Energy Resources, Economics and Environment
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Lecture-19
Input/Output Analysis-Part 3

So, we continue with this module where we are going to go ahead with input output analysis. In the previous module we looked at the basics of input output analysis, we looked at Leontief's initial formulation, we also said that in an economy when we talk of a number of different sectors, an output of one sector is used in the other sectors and it is also then used to meet the final demand. When we look at this, this and we sum up for each sector we get a set of interactions between the different sectors and this is represented, through the matrices that we create.

We then for the input output we said that the requirement of let us say steel for automobiles depends on the total output of the automobiles and these requirement, this correlation is assumed to be linear. So, with linear constants when we have the direct coefficients, we create a matrix equation. It is a set of linear equations in the n variables and with that, we can see that if the final demand for once our sector increases, what happens to the rest of this.

So, we then talked about two sets of coefficients, the direct coefficient, which is the direct requirement, let us say of steel for agriculture or steel for electricity or agricultural output for chemicals and then we have the total which is direct plus indirect and we did this by then creating the matrix creating the Leontief index inverse matrix, and then that relates to the final demand. So that any change in final demand results in a corresponding requirement or a change in the output of the different sectors.

When we created that matrix, we saw that the diagonal element of the matrix is greater than 1 which is sort of intuitive. Because, if we need a certain amount of final demand for steel, because of that final demand for steel to produce that we will need other chemicals, we will need electricity, for that chemicals and that electricity again we need a certain amount of steel. So, when we couple that up, we will see that for the diagonal elements will all be greater than 1.

Now to take this forward, just to illustrate this from the book by Miller and Blair on input output analysis, I would like to just show you some examples of aggregate for a country input output tables and what they mean.

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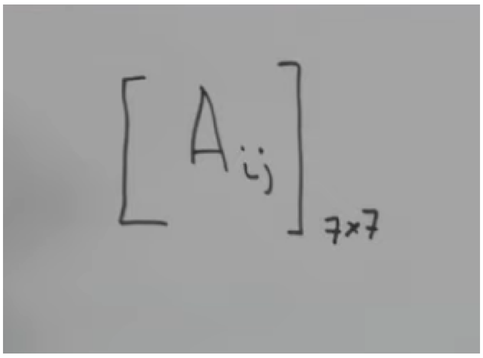
2003 US Direct requirements matrix A

	Sector	1	2	3	4	5	6	7
1	Agriculture	.2008	.0000	.0011	.0338	.0001	.0018	.0009
2	Mining	.0010	.0658	.0035	.0219	.0151	.0001	.0026
3	Construction	.0034	.0002	.0012	.0021	.0035	.0071	.0214
4	Manufacturing	.1247	.0684	.1801	.2319	.0339	.0414	.0726
5	Trade, Transportation & Utilities	.0855	.0529	.0914	.0952	.0645	.0315	.0528
6	Services	.0897	.1668	.1332	.1255	.1647	.2712	.1873
7	Other	.0093	.0129	.0095	.0197	.0190	.0184	.0228



So, this is the US, this is the A matrix which we talked about this is A ij for the US and this is a 7 sector 7 by 7 matrix if you can see. If you look at this, let me just get the laser point. You can see for agriculture, from 1 to 1 is the agricultural products being used for agriculture.

Then agricultural products being used for mining for construction for manufacturing, for trade, transportation, utilities, for services and for others and similarly mining to this manufacturing to variety of things and services going to variety of things and so, you can see all of these are between 0 and 1 and this is the total.

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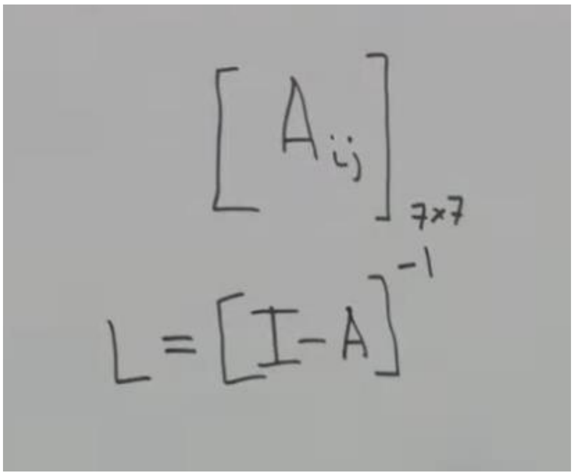

2003 US total requirements matrix L

	Sector	1	2	3	4	5	6	7
1	Agriculture	1.2616	.0058	.0131	.0576	.0037	.0069	.0072
2	Mining	.0093	1.0748	.0122	.0343	.0193	.0033	.0073
3	Construction	.0075	.0034	1.0047	.0064	.0065	.0111	.0250
4	Manufacturing	.2292	.1192	.2615	1.3419	.0692	.0856	.1261
5	Trade, Transportation & Utilities	.1493	.0850	.1371	.1563	1.0887	.0598	.0853
6	Services	.2383	.2931	.2700	.2918	.2712	1.4116	.3138
7	Other	.0243	.0239	.0231	.0367	.0280	.0297	1.0338

Now, when we take this A matrix, we can write down for this matrix, we can calculate I minus A and then take the inverse of that and that gives you the matrix which we are talking of, this is the inverse matrix that we are looking at and this is the L matrix. So, this is the matrix that we calculate. If you look at, this is the Leontief inverse that we are talking of.

