thus energy investment is more likely to be for adding capacity, rather than just in substitution of existing capacity made obsolescent ahead of time.

We conclude that clean energy investment is much more likely to have a positive impact on economic growth in emerging countries where the main obstacle to growth is the lack of investable surplus (and modern energy supply) than in advanced industrial countries. Furthermore, in the context of insufficient finance for clean energy projects, emerging countries may opt for more carbon-intensive but cheaper or more easily financed solutions.[1] Hence, we see clearly that the idea of turning decarbonization into a tool for promoting economic growth is best pursued by promoting clean energy projects in emerging countries, rather than in advanced industrial ones, where the net benefit may be more limited than sometimes proposed.

6 How to Encourage Investment?

The needed shift in the destination of income from consumption to investment is unlikely to be achieved easily. In our capitalist economies, investment is justified by the expectation of profit, which ultimately is supported by consumer demand. In the past half-century at least, economic growth has been driven by consumer spending and international trade. The latter has increased competition, lowered prices of consumer products, and opened wider markets to

[1] Both China and Japan have been criticized for offering cheap export finance to their national companies selling new coal-fired power plants in emerging countries. Large-scale hydro projects also attract export finance, but smaller, distributed solar and wind projects may be more difficult to fund.

producers, thus facilitating the introduction and success of new products. Looking ahead, it is likely that globalization will be at least partially reversed, and consumer spending must be compressed to allow for increased investment. In the context of the decarbonization drive, not just enterprises, also households are requested to invest more: in improving the energy efficiency of their homes and appliances, or buying new mobility tools (perhaps just an e-bike rather than a new electric car). This will leave less money available for other forms of consumption, and consumers may not be willing to accept the shift. In most cases, the time needed for recovering the initial investment on the part of households runs into several years or even decades, meaning that the required parallel decrease in consumption may be long-lasting.

Supporting investment in an economy facing slower consumption growth, or even decline, is a major policy challenge. It entails departing from consumerism, which has been the engine of modern capitalism. Shifts in relative prices such as would be brought about by the imposition of a hefty price on carbon may render investment in clean energy projects potentially profitable, but this is not enough to guarantee that private entrepreneurs will engage in them. The profitability of investment in clean energy solutions must be clearly established and consistently supported for investors to take the plunge.

Governments can encourage investment by limiting the risk for enterprises. This can be accomplished through availability of debt finance at low interest rates, through participation in the equity, through price/demand guarantees such as long-term purchase agreement or contracts for difference. All of the above are widely used instruments for supporting investment especially in the decarbonization of electricity. Then there are also subsidies for the purchase of specific products, such as electric cars, or tax rebates offered to enterprises and households that engage in decarbonization-related investment. In other words, the state must step in and devote resources in ways that may be more or less effective, but in all cases represent a departure from the prevailing liberal credo.

The task is to simultaneously increase the propensity to save (reduce consumption) and increase the propensity to invest even more, so as to move in the direction of fuller employment of resources. It is not clear that financial intermediaries may be able to deliver this major redirection of our economies. The active engagement of the state is needed, but it is limited by fiscal constraints. The state may need to reduce other expenditure or increase taxation to be able to pay for the added burden; only a relatively few governments are in a position to increase their debt, and doing so may push interest rates upwards, which would negatively affect capital-intensive projects.

Such considerations apply even more cogently if we move from the national to the global level. Globally, many investment opportunities in cleaner energy sources are to be found in countries with dubious or precarious governance, presenting a risk profile, which few investors are willing to underwrite. Global decarbonization ideally entails a massive shift of financial resources from the industrial to the emerging countries, because there demand for energy is growing faster, and the deployment of renewable energy sources would in many cases be easier.

7 Income Distribution

It is generally accepted that an increasing cost of energy has a regressive impact on income distribution, because energy expenditure is a larger share of the budget of poorer households. In addition, households are expected to invest to minimize the added cost, for example, in insulation of their homes or buying new electric vehicles, but the vast majority of households have no net savings and no borrowing power. Thus, richer households can contain the added cost by engaging in investment, but poorer citizens simply must bear the brunt of the decarbonization agenda.

In order to palliate the negative effect of higher energy cost brought about by charging a price on carbon, it has been proposed that the revenue from the latter measure should be returned to all citizens in equal installments (CLC 2019; EC 2019). In this way, the poor would receive more than the increase in their energy expenditure, that is, would be net beneficiaries; while the rich would be net contributors. This may certainly facilitate the popular acceptance of imposing a price on carbon, although similar proposals aimed at introducing some form of universal basic income have not found majority support where they have been put to the test of the electorate.

But there is a more systemic reason for expecting a deterioration in income distribution, and this is that the energy transition entails an increase in the capital/output ratio, which in turn automatically results in an increasing share of income accruing to capital, unless investors are ready to accept falling returns on industrial investment or lower interest rates on borrowed capital. We do live in a world of historically low interest rates, but this is creating multiple dislocations and is not accepted as normal in the longer run. Furthermore, there is no evidence that corporations are ready to accept lower returns: in fact, the opposite is true, as the perception of risk has widely increased, and in the energy industry the perspective of decarbonization further increases risk. Thus, the increase in the capital/output ratio associated with the energy transition may be expected to also determine (or require) a shift of income from labor to capital—that is, a widening of inequality in income and wealth distribution.

