The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Physics in the Economy I: Physical Work

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This is the first in an occasional series of posts on the role of physics, particularly energy, in the economy. I've noted that on several sides of the peak oil debate that there is a serious lack of literacy in basic physical theory. On the one hand, classical economics seems to have been developed with an almost complete lack of consideration of the role of energy. For example, I have a college level Macroeconomics textbook by my side. It devotes about two out of 519 pages to consideration of energy, wherein it says nonsense like:

> Because energy constitutes a small proportion of the nation's total expenditure on inputs, most statistical studies suggest that higher energy prices did not contribute much to the slowdown [in the 1970s].

My Microeconomics textbook is even worse: energy is not in the index. The reasons for this lack of consideration have been understandable in the past, as I will discuss later, but I believe will pose serious problems in the future.

On the other hand, there is a tendency for some peak-oil writers to throw around the Second Law of Thermodynamics as though it proves beyond doubt that any reduction in available energy must immediately result in a collapse of society, which is equally nonsensical.

Physics is a notoriously inaccessible subject. In this series, I'll try to make as clear as I can the answers to questions like: What is energy anyway? Why is it so important? And how should we think about its role in the economy? Today, I'll start by explaining the concept of **physical work** in this post, and in the next post we'll solidify the concept by looking at how much work is involved in getting oil out of a reservoir. We'll move on from there to talk about heat, temperature, the laws of thermodynamics, and then get into the energy basis of the economy, culminating, I hope, in explanations of recent work by energy economists.

Technorati Tags: peak oil, oil, energy, gas prices

Forces and Motion

Let us start in the beginning, which is with Newton's laws of motion, the foundation of classical mechanics. These laws are probably the most successful scientific model humanity has ever come up with. The laws allowed Newton, back in 1686, to develop a unified quantitative explanation of both the behavior of the planets, and the motion of objects here on earth. They agree with experiments to incredible precision, as long as we don't deal in objects moving at a sizeable fraction of the speed of light (where we would need to think about Einstein's theory of relativity) or incredibly small objects (where we would need to worry about quantum mechanics). For everyday purposes, Newton's laws still outline a superb model.

No, don't run screaming from the computer yet. We'll take it slow and easy.

The first of the three laws is this:

> A body in a state of rest or uniform motion will remain in the same state indefinitely if no force acts upon it.

and the second goes like this.

> If a net force acts on a body, the body will **accelerate** proportionately to the **force**, with the constant of proportionality being the **mass** of the body.

Mathematically, this can be expressed as

$$F = ma$$

Force = mass x acceleration

These laws are formalizations of ideas that should be intuitive: if you want something stationary to move, you have to push on it (apply force). The increasing movement is acceleration (getting something to go faster and faster). If you push harder, it will accelerate faster. On the other hand, the heavier it is, the harder you'll have to push to get it going to any given speed (thus does the mass come in as the constant of proportionality between force and acceleration).

Similarly, if a heavy thing is already going fast, you're going to have to push hard in the opposite direction to slow it down (negatively accelerate it), or push hard sideways to get it to change course. These are all covered under the second law if we interpret the force and acceleration to have direction as well as magnitude. (Mathematically, they are vector quantities, but don't worry about it if you don't know what that means - we will try to keep things accessible here by not delving into a bunch of vector calculus).

The part of this that is not so intuitive is the idea that a body in a state of uniform motion will continue to move in that state unless there are forces on it. We are used to things always slowing down and/or falling to the ground if we stop pushing on them. But that's because there are pervasive forces down here near the surface of the earth: gravity (which pulls everything down to the earth), and friction, (which tends to slow everything). Any forces we apply must be added to these pervasive ones. If you find an isolated corner of interstellar space, Newton's first law will be a superb model of the behavior of objects there - they will go in a straight line at constant speed for as long as they are isolated. But the three laws together are a superb model down here too if we correctly account for gravity and friction when adding up all the forces on a thing. Gravity and friction will be investigated in more detail in the next post.