Now you see the diagonal elements, agriculture is 1.26, which means that an increase in the final demand of agriculture by 1 unit results in a net overall requirement of increasing agricultural product by 1.26. Because that an increase of agriculture requires all other inputs from the other sectors, which again in turn requires the amounts from the agriculture. So you can see all the diagonal elements 1.26, 1.07, 1.0047, 1.34, 1.008, 1.41, 1.03, all the diagonal elements are greater than 1.

All the off diagonal elements are obviously less than 1 they are between 0 and 1. And so this is the L matrix. We could then take the L matrix and see what happens when you if you change the final demands. So, the assumption in the input output method is that these coefficients are static, and these coefficients remain constant.

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I-O table example in physical units

	1	2	d_i	q_i	Physical units of measure
1	75	250	175	500	bushels
2	40	20	340	400	tons

I-O table example in monetary units

	1	2	f_i	x_i	$ Price per physical unit
1	150	500	350	1000	2
2	200	100	1700	2000	5

I-O table example in revised physical units

	1	2	d_i	q_i	Revised physical units of measure
1	150	500	350	1000	1/2 bushels
2	200	100	1700	2000	1/5 tons

Now just to give you an idea of this, we could also represent… See all of these, when we talked about these input output tables, these were all represented in monetary units. It was also possible that we can talk in terms of the physical units in terms of bushels and tons. So, if you are looking at, let us say corn or agriculture in bushels of corn, and if you are looking at let us say oil, tons of oil. If we had an example, where this is a physical quantity, we said that 75 bushels of corn is used in the agricultural sector, 250 is used in the manufacturing sector and 175 is the final demand. So, the total demand is 500.

Similarly, 40 tons are used in agriculture, 20 tons used here 340 tons and 400 tons. So if you look at this then if we had a price in dollars per physical unit that means dollars 2 per bushel and dollars 5 per ton, then we could multiply each of these units, 75 into 2, 250 into 2 and so on, so that you can get it in money terms and then what we get is this is the conventional matrix that we had used for the input output analysis, then we can do the normal analysis in terms of the Leontief inverse and make the calculations, we can get the coefficients and these will be all in the monetary terms.

We could also go back and if you see this, this 150, 200, 500, 100 that we got after multiplying this, if we change the revised physical units of measures to reflect the price, then this becomes, this is the matrix that we got can be converted into physical terms. That means we now have this as 150, 500, 350, 1000.

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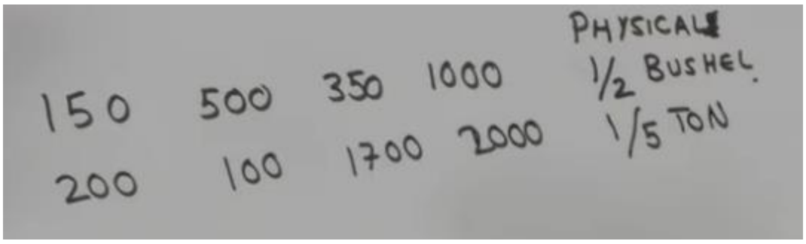

In physical terms, now, this is in rupees or dollars in this example it is when dollars this is, 1 dollar is the cost of half a bushel per unit price. So, physically this represents half a bushel and that is a physical and this one if you look at it in tons 1700, 2000 and this is 1 fifth ton. So, we can actually move between physical and money terms and there are certain cases where we can also look at this in terms of the hybrid unit, where you have both physical as well as money terms.

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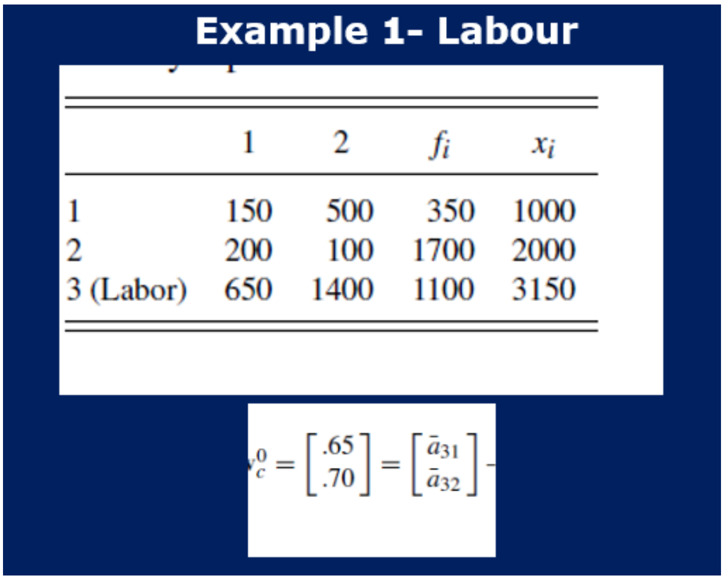
Example 1- Labour

	1	2	f_i	x_i
1	150	500	350	1000
2	200	100	1700	2000
3 (Labor)	650	1400	1100	3150

$$v_c^0 = \begin{bmatrix} .65 \\ .70 \end{bmatrix} = \begin{bmatrix} \bar{a}_{31} \\ \bar{a}_{32} \end{bmatrix}$$

Now, we can have on this side, if you remember in the column, the last row in the column are the different payment sectors, one of them could be wages and if we look at this, this is the wages 650, 1400, 1100, 3150 and if you look at this in terms of the output, you will see that the wages or the labor or the employment is 650 by 1000.