In this respect, the energy transition simply reinforces a trend that has been underway ever since the end of the Second World War (Piketty 2013). Thus, while we certainly cannot attribute exclusive responsibility for growing inequality to the energy transition, the fact that it adds to an unwelcome existing trend further complicates things. Yet, the simple idea of devoting the revenue from a higher price on carbon to the creation of some form of citizens' income is unlikely to be optimal. Why should the introduction of a citizens' income be funded in particular by the carbon tax? These two measures are logically separate and the only reason for coupling them is to facilitate the swallowing of the bitter pill—the carbon tax—with sugar coating—citizens' income. Furthermore, devoting the revenue from a carbon tax to redistribution, rather than in particular supporting investment functional to the transition, would reduce the effectiveness of the policy with respect to its environmental goal.

In perspective, the carbon tax has the ambition of eventually generating no revenue at all, when decarbonization will have succeeded; in other words, to the extent that the tax is successful, the revenue it generates will progressively shrink, and the citizens' income will need funding from other sources; the tax is therefore not an appropriate fiscal tool for addressing a problem (inequality) that will remain long after decarbonization has succeeded.

Rather, what is needed is acceptance of lower rates of return for industrial and financial investment—that is, as earlier indicated, an increase in the propensities to save and invest. But the transition from an economy driven by consumption and encouraging consumer debt, to an economy encouraging frugality and investment is not achieved easily.

8 Employment

Another effect commonly associated with accelerated decarbonization is employment creation. This expectation is commonly supported with estimates of the number of people potentially employed in the manufacturing and deployment of renewable energy systems. It is not difficult to see that this approach is highly simplistic, because it does not take into account the parallel potential destruction of employment in industries that will be negatively affected by the process. It is difficult to argue in abstract whether the net employment effect of the decarbonization drive will be positive or negative, as the conclusion depends on many circumstances and assumptions. It is nevertheless interesting to explore the implication and significance of the possibility that the net effect is in fact positive, that is, that more jobs are created than destroyed.

The point is that, although employment creation is a constant preoccupation for governments, labor is a cost, which enterprises strive to minimize. There is constant tension between increasing labor productivity and full employment: the former should be maximized, preferably with no detriment to the latter; but this is only possible if total production is growing in line with productivity. The energy transition is expected to lead to an increase in the capital/output ratio, that is, a decrease in the productivity of capital (output per unit of capital is the inverse of capital/output). Assuming that, other things being equal, employment will also grow for a given output is tantamount to saying that the productivity of labor (which is the ratio of output to employment, or output per worker) will also decrease. In other words, we are envisaging a decline in both the productivity of capital and of labor, that is, a poorer world.

This seeming paradox can be partly explained by noting that the production of decarbonized energy is capital intensive, but the manufacturing and installation of the fixed capital required may be labor intensive. In fact, most of the expected employment creation is not linked to the utilization of clean energy production capacity, but to the creation of it (see text box above). With respect to the improvement of energy efficiency, much of what needs to be done for buildings will translate into support to construction jobs. This may mean that the employment creation effect is purely temporary; if it is not, because of the need for frequent replacement or expanding capacity, then the previous conclusion remains valid, and the economy will record a decline of productivity of both capital and labor.

9 Conclusions

Although the economic implications of energy transitions very much depend on the specific circumstances of each economy, some broad generalizations are possible.

Firstly, internalizing the cost of emissions in order to address the market failure that generated the threat of climate change adds a cost to most production activities, which inevitably leads to some reduction of aggregate value added, that is, GDP.

Secondly, as a price for carbon is akin to a tax, it may have a recessionary or expansionary effect depending on the prevailing equilibrium in government finance in the country concerned. If it leads to less deficit spending, it will be recessionary. In this respect, a carbon price is not different from any other indirect tax.

Thirdly, clean energy solutions are almost invariably more capital intensive than those that the market would support in the absence of a price for carbon. Thus, mitigating climate change entails an increase in the average capital-output ratio in the economy, which in turn tends to slow down growth. To avoid this effect, it would be necessary to increase the propensity to invest given available savings; and if the economy does not suffer from excess savings, also increase the propensity to save and compress consumption accordingly.

Therefore, there is an intrinsic link between the clean energy agenda and the overcoming of the consumerist growth model that has prevailed for longer than half century. How a shift from this model toward an alternative model based on frugality and more investment can be obtained is not clear. It is a question that touches the respective roles of the state, the market and financial intermediaries, and may require important institutional and policy adaptation.

It is also to be expected that the increasing capital-output ratio will tend to shift income from labor to capital, and widen inequality. This can only be prevented if the expected return on capital is permanently lowered, which is possible, but has cascading effects on the stability of important financial institutions, as experienced in recent years because of negative interest rates.

Finally, while there may be a positive effect on employment, the reverse side of the coin is that labor productivity would decline, and this while the productivity of capital would also decline.

With respect to all of the above, the importance of the effect is crucially linked to the desired speed of the transformation. If transitions are allowed to stretch out in time and accommodate the high inertia of energy systems, the difficulty would be greatly reduced. But we increasingly are convinced that there is no time, and changes must take place within close deadlines.

Besides their sheer cost, which may be bearable, the challenge of energy transitions is in the required change in the growth model. Energy transitions are not the only development necessitating a change in the growth model: the aging of our societies and almost universal increase of capital-output ratios in most industries point to the same direction. The way in which the economics of energy transitions will play out will have much broader implications than for the energy industry alone.

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