A very little thought should suggest that this *force* concept has economic significance. An economy consisting entirely of bodies in a state of rest or uniform motion would not be much of an economy. Instead, almost all economically significant actions involve some forces being applied to some bodies. For example:

- A bottle of beer in the bar refrigerator will remain there in its state of rest until the bartender applies force to it by picking it up and handing it to us in exchange for our money.

- A lump of coal at the bottom of a mine will remain there unless we apply a force to pry it away from it's neighbors, and then more force to lift it to the surface.
- A car or truck will remain in a state of rest until the engine is started and begins applying a force to the wheels to move the vehicle.
- Oil in an oil reservoir will remain there, resting, unless there is some force that pushes it to the surface.
- Pallets on a warehouse shelf will remain in a state of rest on the shelf until a forklift applies force to them to get them moving towards the truck.
- Electrons in a wire will not flow along it to power an industrial machine, or a computer, unless some force is applied to push them along the wire. No force, and the electrons will sit in a state of rest (ok, not quite, but we'll get to temperature later - at any rate the average movement of all the electrons will be zero).

From an economic perspective, if you want action faster (more acceleration) you will need more force, and if you want more stuff moved (greater mass), you will need proportionately more force also. So there should already be some sense that the total amount of forces being thrown around in the economy must be related somehow to the total amount of economic activity. We will make this more precise as we go.

The Third Law, and Physical Work

Newton's third law goes as follows:

> Whenever one body exerts force upon a second body, the second body exerts an equal and opposite force upon the first body.

As the Wikipedia graphically puts it:

> If a cement truck hits an old lady, the old lady's force on the truck is the same as the truck's force on her (although, due to her smaller mass, Newton's second law predicts that her acceleration will be much greater).

And thus we get to the idea of **physical work**. If we want something to move, we must push on it, and it pushes back on us (this is the sense of resistance you get when you try to push start your car after the battery has gone dead). That amount of physical work we have to do is defined as the **total distance** we move these resistance forces, times the size of the forces themselves. Mathematically:

$$W = Fd$$

Work = Force x Distance

Physical work intuitively corresponds to our subjective sense of how hard a task is. If we have to push our dead car up a hill, the damn thing is trying to push us down the hill and it takes a great deal of effort to overcome that. The heavier the car is, the greater the force required, and the harder the task. But also, it's clearly a lot more work to push it 100 yards up the hill than 2 feet up the hill (which is how the distance component comes into the definition).

But physical work also corresponds with **energy**. It turns out that doing physical work on a thing exactly corresponds to transferring energy to it. If we do physical work on our car by pushing it, the amount of energy transferred from us to the car is exactly the physical work. I'm not expecting this to be intuitive yet - at this point, physical work is pretty much just a definition and we'll round out the energy concept as we go. But hopefully it's intuitive that the amount of physical work going on in the economy is somehow closer as a measure of total economic activity than the total force - we aren't just pushing on things, we are actually getting them somewhere when we do physical work!

You might ask, why don't we define work as Force times the length of time the force is applied for? If the car is too heavy and we are just barely able to hold it on the hill but not move it, it will certainly feel like we are doing an enormous amount of hard work as we vainly attempt to push it. But note that we aren't doing the slightest bit of good to the task of moving the car - it isn't moving and no energy is being transferred to it. Instead, all we are doing is wasting our effort (in internal inefficiencies in our muscles as it turns out). So this is a less useful definition - we want a definition of work that involves actually getting somewhere with the task, not just trying in vain. Hence Force times distance moved is a more useful definition (and indeed is the one that will correspond with energy transfer as we will see as we get a deeper understanding of the energy concept).

That's it for today. Next time, we'll apply these concepts to something more concrete in an attempt to solidify our understanding. We'll look at how much work it takes to get a barrel of oil out of a reservoir and up to the wellhead.