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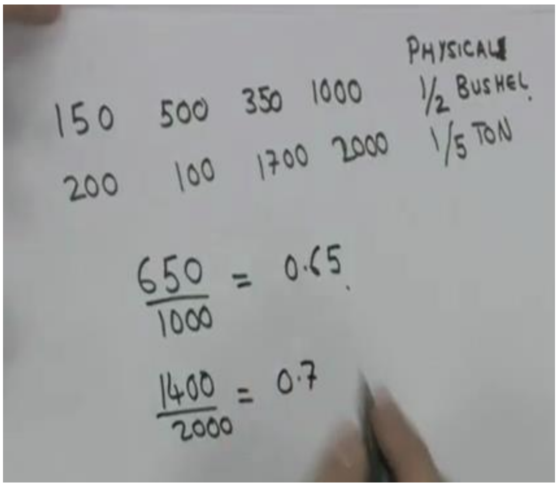

And so that unit is, we can get a coefficient which is 650 by 100 which is 0.65 and 1400 by 2000 which is 0.7. And these are representing the employment factors, or the employment index per unit of the money that we are spending in that sector. And this could be useful for instance, if we were thinking in terms of, instead of coal we go for renewables and we go for photovoltaics, we can see the growth in the two different sectors. We can have an employment factor in terms of ratios, and then see how many jobs are being created, how many jobs are being lost. And so that that is an interesting way in which we can look at that.

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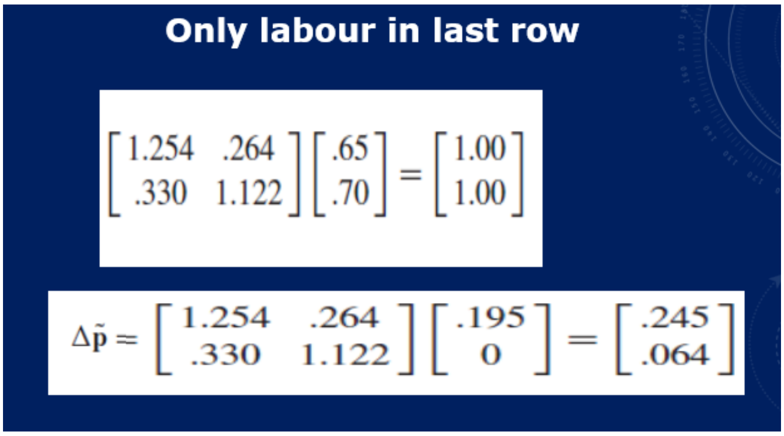

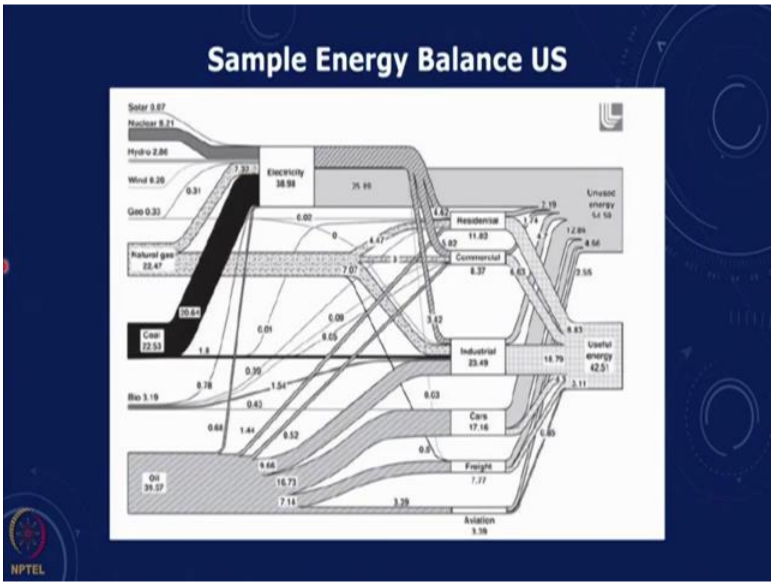

So, that we could actually take for instance, the ratios of this and then use that to then calculate what is the amount of labor under different conditions. We can come make a composite index of energy. For instance, in the case of US, we saw the Input Output matrix for a particular year, we can also draw as we have seen, in the initial lectures, we saw the Sankey or the energy balance diagram for the world and for India and these diagrams will represent the relative proportions of the different fields and the flows in different sectors and this can be then converted into…

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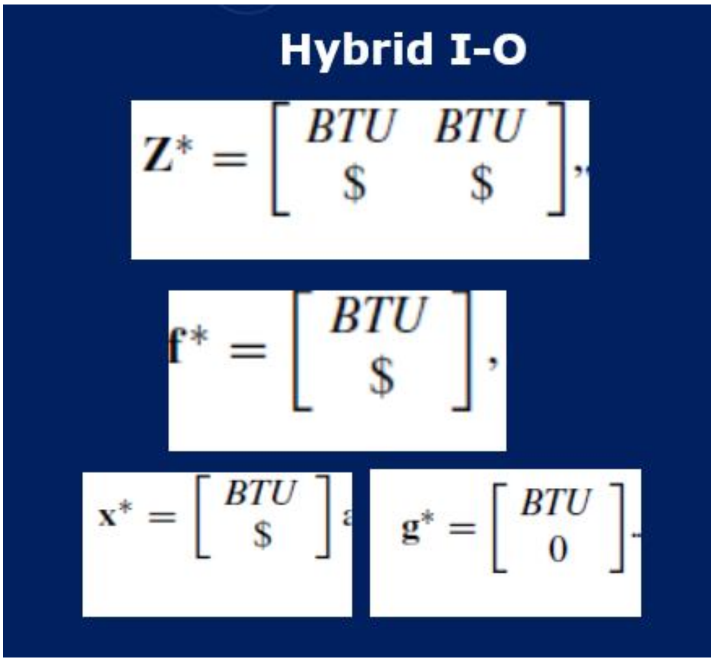

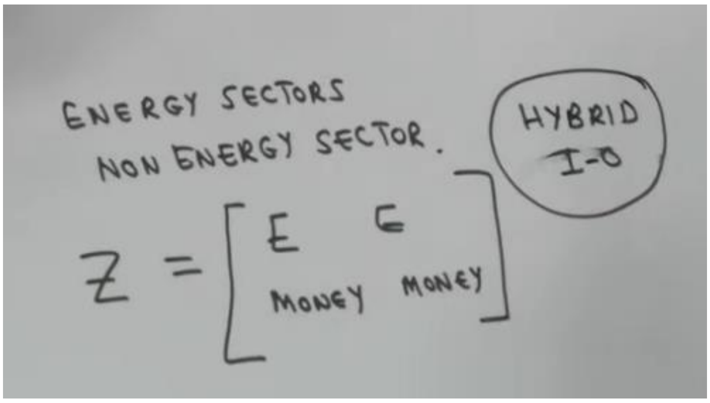

So, we could have the input output in terms of some sectors, the energy sectors and non-energy sectors. So, we could create a hybrid input output table where your transaction matrix has energy units and money. So that, then what happens is that when I have a transaction from energy to another sector, it will be in terms of the value add which is provided by steel. The steel, cement or the other industrial sectors chemicals all of them are put in terms of millions of rupees or millions of dollars and the energy could be in mega joules, pita joules or in kilowatt hours. In the case of in the Miller and Blair example, they have talked of it in terms of BTU and dollars, British thermal Unit

So, when we have this kind of this is called a hybrid input output framework. Please remember this is equivalent to the same thing we can take the hybrid, the energy terms multiplied by the price and then convert it into the conventional input output table that we had seen earlier, which would be everything in money terms. And then we can see the amount of electricity which is in money given to the industry sector. In the case of a hybrid system, where you have energy, we can actually look at the energy use per million rupees of steel produced.

And so, this is as long, as we are consistent in terms of the units we can otherwise go ahead and do the same kind of example. So, to just give you an example, this is again the example from the textbook.

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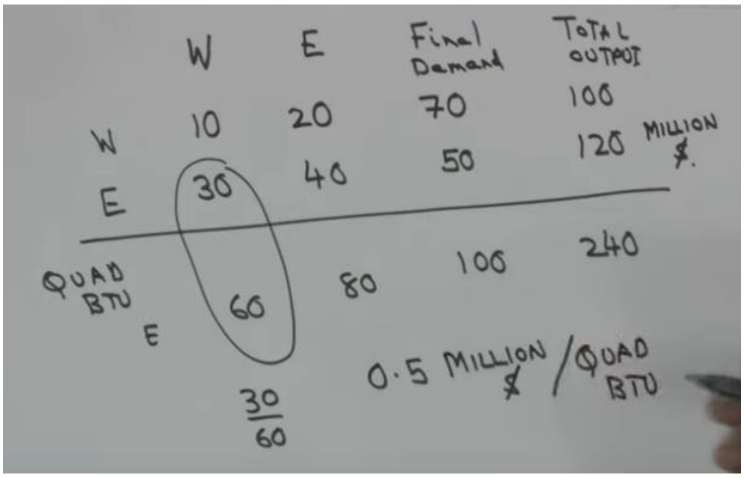

And there are two things here, there are some output of some products which are called widgets and there is energy and then there is a final demand, final demand we saw, FI and then we have the total output. So, in this case, if you see 10 million dollars of widgets being used for the widgets, for making the widget and 10 million dollars of widgets being used for the 20 million dollars for the energy sector and 70 is the final demand for widget. So, total when we add it up, this is 100 million dollars and in this case it is 30, this is 40 and this is 50, this is 120.

So, in quad BTU this is given in terms of this can the same the same row can also be represented. Now this is million dollars and this one is in quad BTU in energy units, this will be 60, 80, 100, 240. So, if you clearly see this is equivalent to a price in terms of 30 by 60, the price is 0.5 million dollars per quad BTU. And one could operate this with the money terms, do the calculations, after we get the final results, use this factor to get it into the energy term.

So, we can move seamlessly between energy and money. Of course, another way is sometimes you operate with a hybrid input output framework, but we just have to remember this that these coefficients will have then units. In the case, in the normal case, the aijs are all ratios, which are in terms of between 0 and 1 and so then that becomes an easy way of doing this.

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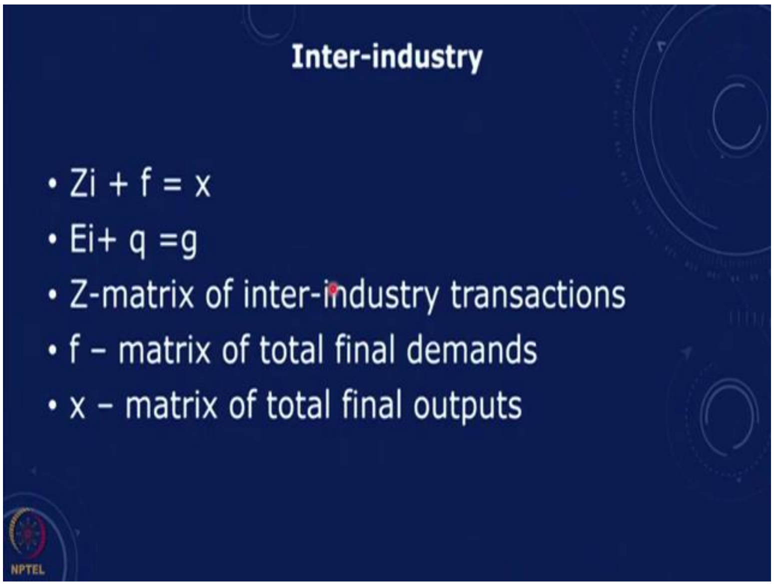

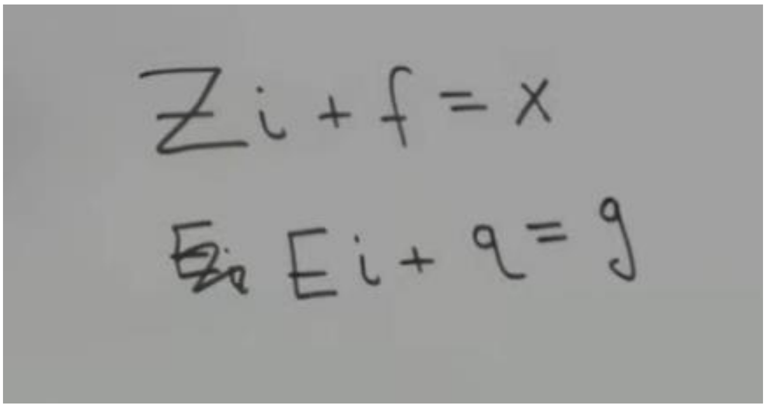

So, this is in terms of the essentially, we then have the following matrices, the normal matrix that we talked Zi plus f is equal to x. This was our financial one and instead of this now, we also have the Ei, that is the energy plus the demand for energy is equal to the total g and then that could be the way in which we could write this. So, q is a vector of energy deliveries to the total final demand and g is the factor of the total energy consumption. So, we could operate it this way or we could operate it in the normal input output with the money terms and then make the calculation.

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Ex 9.2 Millions of US $

	Crude Oil	Refined Petroleum	Electric Power	Autos	Final Demand	Total Output
Crude Oil	0	5	5	0	0	10
Refined Petroleum	2.5	2.5	0	2.5	12.5	20
Electric Power	2.5	1.25	1.25	2.5	12.5	20
Autos	0	0	0	0	20	20

So, just to give you, if you look at you can look at the textbook by Miller and Blair, there are several examples of this. So, for instance, there are these three sector, three sectors and one automobile sector. So, you have crude oil, refined petroleum, electric power, and then you have the crude oil is going for refined petroleum sector then it goes, some of it goes to the electric power sector, there is no final demand for the crude oil, you add it up that comes to 10 million US dollars.

Refined petroleum, some of it is being used in the crude oil sector and some of it, of course is going into this and so on, when you add it up, this is the total. And then electric power electricity going into each of these sectors and they have, there is a final demand for automobiles and then this is the total output.

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Ex 9.2 10^{15} BTU

	Crude Oil	Refined Petroleum	Electric Power	Autos	Final Demand	Total Output
Crude Oil	0	20	20	0	0	40
Refined Petroleum	1	3	0	1	15	20
Electric Power	2.5	1.25	1.25	2.5	12.5	20

And one could then convert this in terms of the price. And you can get the in terms of BTU, this is the kind of matrix which will then come. So, it is basically dividing those money units by the prices. And please remember, in a situation it is possible that prices of energy to different sectors may be different and that can be also configured into this framework.

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Example 9.3

	Coal	Electric Power	Autos	Final Demand	Total Output
Coal (Quadrillion BTU)	0	300	0	0	300
Electric Power (Quadrillion BTU)	20	20	20	60	120
Automobiles (million dollars)	0	0	0	100	100

So that is the situation in terms of looking at the examples, different kinds of examples where we take these different sectors, the energy sector and the automobile sector and then convert it into this.

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USA I-O Hybrid table

Table 9.5 Input-Output Transactions for the US Economy in Hybrid Units (1967)*

	Coal Mining	Oil & Nat. Gas	Ref. Petrol.	Elec. Utilities	Gas Utilities	Chem.	Agric.	Mining & Manuf.	Transp. & Comm.	Rest of Economy	Final Demand	Total Output
1. Coal Mining	96			7,750	14	551	71	4,702			2,740	15,924
2. Oil & Nat. Gas		1,113	23,326		17,737	148					499	42,823
3. Ref. Petroleum	32	43	1,624	906	14	741	847	4,030	3,691	2,037	14,037	28,002
4. Elec. Utilities	16	43	56	445		381	71	1,343	75	509	1,181	4,120
5. Gas Utilities		86	896	3,148	977	868	212	1,343	151	1,528	4,948	14,157
6. Chemicals	48	171	616	41		4,025	2,540	10,075	75	1,018	2,672	21,281
7. Agriculture						763	19,898	36,270	75	3,055	10,498	70,559
8. Mining & Manuf.	350	1,328	868	943	283	3,008	6,562	255,235	4,897	49,902	348,295	671,671
9. Transp. & Comm.	32	171	1,344	610	42	635	1,552	16,120	6,102	17,313	31,412	75,333
10. Rest of Economy	366	4,197	2,968	3,650	849	1,271	11,007	82,616	13,108	99,294	289,873	509,199

*Transactions are in millions of dollars for nonenergy sectors and in Quads (10^{15} BTU) for energy sectors.

We also, I showed you earlier the input output table from the textbook on the Input Output analysis and similar kind of input output table is shown here, which is now a hybrid unit and this is hybrid unit has transactions millions of dollars for non energy sector and in quads or 10 raised to 15 BTU for the energy sector. So, you can see basically coal mining oil, natural gas, petroleum utilities, gas utilities, all of these will be in BTU. The chemicals agriculture, mining, transport and communication rest of economy are all going to be in the money terms and then we can make the if we know the prices, we can convert it into a money term aspect and then do.

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US I-O direct coefficients 2006

US Technical Coefficients 2006	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1 Agriculture	0.2403	0.0000	0.0014	0.0345	0.0001	0.0018	0.0007
2 Mining	0.0028	0.1307	0.0079	0.0756	0.0310	0.0004	0.0066
3 Construction	0.0035	0.0002	0.0010	0.0019	0.0039	0.0072	0.0242
4 Manufacturing	0.1858	0.0959	0.2673	0.3311	0.0581	0.0558	0.1027
5 Trade, Transport & Utilities	0.0774	0.0379	0.1063	0.1003	0.0698	0.0329	0.0439
6 Services	0.0875	0.1298	0.1262	0.1239	0.1846	0.2889	0.2029
7 Other	0.0102	0.0096	0.0095	0.0233	0.0223	0.0192	0.0225

And so, we saw last time, the numbers in terms of direct coefficients for 2003. Please remember that as the economy changes, you will find that the coefficients also will change. And so, when we talk about input output analysis, if you are taking fixed coefficients that will be valid only for short term kinds of calculations. If you are looking at long term calculations and if the structure changes, it is quite likely that there will be very significant changes.

Even when we compare, you can take this table with the values and compare it with the 2003 coefficients and you will find that there are some changes in some of these coefficients and over a longer period of time, you will see that these coefficients change quite significantly. For instance, the energy use for industry may decrease if there has been significant improvements in energy efficiency and so that those are that is the way in which there is coefficients.

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US I-O total coefficients 2006

US Total Requirements 2006	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1 Agriculture	1.3365	0.0101	0.0238	0.0735	0.0075	0.0101	0.0118
2 Mining	0.0482	1.1716	0.0566	0.1470	0.0525	0.0162	0.0306
3 Construction	0.0091	0.0036	1.0058	0.0081	0.0079	0.0120	0.0286
4 Manufacturing	0.4275	0.2064	0.4650	1.5972	0.1424	0.1438	0.2173
5 Trade, Transport & Utilities	0.1728	0.0823	0.1826	0.2013	1.1076	0.0719	0.0911
6 Services	0.3041	0.2799	0.3294	0.3829	0.3344	1.4661	0.3698
7 Other	0.0346	0.0239	0.0323	0.0525	0.0359	0.0342	1.0382

US I-O direct coefficients 1997

US Technical Coefficients 1997	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1 Agriculture	0.2618	0.0001	0.0015	0.0401	0.0013	0.0020	0.0008
2 Mining	0.0017	0.1150	0.0062	0.0306	0.0236	0.0003	0.0036
3 Construction	0.0039	0.0002	0.0011	0.0020	0.0052	0.0060	0.0101
4 Manufacturing	0.1740	0.1162	0.2372	0.3627	0.0758	0.0583	0.0424
5 Trade, Transport & Utilities	0.0731	0.0643	0.0975	0.0980	0.0847	0.0288	0.0267
6 Services	0.1110	0.2570	0.1376	0.1232	0.2294	0.2146	0.0902
7 Other	0.0063	0.0181	0.0086	0.0177	0.0212	0.0169	0.0167

And if you look at the total coefficients, now this is after we take that same, if you take this 2006 matrix that we had get I minus A, take the inverse of that, that will give you the Leontief inverse. And you will find then that these coefficients, we talked about the diagonal coefficients being greater than 1 and you can remember. If you remember the earlier in 2003, this value was lower than this, this is now almost 1.6 times, and so on. So, this gives you an idea of how you can use this and then also that these things change.

And that is just to show you another set of data, this is the 97 data. And you can clearly see when you take 97, 2003 and 2006, you can see quite clearly there are reasonable differences in all of this.

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An integrated modeling framework for energy economy and emissions modeling: A case for India

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And so, we will take an example before we take that example, let me talk to you about the way in which this can be used, to assess the impact of different kinds of possibilities for a particular sector. So, this is one of the papers, one of the research work done by one of our PhD students and you can see this paper, you can look it up in the energy journal. It is an integrated modeling framework for energy economy and emissions modeling and this is a case study for India.

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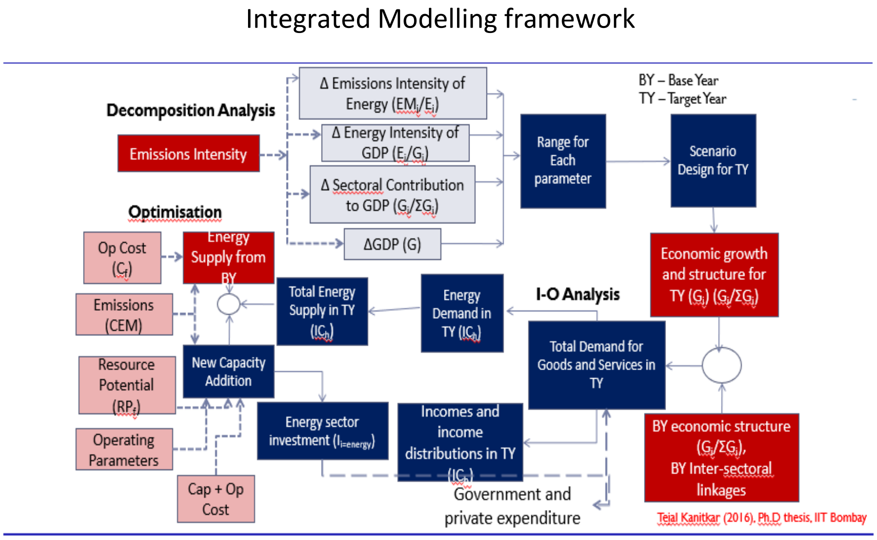

So, in this if you see the approach that we had was, we essentially looked at the emissions intensity, the emissions intensity is the emission per unit of GDP. And we broke up the emission intensity into the difference in terms of the energy intensity of the GDP and the sectoral contribution to the GDP. So, typically what happens is in any, in any country, the GDP comes from a whole set of different sectors.

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So, if you look at it, typically the most important sectors are industry, services and agriculture and over a long period of time, if you look at India, for instance, over the last 10-20 years, you will see that the share of agriculture in the GDP has been declining. Share of services has been increasing, share of industry more or less remain constant, slight increases slight decreases. So, when we look at this, what has happened is that the share of services in the total GDP has been much higher than, has grown and as compared to the industry and industry share has declined a bit.

Now, if you look at the energy requirement for industry and for the high energy intensive industries, that energy requirement is much higher per million rupees of value add as compared to something in the services sector and in the services sector, at most your need something with the energy for the air conditioning and space cooling. But in industry, we are looking at manufacturing and transformations and so that is much more energy intensive.

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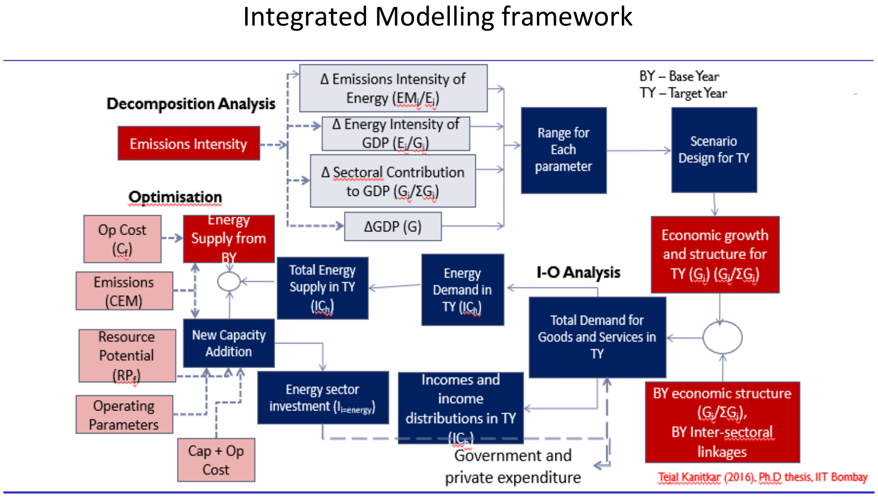

So, we can the first thing is we did a decomposition analysis to see what is the share of what is the breakup of the share of the sectoral contribution and the how much of the energy intensity improvements and then we got ranges for these parameters. This is from the past and from that we started with a particular base year and then made projections for the target year.

So, when we looked at the projection, we projected different possible scenarios for India in terms of industrial growth, services growth and agricultural growth. And based on that, we got, we took an input output model with some coefficients and then, saw when we looked at this with the kind of investments required we also built a detailed model for the power sector. And for this kind of requirement we estimated what is the demand for electricity, then saw what kind of new capacities have to be added, we try to do an optimization model under different scenarios.

And using that we estimated what is the total demand for goods and services and then ran an input output method to model to see what will happen in different sectors and this then gives us an idea to see, we then saw what is the impact of different household classes and the income and income distributions and if you remember earlier we talked about equality and inequality in incomes and we talked about the GINI coefficients.

So, after looking at these kind of investments in the energy sector, and whether how much is the government and private investment, based on that we try to see what will be the investment in the other sectors and as a result of that, we try to see the impact on the income and income distribution.

So, this is basically the method, it is a set of coupled models. There is an optimization model of the power sector, there is an input of model and then there is a decomposition analysis and different scenarios.

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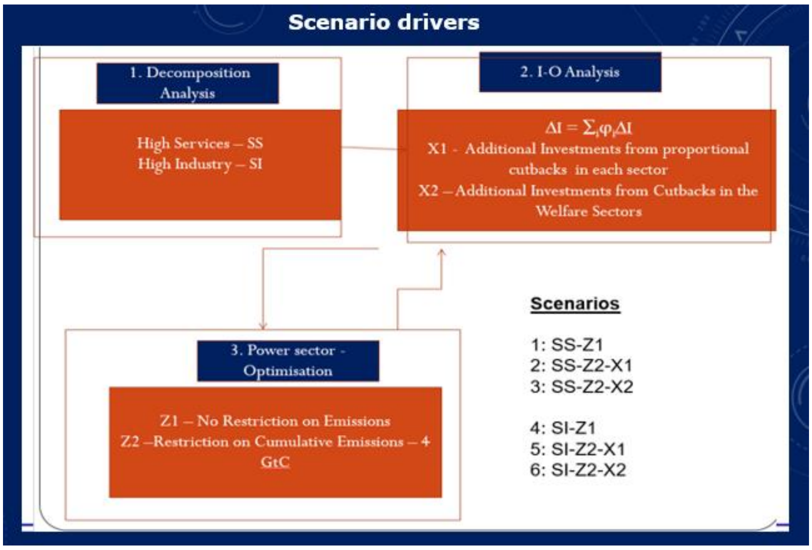

So, under each of these scenarios, we first identify different drivers, we took a high services scenario, high industry scenario, and then we looked at the additional investment, either if it is, if the investment which is made, have been proportional cut backs from each of the sectors, or the additional investment from cutbacks in welfare sector and then in the power sector, we ran 2 scenarios where there is no restriction on emissions and we go for the minimum cost or if there are restrictions on emissions, and then the initial investments may be higher.

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Sample scenario results

	Base year	1-SS-Z_1	2-SS-Z_2-X_1
GDP (Billion $)	415	2415	2354
GDP Growth p.a.	-	7.08%	6.98%
Per Capita Income of all Households ($/year/person)	338	1354	1308
Per Capita Income of all Households class RH1($/year/person)	62	185	154
Per Capita Income of all Households RH4 ($/year/person)	354	1662	1600
Per Capita Income of all Households UH1($/year/person)	77	108	92
Per Capita Income of all Households UH3 ($/year/person)	323	1231	1185
GINI Coefficient	0.497	0.531	0.536

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And based on that we could actually see under these scenarios, what happens in terms of the growth rates and the per capita income, and interestingly we can also see the difference in the GINI coefficient. So, for instance, in this case, in the case when we have more restrictions on emissions, we see that it results in a slightly higher inequality and this is just, the numbers are not that important, you can look at the details in the paper, but basically it gives you an illustration of how input output analysis can be used to answer what-if questions about the impacts of policy.

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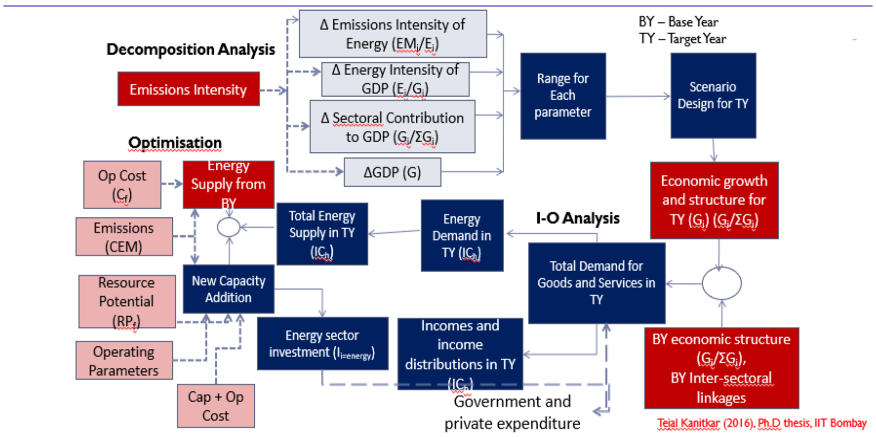

So, that is basically the idea of how this input output analysis can be used at the aggregate level for the energy sector.